Table 5.10a

Empirical Results for a 1971 Sample[a,b]
Recursive Labor Supply

1. $$\text{LDSA} = -1.018 + \underset{(0.04)}{0.06(\text{NCIG})} - \underset{(0.07)}{0.17(\text{DSAB})^*} + \underset{(0.68)}{0.05(\text{RELG})} - \underset{(0.19)}{0.40(\text{CITY})^*}$$

$$- \underset{(0.04)}{0.05(\text{FEDU})} + \underset{(0.05)}{0.06(\text{EDUC})} + \underset{(0.19)}{0.15(\text{FOOD})} + \underset{(0.006)}{0.025(\text{AGEH})^*}$$

$$+ \underset{(0.002)}{0.001(\text{COLD})} + \underset{(0.002)}{0.001(\text{ULTV})} - \underset{(0.003)}{0.002(\text{SULM})} + \underset{(0.002)}{0.005(\text{NOXM})^*}$$

$$+ \underset{(0.004)}{0.008(\text{TSPM})^*}$$

$R^2 = 0.21$; $F(13, 305) = 5.76$; S.E. = 1.56

2. $$\text{ACUT} = 35.397 + \underset{(6.20)}{0.25(\text{NCIG})} - \underset{(9.40)}{0.38(\text{DSAB})} - \underset{(7.59)}{4.98(\text{LDSA})} - \underset{(35.76)}{47.39(\text{EXER})}$$

$$+ \underset{(4.85)}{5.14(\text{EDUC})} - \underset{(0.87)}{0.36(\text{AGEH})} + \underset{(0.27)}{0.06(\text{COLD})} - \underset{(0.02)}{0.01(\text{ULTV})} - \underset{(0.44)}{0.38(\text{SULM})}$$

$$+ \underset{(0.31)}{0.06(\text{NOXM})} + \underset{(0.52)}{0.49(\text{TSPM})}$$

$R^2 = 0.15$; $F(11, 307) = 0.43$; S.E. = 215.15

3. $$\text{WAGE} = -5.619 + \underset{(0.06)}{0.08(\text{BDALO})} + \underset{(0.10)}{0.02(\text{ACUT})} - \underset{(44.41)}{156.70(\text{SEXH})^*} + \underset{(10.81)}{33.46(\text{LOCC})^*}$$

$$- \underset{(14.35)}{3.00(\text{DSAB})} - \underset{(15.72)}{41.73(\text{LDSA})^*} + \underset{(10.20)}{20.31(\text{EDUC})^*} + \underset{(32.08)}{50.80(\text{RACE})}$$

$R^2 = 0.20$; $F(8, 310) = 9.72$; S.E. = 367.66

4. $$\text{WORK} = 2011.671 - \underset{(0.15)}{0.12(\text{BDALO})} - \underset{(0.23)}{0.01(\text{ACUT})} - \underset{(0.01)}{0.05(\text{ICTR})^*} + \underset{(26.35)}{123.40(\text{SVGS})^*}$$

$$- \underset{(34.26)}{10.55(\text{DSAB})} - \underset{(36.52)}{212.00(\text{LDSA})^*} + \underset{(0.13)}{0.50(\text{WAGE})^*}$$

$R^2 = 0.35$; $F(7, 311) = 23.68$; S.E. = 865.51

(continued)

Table 5.10a
(continued)

[a]Standard errors are in parentheses.

[b]The sample includes only respondents who resided in 50 large U.S. cities.

*Significant at the 0.05 level of the one-tailed t-test.

Table 5.10b

Empirical Results for a 1970 Sample[a]
Recursive Labor Supply

1. $$LDSA = 2.980 + \underset{(0.035)}{0.554(DSAB)^{**}} + \underset{0.004}{0.005(AGEH)} + \underset{0.029}{0.013(EDUC)} - \underset{0.037}{0.044(FEDU)}$$

$$- \underset{0.103}{0.069(POOR)} + \underset{(0.488)}{0.072(RACE)} + \underset{(0.114)}{0.139(SEXH)} - \underset{(0.975)}{0.902(FOOD)} - \underset{(0.129)}{0.454(INSR)^{*}}$$

$$- \underset{(0.575)}{1.645(CHEM)^{*}} + \underset{(0.0011)}{0.0028(TSPM)^{*}}$$

$R^2 = 0.525$; $F(11,388) = 38.920$; S.E. = 0.964

2. $$ACUT = 165.208 + \underset{(13.34)}{39.52(LDSA)^{*}} - \underset{(1.312)}{1.421(AGEH)} - \underset{(39.16)}{16.92(SEXH)} - \underset{(0.118)}{0.086(CIGE)}^{b}$$

$$- \underset{(40.11)}{78.40(EXER)^{*}} - \underset{(0.033)}{0.105(FOOD)^{*}} - \underset{(13.26)}{38.84(RISK)} + \underset{(47.47)}{187.0(INSR)^{**}} + \underset{(0.317)}{0.623(TSPM)^{*}}$$

$R^2 = 0.195$; $F(10,389) = 6.139$; S.E. = 204.462

3. $$WAGE = -132.318 - \underset{(14.440)}{25.930(LDSA)^{*}} + \underset{(8.5780)}{24.070(EDUC)^{*}} + \underset{(18.260)}{15.370(DSAB)}$$

$$+ \underset{(6.079)}{26.880(FMSZ)^{*}} + \underset{(6.138)}{42.380(BDALO)^{*}} + \underset{(22.130)}{52.950(LOCC)^{*}} - \underset{(33.88)}{7.163(LTWK)}$$

$$+ \underset{(34.580)}{66.090(UION)^{*}} + \underset{(34.22)}{47.60(RACE)}$$

$R^2 = 0.408$; $F(11, 388) = 24.28$; S.E. = 258.908

4. $$WORK = 1266.680 - \underset{(27.220)}{163.900(LDSA)^{*}} + \underset{(0.130)}{0.354(WAGE)^{*}} + 44.260(FMSZ)^{*}$$

$$+ \underset{(80.27)}{519.800(SEXH)^{*}} - \underset{(0.022)}{0.272(ICTR)^{*}} + \underset{(15.200)}{23.060(BDALO)} - \underset{(0.031)}{0.074(ACUT)^{*}}$$

$R^2 = 0.551$; $F(6, 393) = 80.41$; S.E. = 663.196

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[a]Standard errors are in parentheses

[b]Annual family expenditures on cigarettes in dollars

*Significant at the 0.05 level of the one-tailed t-test.

**Significant at the 0.05 level of the two-tailed t-test.

Table 5.10c

Empirical Results for a 1971 Sample[a]
Recursive Labor Supply

1. $$\text{LDSA} = \underset{}{0.265} + \underset{(0.049)}{0.808(\text{DSAB})^{**}} + \underset{(0.004)}{0.007(\text{AGEH})^{*}} - \underset{(0.030)}{0.057(\text{EDUC})^{*}} - \underset{(0.035)}{0.044(\text{FEDU})}$$

$$+ \underset{(0.096)}{0.086(\text{POOR})} - \underset{(0.119)}{0.057(\text{RACE})} + \underset{(0.109)}{0.233(\text{SEXH})^{**}} - \underset{(0.81 \times 10^{-4})}{0.138\text{x}10^{-3}(\text{FOOD})^{*}}$$

$$- \underset{(0.125)}{0.496(\text{INSR})^{*}} - \underset{(0.916)}{0.002(\text{CHEM})} + \underset{(0.0017)}{0.0019(\text{TSPM})}$$

$R^2 = 0.530$; $F(11,388) = 39.800$; S.E. = 0.904

2. $$\text{ACUT} = 99.839 + \underset{(1.038)}{0.985(\text{AGEH})} + \underset{(27.69)}{55.55(\text{INSR})^{*}} - \underset{(33.34)}{67.50(\text{EXER})^{*}} - 0.052(\text{FOOD})^{*}$$

$$- \underset{(11.29)}{10.59(\text{RISK})} + \underset{(12.637)}{21.784(\text{LDSA})} + \underset{(0.676)}{1.177(\text{TSPM})^{*}}$$

$R^2 = 0.091$; $F(10, 389) = 4.095$; S.E. = 236.224

3. Acute illness, ACUT, is assumed not to effect marginal hourly earnings. Marginal hourly earnings expressions that include ACUT as an explanatory variable have been estimated from three different samples. In each case, ACUT has proven to be statistically nonsignificant. See, for example, expression (3) of Table 5.10a.

4. $$\text{WORK} = 682.263 - \underset{0.032}{0.078(\text{ACUT})^{*}} - \underset{(34.073)}{50.119(\text{LDSA})} - \underset{(46.490)}{154.20(\text{DSAB})^{*}}$$

$$+ \underset{(14.02)}{30.460(\text{FMSZ})^{*}} + \underset{76.190}{515.000(\text{SEXH})^{*}} - \underset{(0.022)}{0.2771(\text{ICTR})^{*}} + \underset{7.148}{8.969(\text{BDALO})}$$

$R^2 = 0.562$; $F(7, 392) = 72.34$; S.E. = 654.473

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[a]Standard errors are in parentheses.

*Significant at the 0.05 level of the one-tailed t-test.

**Significant at the 0.05 level of the two-tailed t-test.

Table 5.10d

Empirical Results for a 1969 Sample[a]
Recursive Labor Supply

1. $$\text{LDSA} = -0.223 + \underset{(0.019)}{0.041(\text{NCIG})^*} - \underset{(0.104)}{0.090(\text{INSR})} + \underset{(0.109)}{1.964(\text{DSAB})^*}$$

$$+ \underset{(0.078)}{0.1212(\text{POOR})} - \underset{(0.199)}{0.098(\text{EDUC})} + \underset{(0.52 \times 10^{-3})}{0.10 \times 10^{-4}(\text{FOOD})} + \underset{(0.003)}{0.003(\text{AGEH})}$$

$$+ \underset{(0.0011)}{0.0013(\text{TSPM})} + \underset{(0.0021)}{0.0018(\text{SULM})}$$

$R^2 = 0.478$; $F(9,390) = 39.69$; S.E. = 0.736

2. $$\text{ACUT} = 447.874 + \underset{(35.56)}{16.61(\text{MARR})} + \underset{(9.844)}{16.13(\text{NCIG})^*} - \underset{(47.09)}{88.71(\text{INSR})^*}$$

$$+ \underset{(16.08)}{47.04(\text{LDSA})^*} - \underset{(34.03)}{29.80(\text{POOR})} - \underset{(0.231)}{0.564(\text{FOOD})^*} - \underset{(12.33)}{7.676(\text{RISK})}$$

$$- \underset{(1.456)}{1.306(\text{AGEH})} - \underset{(0.706)}{0.963(\text{TSPM})} + \underset{(0.925)}{1.518(\text{SULM})^*}$$

$R^2 = 0.095$; $F(10,389) = 3.139$; S.E. = 317.201

3. $$\text{WAGE} = 49.305 + \underset{(2.869)}{1.275(\text{FMSZ})} + \underset{(4.312)}{28.20(\text{LOCC})^*} - \underset{(7.203)}{12.07(\text{LDSA})^*}$$

$$+ \underset{(15.73)}{34.98(\text{UION})^*} - \underset{(38.13)}{24.16(\text{EDUC})} + \underset{(16.95)}{136.6(\text{RACE})^*} + \underset{(17.75)}{116.9(\text{SEXH})^*}$$

$R^2 = 0.411$; $F(7,392) = 39.03$; S.E. = 143.265

4. $$\text{WORK} = 1779.540 - \underset{(0.082)}{0.623(\text{ACUT})^*} + \underset{(10.15)}{25.87(\text{FMSZ})^*} - \underset{(0.026)}{0.077(\text{ICTR})^*}$$

$$+ \underset{(59.63)}{143.8(\text{SVGS})^*} - \underset{(25.90)}{15.02(\text{LDSA})} - \underset{(0.165)}{0.277(\text{WAGE})^*} + \underset{(66.31)}{394.8(\text{SEXH})^*}$$

$R^2 = 0.253$; $F(7,392) = 18.95$; S.E. = 514.153

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[a] Standard errors are in parentheses.

*Significant at the 0.05 level of the one-tailed t-test.

Table 5.11a

Labor Supply Effects of Air Pollution-Induced Chronic and/or Acute Illnesses

From Table 10a: Air Pollution Induced Chronic Illness Only

Effect of a One Unit Increase in Air Pollution Upon Labor Supply

	NOXM	TSPM
Direct Effect	-1.0600 hours	-1.6960 hours
Indirect (via WAGE) Effect	-0.1044 hours	-0.1669 hours
Total Effect	-1.1644 hours	-1.8629 hours

Sum of total effects from Table 10a expressions = -1.1644 - 1.8629 = -3.0273 hours.

From Table 10b: Air Pollution Induced Chronic and Acute Illnesses

Effect of a One Unit Increase in Air Pollution Upon Labor Supply via Direct Impact of Chronic Illness

	TSPM
Direct Effect	-0.458 hours
Indirect (via WAGE) Effect	-0.026 hours
Total Effect	-0.484 hours

Effect of a One Unit Increase in Air Pollution Upon Labor Supply via Impact of Chronic Illness on Acute Illness

	TSPM
Direct Effect	-0.017 hours
Indirect (via WAGE) Effect	Zero, by assumption
Total Effect	-0.017 hours

(continued)

Table 5.11a
(continued)

Effect of a One Unit Increase in Air Pollution
Upon Labor Supply via Direct Impact
of Acute Illness

	TSPM
Direct Effect	-0.046 hours
Indirect (via WAGE) Effect	Zero, by assumption
Total Effect	-0.046 hours

Sum of total effects from Table 10b expressions = -0.484 - 0.017 - 0.046 = 0.547 hours.

From Table 10C: Air Pollution Induced Acute Illness Only

Effect of a One Unit Increase in Air Pollution
Upon Labor Supply via Direct Impact
of Acute Illness

	TSPM
Direct Effect	-0.092 hours
Indirect (via WAGE) Effect	Zero, by assumption
Total Effect	-0.092 hours

From Table 10d: Air Pollution Induced Acute Illness Only

Effect of a One Unit Increase in Air Pollution
Upon Labor Supply via Direct Impact
of Acute Illness

	TSPM
Direct Effect	-0.9457 hours
Indirect (via WAGE) Effect	Zero, by assumption
Total Effect	-0.9457 hours

Table 5.11b

Value of Labor Supply Effects of Air Pollution-Induced Chronic and/or Acute Illnesses for Pollution Concentrations Two Standard Deviations Removed from the Mean Concentration

<u>From Tables 10a and 11a</u>

Mean air pollution ± two standard deviations

NOXM = 95.320 ± 82.470
TSPM = 115.818 ± 65.756

Labor supply effects

NOXM = (-1.164 hours) (± 82.470) ≡ 95.9951 hours
TSPM = (-1.8629 hours) (± 65.756) ≡ 122.4975 hours

Total Effects 218.4926 hours

Value of labor supply effects: ($2.92)(215) = $638.00

<u>From Tables 10b and 11a</u>

Mean air pollution ± two standard deviations

TSPM = 74.837 ± 87.864

Labor supply effects

TSPM = (-0.547 hours) (± 87.864) = 48.062 hours

Value of labor supply effects: ($3.23)(48) = $155.00

<u>From Tables 10C and 11a</u>

Mean air pollution ± two standard deviations

TSPM = 89.210 ± 55.938

Labor supply effects

TSPM = (-0.092 hours) (55.938) = 5.146 hours

Value of labor supply effects: ($3.59)(5.146) = $18.47

(continued)

Table 5.11b

Value of Labor Supply Effects of Air Pollution-Induced Chronic and/or Acute Illnesses for Pollution Concentrations Two Standard Deviations Removed from the Mean Concentration

From Tables 10d and 11a

Mean air pollution ± two standard deviations

SULM = 24.583 ± 46.690

Labor supply effects

SULM = (-0.9457 hours) (46.690) = 44.155 hours

Value of labor supply effects: ($3.32) (44.155) = $146.59

hours worked. Similarly, hourly earnings are determined independently of hours worked and then hours worked are determined from hourly earnings. As Kmenta (1971, p. 585) shows, estimation of a recursive system by ordinary least squares is equivalent to estimation by full information, maximum likelihood.

At this juncture, we wish to emphasize that the use of a single air pollution health effect, or effect of health on wages and/or hours worked, may be somewhat misleading. These effects may differ, for example, with age and numerous other variables. As one gets older, it may be that air pollution-induced health effects become progressively more severe, implying, for given levels of training and work experience, that the absolute effect of air pollution upon hourly earnings and hours worked increases with age. Ideally, this possibility makes it worthwhile to estimate separate expressions for different age groups. Otherwise, one obtains, as we do, a coefficient representing effects for neither old nor young people but simply a weighted average of the two from which it is impossible to disentangle the separate contributions of each group effect. In essence, in addition to all the other caveats that must be applied to the empirical results set forth here, one cannot blindly transfer these estimated air pollution-induced health, hourly earnings, and hours worked effects to other samples of individuals unless their age distribution is similar to the age distribution in these samples. If air pollution-induced effects also differ by other demographic attributes such as race and sex, a similar caution applies.

Tables 5.10a, 5.10b, 5.10c, and 5.10d present estimates of the chronic illness dose-response expressions, the acute illness dose-response expressions, the marginal earnings expressions, and the labor supply expressions. The samples of individuals used to estimate these expressions include housewives, retirees, and students, all of whom were assigned zero hours of acute illness by the Survey Research Center. These individuals constitute about twenty percent of the sample, thus imparting what is probably a substantial downward bias for these labor supply calculations in the estimated effects of air pollution upon acute illness. Failure to include these groups would have resulted, however, in the removal from the sample of a disproportionately high number of individuals with chronic illnesses.

Table 5.11a provides estimates of the direct and indirect effects upon labor supply, as measured by annual hours worked, of air pollution-induced acute and/or chronic illnesses. Assuming that the marginal hourly wage is an accurate representation of the market value of the worker's marginal productivity, these reduced work hours are valued in Table 5.11b at the marginal wage applying before the reduction in work hours. Apart from any issues dealing with the estimation procedures used to obtain each expression, the reader should be sensitive to the fact that assumptions stating that illness is unaffected by work-hours and/or wages underlie the calculations in these two sets of tables.

Detailed description of the calculation procedures in Tables 5.11a and 5.11b is both tedious and repetitious. In order to inform the reader of the procedure, we describe that applied to the material in Table 5.10a, leaving the reader the responsibiliy to invent for himself the procedures we have applied to Tables 5.10b, 5.10c, and 5.10d, which have resulted in the labor supply effect estimates set forth in Tables 5.11a and 5.11b.

Of the three air pollution variables in the chronic illness dose-response expression of Table 5.10a, two, NOXM and TSPM, have a positive sign and are statistically significant.[16/] Making the already acknowledged dangerous assumption that each discrete interval of LDSA is slightly more than two years, or 830 days, the coefficient attached to NOXM implies that, on average, each unit increase in annual geometric mean concentrations of ambient nitrogen dioxide increases the length of chronic illness by 4.15 days.[17/] Similarly, on average, each unit increase in annual geometric mean concentrations of ambient total suspended particulates increases the length of chronic illness by 6.64 days. Calculated at the arithmetic means, the elasticity of LDSA with respect to NOXM is 0.47, while the elasticity for TSPM is 0.95.

The signs of the coefficients for the non-health variables in the hourly earnings expression, (3), in Table 5.10a are in accord with _a priori_ expectations. Except for BDALO and RACE, all are statistically significant at generally accepted levels. As for the health-related variables, neither acute illness nor the severity of disability appears to have an effect upon hourly earnings. However, the length of time over which the individual has been disabled has a substantial and statistically meaningful effect. An increase of two years in the length of time the individual suffers from a chronic illness reduces hourly earnings, on average, by 41.73 cents. When calculated at the means, the elasticity of WAGE with respect to LDSA is -0.17, implying that within the ranges of chronic illness time length and hourly earnings considered here, the response of hourly earnings to chronic illness is rather sluggish.

Using the above results for the effect of LDSA on WAGE, and the earlier results for the effect of NOXM and TSPM on LDSA, one can calculate the average effect of each of the two air pollutants upon hourly earnings. The 4.15 day effect of an additional unit of NOXM on LDSA is 0.50 percent of the 830 days said to constitute one unit of LDSA. Since a one unit increase in LDSA reduces hourly earnings by 41.73 cents, the average effect of an additional unit of NOXM on hourly earnings is (0.005)(-41.73) = -0.2087 cents. Performing the same calculations for TSPM, the average effect of an additional unit of total suspended particulates on hourly earnings is (0.008) (-41.73) = -0.3338 cents.

Among the non-health variables in the labor supply expression, (4) of Table 5.10a, only BDALO fails to be statistically significant. The coefficient for WAGE has a t-value slightly less than four, and it implies an elasticity of WORK with respect to WAGE of 0.12. This means that the substitution effect of a change in real earnings exceeds the income effect. The highly significant and negative coefficient attached to 1971 income secured by means other than 1971 labor, ICTR, is consistent with a substantial income effect that causes the individual to substitute consumption hours for work hours. The elasticity of WORK with respect to ICTR, when evaluated at the means of the variables, is -0.18.

The positive and statistically significant coefficient attached to WAGE implies that the length of time the individual has been chronically ill, LDSA, has an indirect as well as a direct effect upon the annual hours of work the individual supplies. This occurs because, as was observed in the references to (3) of Table 5.10a, LDSA lowers hourly earnings as well as having a powerful direct effect, according to (4), upon labor supply. Table 5.11a exhibits the direct, indirect, and total effects of NOXM and TSPM upon labor supply, as measured by annual hours worked. The total effect is an estimate of the coefficient for LDSA in a reduced form expression.

Assuming the average work day to be eight hours long, a one unit increase in LDSA directly brings about a 212 hour or 26.50 day reduction in annual working time. As earlier noted, 0.5 percent of a one unit change in LDSA is attributable to NOXM, while 0.8 percent of a similar change is due to TSPM. The direct effect of an additional unit of NOXM upon annual hours worked is therefore $(0.5 \times 10^{-2})(-212) = -1.06$ hours, while the direct effect of TSPM is $(0.8 \times 10^{-2})(-212) = -1.6960$ hours.

The indirect effect of air pollution upon labor supply is obtained by first recognizing that in (4) of Table 5.10a, each one cent change in hourly earnings generates an average change of the same sign of 0.50 in annual work hours. As was noted in the discussion of the empirical results for (3), an additional unit of TSPM reduces hourly earnings by 0.3338 cents. The indirect effect of an additional unit of TSPM upon annual work hours is then (-0.3338)(0.50) = -0.1669 hours; the indirect effect of an additional unit of NOXM on annual work hours is then (-0.2087)(0.50) = -0.1044.

On average, the total reduction in labor supply caused by a one unit increase in TSPM is 1.8629 hours, while the reduction for a one unit increase in NOXM is 1.1644 hours. Assuming the health of the representative individual in this sample to be exogenously determined, and that no potential interviewee died between the year for which behavior and status is recorded and the time of the interview, the total reduction in his annual hours worked caused by simultaneous one unit increases in NOXM and TSPM is then 3.0273 hours, i.e., approximately three hours. This last figure assumes that the effects of NOXM and TSPM are additive. Making the exceedingly strong assumptions that the effects of these two air pollutants upon hourly earnings and annual hours worked are constant over all ranges being considered and that the effect of hourly earnings upon annual hours worked is also. constant, those individuals living in cities having air pollution concentrations two standard deviations removed from the mean concentration of the cities considered in this paper will have changes in annual hours worked of 95.9951 hours due to NOXM, and 122.4975 hours due to TSPM; that is, an individual who works and resides in an extremely clean city might work 218 hours more a year than the individual who works and resides in a city with average air pollution concentrations. Valuing these 218 hours at the marginal wage applying before the reduction in work hours, we have a loss in average total earnings of (218) ($2.92) or $638 per individual, a figure which, in spite of the grossness of our assumptions, is not in great discord with intuitive possibilities. Given our linearity assumption about the response of labor supply to air pollution, this results in $1,276 in lost wages for an individual living in an extremely dirty location as compared to that same individual living in an extremely clean location.

In the preceding paragraphs, we have calculated:

$$\text{WAGE}\left(\frac{d\text{WORK}}{d\text{Pollution}}\right) = \frac{\partial\,\text{Illness}}{\partial\text{Pollution}} + \frac{\partial\,\text{WORK}}{\partial\text{WAGE}} \cdot \frac{\partial\,\text{WAGE}}{\partial\,\text{Ilness}} \cdot \frac{\partial\,\text{Illness}}{\partial\text{Pollution}}\ \text{WAGE}$$

As an alternative, we could readily have calculated:

$$\frac{d(\text{WORK}\cdot\ \text{WAGE})}{d\text{Pollution}} = \frac{d\text{WORK}}{d\text{Pollution}} \cdot \text{WAGE} + \frac{d\text{WAGE}}{d\text{Pollution}} \cdot \text{WORK}$$

This latter calculation procedure would yield results comparable to those obtained from the first calculation procedure. For example, the calculation for the expressions in Table 5.10a would have yielded ($1,276)[-0.2087 + (-0.3338)] = $692.

The lost wages occurring in the remaining three samples are considerably less. In the example from Table 5.10b, the difference between an extremely dirty location amounts to $310, mainly because the total effect of air pollution upon chronic illness is much less in this sample (a coefficient of approximately 0.003 as opposed to a sum of coefficients of approximately 0.13) than in the sample of Table 5.10a. The lesser impact in the sample of Table 5.10b exists even though this sample includes a statistically significant acute illness effect of air pollution whereas the sample of Table 5.10a does not.

On the basis of the limited experience of these four samples, air pollution-induced acute illness appears to have a much smaller effect upon labor supply and productivity than does air pollution-induced chronic illness. This is reflected in the example from Table 5.10c as well as that from Table 5.10b. In the latter, although air pollution does significantly affect acute illness, its effect, via acute illness, upon labor supply is overwhelmed by the effect of air pollution-induced chronic illness. The sample of Table 5.10c must depend for its labor supply effects upon acute illness alone. Its magnitude is trivial relative to the air pollution induced chronic effects of Tables 5.10a and 5.10b. Note, however, that the money value of the labor supply effects of the air pollution-induced acute illness in Table 5.10d are nearly one-quarter of the total effects of the air pollution induced illnesses in Table 5.10a.

The empirical results set forth in this section suggest that air pollution, mainly via its influence on chronic illness, affects labor productivity, that at least the order of magnitude of the effect can be estimated within the immediate neighborhood of existing air pollution concentrations and health states, and that the estimates can be given meaning within a rigorous analytical framework. Nevertheless, the estimates we have obtained are basically reduced form estimates: the causally subsequent expressions relating to chronic and acute illnesses and marginal hourly earnings are simply substituted into the labor supply expression to obtain the total of the direct and indirect effects of air pollution induced health effects upon labor supply. This may be too extreme. We allow the individual's state-of-health to influence his earnings and his annual hours of work, but we do not permit these hours of work or earnings to influence his state-of-health.

Yet some empirical evidence exists that long hours of strenuous physical work may generate fatigue and thereby initiate or accentuate air pollution induced health effects.[18/] Moreover, presumedly in order to try to capture socioeconomic and background influences for which they have no overt measures available, epidemiologists have often included earnings as an explanatory variable in dose-response functions. Even economists [e.g., Grossman (1972) and Cropper (1977)] have included wages or earnings in analytical statements of health production functions.

In a succeeding section, we attempt to establish empirically whether reciprocal relations exist between health states, work hours, and wages for a sample of respondents in the SRC data. Before doing so, however, we present an analytical model of consumer behavior which enables us to provide some a priori structure for these reciprocal relations. In particular, with this model we are able to interpret the estimated relations as demand functions for avoiding acute or chronic illnesses and predict the behavior of several of the function parameters. To the best of our knowledge, the model set forth in the next section is the first to conform to the common sense notion that health status is a direct source of utility as well as a factor that influences the efficiency of production and consumption activities.

5.5 A Model of the Effect of Air Pollution on the Demand for Health[19/]

Let an individual obtain utility from two commodities: H, the discounted flow of health services in each period i, h_i; and Z, the present value of the stream of services per period of a composite commodity, z_i. Thus:

$$U = U(H,Z) \tag{5.5}$$

where

$$H = \sum_{i=0}^{I} \alpha_i h_i, \text{ and } Z = \sum_{i=0}^{I} \alpha_i z_i,$$

and α_i is the individual's discount factor for the ith period.

Presume that the individual has an initial health endowment, H_0 , that was provided instantaneously in period 0. However, due to natural aging this initial health stock depreciates exogenously over time as given by (5.6), where β_i is the proportion of H_o remaining in the ith period.

$$H_i = \beta_i H_o \tag{5.6}$$

The h_i and z_i are produced by linear homogeneous production functions $f_j (j = H,Z)$ whose inputs are goods, X_{ij}, and time in each period i. Air pollution and other environmental goods are included among the X_{ij}. In general $\partial h_i/\partial X_i$, when i is pollution.

$$h_i = f_h(X_{hi},T_{hi}), \tag{5.7}$$

$$z_i = f_z(X_{zi}, T_{zi}), \tag{5.8}$$

where T_{hi} is the time allocated specifically to health Care, and T_{zi} is leisure time In the X_{hi}, no distinction is made between ameliorative and preventive medical care, since, if the ameliorative care returns the individual to his former health status, he is dropped back into the same risk pool he was in before receiving the ameliorative care.

We make a distinction between the time-based wage rate and an incentive payment based on the flow of productive services the individual provides. The latter is viewed as a supplement to the time-based salary. It is a reward varying directly with the effort the individual expends over and above that minimum expenditure necessary for him to keep his job. This distinction between time-based salary and incentive payments for non-prescribed effort expenditures allows us to discriminate between acute and chronic health effects insofar as they influence the efficiency of production and consumption activities. Acute health effects do not alter total earnings except when they reduce time on the job, whereas chronic effects alter both time on the job and total earnings for any given amount of time on the job.

Total incentive payments, M_i, are given by (5.9), where $g(\cdot)$ is a twice-differentiable, decreasing returns-to-scale production function, P is the incentive payment, and E and e are respectively stock and flow non-health environmental variables (e.g., schooling, services of a mate, air pollution that directly affects productivity, rather than via health, coffee, air conditioning, etc.) that may influence the ability to put forth effort. The c's are their respective unit prices. Note that M_i varies directly with the amount of output the individual's efforts produce, rather than the amount of effort he expends.

$$M_i = Pg(h_i, E_i, e_i, T_{Di}) - c_E E_i - c_e e_i. \tag{5.9}$$

In (5.9) T_{Di} represents time expended on other work activities in the the period, including household production. These activities are presumed to dissipate energies that could otherwise be devoted to work. Alternatively, one could include T_{Wi}, work time, rather than T_{Di} in (5.9) on the presumption that, beyond some time expenditure, additional work time causes fatigue and/or ennui. 20/

The individual's ith period time constraint is given by (5.10) where θ_i is Becker's (1967) "full-time," and T_{Wi} is work time.

$$\theta_i = T_{hi} + T_{zi} + T_{Di} + T_{Wi} \tag{5.10}$$

If P_h, P_z, are the price indices of the goods used in the production of h and z, and if x_h, x_z are the average (= marginal) composite purchased good coefficients of h_i and z_i then the individual's budget constraint over his planning horizon can be represented as:

$$\sum_{i=0}^{I} Y_i = T_{Wi}W + M_i - p_h x_h h_i - p_z x_z z_i = 0, \tag{5.11}$$

where Y_i is the ith period flow of non-earnings income, and W is the time-based wage rate.

Upon combining (5.10) and (5.11), assuming W represents the shadow-price of time, one obtains the "full" intertemporal wealth constraint, (5.12):

$$= \sum_{i=0}^{I} \alpha_i [\theta_i W + Y_i + P_g(h_i, E_i, e_i, T_{D_i}) - (P_h X_h + WT_h)h_i$$

$$- (P_z X_z + WT_z)z_i - c_E E_i - c_e e_i] = 0 \qquad (5.12)$$

The optimal levels of H and Z, the optimal uses of stock and flow non-health environmental variables, and the utility-maximizing time allocations in each period are obtained by maximizing (5.5) subject to (5.12) with non-negativity constraints on H_0, Z, E, e, and T_D. There are thus 3I + 2 first-order conditions including the full-wealth constraint.

$$\sum_{i=0}^{I} \alpha_i U_H + \lambda[\sum_{i=0}^{I} \alpha_i (\beta_i P_{g_{h_i}} - \beta_i [P_h X_h + WT_h])] \leq 0; \qquad (5.13)$$

$$U_z + \lambda[- \Sigma \alpha_i (P_z X_z + WT_z)] \leq 0; \qquad (5.14)$$

$$P_{g_{T_{D_i}}} - W \leq 0; \qquad (5.15)$$

$$P_{g_{E_i}} - c_E \leq 0; \qquad (5.16)$$

$$P_{g_{e_i}} - c_e \leq 0; \qquad (5.17)$$

Assuming internal solutions, expression (5.13) can be rewritten to form (5.18):

$$\sum_{i=0}^{I} \alpha_i \beta_i (P_h X_h + WT_h) - \sum_{i=0}^{I} \alpha_i \beta_i P g_{h_i} = \sum_{i=0}^{I} \frac{\alpha_i U_H}{\lambda}, \qquad (5.18)$$

which says that the optimal state-of-health occurs where the present value of health is less than the capitalized cost by the value of the marginal utility of the health stock. Thus, the net price of health as an unput into the work process is the horizon period consumption price, $\Sigma \alpha_i \beta_i (P_h X_h + WT_h)$, <u>less</u> the pecuniary equivalent of marginal utility.

Upon combining (5.13) and (5.14), one obtains:

$$\sum_{i=0}^{I} \alpha_i \left(\frac{U_H}{U_Z}\right) = \frac{\sum_{i=0}^{I} \alpha_i \beta_i \, (P_h X_h + WT_h) - \sum_{i=0}^{I} \alpha_i \beta_i P g_{h_i}}{- \sum_{i=0}^{I} \alpha_i (P_z X_z + WT_z)}, \tag{5.19}$$

$$\equiv c_h / c_z$$

which states that the marginal value product of health in work offsets the predetermined consumption price component. Thus, one consequence of the dual role of health is that, even though the time-based wage rate is fixed and the household production functions are linear homogeneous, the full shadow price of health in production or consumption is endogenous, dependent on the state-of-health demanded since the marginal product of better health, Pg_{h_i}, and the marginal utility of better health, U_H/λ, will decline as H_o increases.

To ascertain the response of health states demanded to changes in the parameters specified in the model and to formulate a demand function for health states, the first-order conditions (5.13) - (5.17) must be totally differentiated and the relevant partials for H_0 calculated.

The response of health demand to own predetermined price, $\Sigma \alpha_i \beta_i (P_h X_h + WT_h)$ can be decomposed into compensated substitution and (full) income effects:

$$\frac{\partial h}{\partial [\Sigma \alpha_i \beta_i (P_h X_h + WT_h)]} = \frac{\partial \bar{h}}{\partial [\Sigma \alpha_i \beta_i (P_h X_h + WT_h)]} + h\left(\frac{\partial h}{\partial s}\right), \tag{5.20}$$

Since the first term on the right-hand side of (5.20) corresponds to a compensated price effect, the second-order conditions require it to be negative. It is unclear what the sign of $h\left(\frac{\partial h}{\partial s}\right)$ should be.

Under the assumption that the individual's price of time is equal to the time-based wage rate, the uncompensated substitution elasticity of health with respect to the time-based wage rate is:

$$G_{H_W} = \varepsilon^*_{H c_H} (\lambda H - \lambda_z) + \sum_{i=0}^{I} \phi_{H_W} + \left[\sum_{i=0}^{I} \alpha_i T_{D_i} W \varepsilon_s \right] / s \tag{5.21}$$

where $\varepsilon^*_{H c_H}$ is the own compensated price elasticity of health; ε_s is the (full) income elasticity of health stock, H; and the consumption price time intensities are defined as:

$$\gamma_H \equiv \left(\sum_{i=0}^{I} \alpha_i WT_H \right) / c_H \tag{5.22}$$

$$\gamma_Z \equiv (\Sigma\, \alpha_i WT_Z)/(c_Z = p_Z x_Z + WT_Z) \tag{5.23}$$

In (5.21) a compensated increase in the time-based wage rate reduces the demand for the absence of acute health effects (causing the value of freedom from air pollution exposures to be reduced) if the individual's production of freedom from acute health effects is more time-intensive than is his production of other goods from which he obtains utility. This is because the second-order conditions require that $\varepsilon^*_{H} c_H < 0$. Although we can only speculate, activities such as daily exercise programs and the careful preparation of healthy menus do seem more time-intensive than reading a novel or eating at the local fast-food emporium. Even if the consumption price time intensities are equal, i.e., $\gamma_H = \gamma_Z$, an increase in W might still reduce the demand for freedom from acute health effects, since, from (5.22) and (5.23), $\gamma_H > \gamma_Z$ as $c_H > c_Z$.

The second-order conditions imply that there will exist a discrepancy between the observed income elasticity of health status and the "true" income elasticity. In fact, the former is likely to be less than the latter because the data used to calculate the observed elasticity will frequently be unable to distinguish between the time-based and the incentive payment components of the total wage. These two components imply that the individual's budget constraint will be nonlinear since chronic health status influences the ability of the individual to provide those productive services rewarded by incentive payments. This downward bias further implies that estimates of the demand for the absence of air pollution induced chronic health effects will also be biased downward whenever the data do not allow a distinction between the two earnings components. If an exogenous reduction in air pollution increases the optimal degree of absence of chronic illness, the marginal productivity portion of the full shadow price of health diminishes, assuming that the supply of effort is negligibly reduced by the additional earnings. The shadow price of the health stock therefore, rises.

A second general consequence of the contribution of freedom from chronic illness to incentive payments is that changes in education and similar factors related to the provision of productive services will influence the shadow price of health by altering horizon period productivity. In turn, these factors will affect the value the individual attaches to the absence of air pollution-induced chronic illness. In short, the individual's demand for freedom from air pollution exposures will be related to his education, job experience, and other influences on his productivity.

The uncompensated elasticity of freedom from chronic health effects with respect to the price, c_j, of any of the aforementioned factors related to the provision of productive services is ambiguous, however. This elasticity is given by (5.24), where q_j refers to one of these productive services.

$$\varepsilon_{H_{c_j}} = \sum_{i=0}^{I} \phi_{H_{c_j}} + \frac{\sum_{i=0}^{I} \alpha_j q_j c_j \varepsilon_s)}{s} \tag{5.24}$$

The sign of this expression depends on whether the factor in question is a substitute for ($\phi > 0$, as with education), or a complement of ($\phi < 0$ as perhaps with comfortable job surroundings) freedom from chronic illness. For example, assuming non-inferiority ($\varepsilon_s > 0$), if freedom from chronic illness and the services of a mate are (imperfect) substitutes in the provision of productive services, then a compensated increase in c_j would raise the demand for health; the sign of the uncompensated effect, however, would depend on the magnitude of ε_s and the share of the costs of the services of a mate in full income.

The effect of a change in the price, P, of the output of productive services is also ambiguous. Expressed in elasticity terms, this effect is:

$$\varepsilon_{Hp} = -\varepsilon^*_H c_H \sum_{i=0}^{I} \alpha_i \beta_i Pg_i / c_H + \sum_j \sum_{i=0} \phi H_{c_j} + \sum_{i=0}^{I} Pg_i / R\varepsilon_R.$$

While an increase in P raises the marginal value product of good health, thus lowering c_H, and increases incentive-based income, the value of the output contributions of the other input factors in $g(\cdot)$ also rises. The sign of the compensated substitution effect will thus depend on the complementarity-substitution relations between freedom from chronic health effects and other inputs.

Accounting for the preceding development, we can express the demand for freedom from chronic and acute illnesses in terms of two functions differing according to whether we are considering acute or chronic illness. Both of these functions will involve arguments, however, relating to predetermined variables that influence the pride of time, in addition to variables that relate to production and consumption activities. Thus, for the willingness to accept chronic illness, we can write the demand function as:

$H_{LDSA} = \mu_1$ (Time-based wage, Incentive payment, Non-earnings income, Environmental variables, Cost-of-living, Endowment variables).

In the case of the demand for acute illness, the demand function, $\mu_2(\cdot)$, for H_{ACUT} similar to H_{LDSA} above, except that the term for incentive payments is deleted.

5.6 Some Empirical Results: The Demand for Freedom from Air Pollution-Induced Acute and Chronic Illness

The model of the preceding section implies that changes in the willingness to accept acute illness will result in changes in work time alone, although the extent of the change will depend on other parameters such as the time-based wage rate, transfer income, and assorted background variables.

In contrast, the wage rate is endogenous in the demand for freedom from chronic illness, since the extent of chronic illness determines, in part, the wage rate. Thus, although the wage rate is determined outside the system in the demand for freedom from acute illness, it is determined within the system in the demand for freedom from chronic illness. This implies that we can treat the demand to avoid acute illness as a single expression, but must account for the simultaneity between the wage rage and chronic illness when estimating the demand to avoid chronic illness.[21] In the latter case, we must resort to simultaneous equation estimation procedures. Here we adopt two-stage least squares.[22]

The appropriate expressions to calculate the pecuniary amounts the individual would have to receive to be willing to pay to avoid an increase in acute or chronic illness are, respectively, (5.21) and (5.24) of the previous section. Calculation of these expressions is clearly rather complex. As an alternative, we have calculated this willingness to accept as:

$$\frac{d(\text{Income})}{d(\text{Pollution})} = \frac{d(\text{Illness time})}{d(\text{Pollution})} (\text{Price of time})(\text{Illness time})$$

Upon reflection, this proposed method of calculation seems no different than the procedure employed to calculate the pecuniary equivalent of the recursive effects of air pollution upon labor supply. A somewhat subtle difference does nonetheless exist. In particular, a difference exists in the definition of illness time and its response to pollution variation: The recursive estimates dealt only with the physical effects of air pollution, while illness time in the above expression represents the individual's utility-maximizing illness time. When estimating dose-response expressions, we included as explanatory variables only predetermined variables either that described the individual's current health status or were a priori physical determinants of changes in this status. In contrast, when estimating the individual's demand expression for willingness to pay to avoid illness, we include variables such as the time-based wage rate, transfer payments, incentive payments, etc., that influence the sacrifices the individual is willing to make in order to avoid illness time. For consistency, and only when we have no alternative, we even sometimes reinterpret the meanings of identical explanatory variables that appear in both the dose-response expressions and the demand expressions. Thus, INSR, which was conveniently interpreted as a proxy for the availability of medical care in the dose-response expressions, will be interpreted in the demand expressions as a proxy for the price that the individual faces for a given quantity of medical care.

In the analytical model of the preceding section, increased air pollution reduces the flow of health services, and, as a consequence, reduces utility and usually increases the marginal product of particular health investments. These effects are opposing, causing the sign to be expected for the coefficients attached to the pollution variables to be ambiguous. However, pollution also causes the cost of supplying a given health status to increase. The result is that the income the individual is willing to forego to avoid pollution-induced illness is positive. We therefore expect the signs attached to the pollution coefficients in the demand expressions to be unambiguously positive.

Table 5.12 below presents three estimated demand expressions relating to acute illness for two different samples drawn from the 1971 SRC data. These samples include housewives, retirees and students, all of whom were assigned zero hours of acute illness by the SRC. The expressions are linear in the original variables. Expressions (1) and (3) were estimated from the same example. Only in the first two expressions is at least one of the air pollution variables statistically significant. The individual's time-based wage, which was measured as his hourly earnings on his regular job, appears to have no influence on his demand for avoiding increased hours of acute illness. Neither does annual work hours nor cigarette expenditures. As previously noted, substantial measurement error is involved in CIGE. People who participate in energetic activities and have adequate diets tend to have greater demands for the avoidance of acute illness, as do those who are risk averse. Older people and those who face lower prices for medical care seem less willing to pay to avoid additional acute illness. As in the dose-response expressions for acute illness, the sign attached to INSR is puzzling. Additional income, the acquisition of which does not involve any current time, increases the demand for acute illness avoidance.

In expressions (1) and (2), each additional unit of TSPM results, respectively, in an additional 1.212 and 0.796 additional optimal acute annual hours of illness. In expression (1) of Table 5.12, the arithmetic mean of WAGE is \$3.62, meaning that the representative individual would, on average, be willing to pay an additional \$4.39 annually to avoid one additional unit of TSPM. The arithmetic mean of WAGE for expression (2) in Table 5.12 is \$3.58. Thus, the representative individual in this sample would be indifferent between paying \$2.85 and an additional unit of TSPM. In expression (2), the arithmetic mean TSPM is 87.315 and 54.749 units of TSPM is two standard deviations removed from this mean. Assuming a linear extrapolation of the preceding marginal (= average) willingness to pay of \$2.85 for avoiding an additional unit of TSPM to be valid, the representative individual in expression (2) would be willing to pay \$312 annually to avoid the additional hours of acute illness associated with living in a location where TSPM is extremely high as opposed to being extremely low. A similar calculation for the representative individual in expression (1) indicates that he would be willing to pay \$457.97 in 1971 dollars annually in order to avoid a similar fate.

The basic calculations from the willingness to pay to avoid chronic illness expressions in Tables 5.13a and 5.13b are identical to the procedures used for the willingness to pay to avoid acute illness expressions of Table 5.12. The sole difference is the use of the arithmetic mean value $\widehat{WAGE}$ rather than WAGE. Table 5.13a holds no special surprises except for the sign attached to the statistically significant coefficients of DSAB. None-the less the sign is consistent with a finding of Hamushek and Quigley (1978) that disabliities appear to affect negatively the earnings of the blue-collar workers but have little, if any, effect on the earnings of (presumedly) higher paid white-collar workers.

The estimates in Table 5.13b indicate a reduced quantity demanded of chronic illness avoidance with an increase in age, and an increased quantity demanded with reduced prices for medical care. The significance of the

Table 5.12

Willingness to Pay to Avoid Acute Illness

Sample	(1)		(2)		(3)	
Variable	β 1971	s	β 1971	s	β 1971	s
WORK	0.007	0.018	-0.007	0.010	0.012	0.018
WAGE	0.047	0.032	-0.016	0.020	0.039	0.052
CIGE	-0.057	0.094	-0.108	0.118	-0.067	0.095
EXER	-66.990*	33.320	-30.033	40.019	-60.520*	33.620
FOOD	-0.052*	0.024	-0.115*	0.033	-0.052*	0.024
RISK	-10.460	11.250	-40.020*	13.420	-12.680	11.360
AGEH	0.955	1.034	-0.506	1.286	1.246*	0.742
INSR	54.85**	27.58	161.800**	47.230	63.480*	27.890
ICTR	-0.244*	0.022	-0.278*	0.022	-0.233*	0.021
TSPM	1.212*	0.668	0.796*	0.384	0.500	0.478
SULM	-0.610	0.419				
Constant	99.057		182.339		128.082	
R^2	0.091		0.086		0.089	
S.E.	245.647		267.306		258.336	
F	(10,391) = 3.094		(9,390) = 4.112		(9,390) = 3.475	

*Statistically significant at the 0.05 level of the one-tailed t-test.

**Statistically significant at the 0.05 level of the two-tailed t-test.

Table 5.13a

Two-Stage Least Squares Estimates of WAGE Expressions for Chronic Illness

Sample	(1)		(2)	
Variable	β 1970	s	β 1971	s
EDUC	31.730*	8.735	23.740*	5.307
WORK	0.016	0.021	0.0017*	0.0011
DSAB	179.200**	50.230	35.670**	17.220
FMSZ	33.610*	6.293	63.790*	37.980
BDALO	40.470*	6.075	14.610*	3.447
HMPN [b]	0.554**	0.218	0.642	0.927
LTWK	-17.430	33.520	-35.160	32.070
ABSN [a]	-5.401	44.010	-	-
UION	87.320*	34.620	29.880	19.920
RACE	41.310	33.780	68.430	81.210
LDSA	-255.600*	58.880	-69.940*	30.530
Constant	-59.852		-28.345	
S.E.	255.199		159.234	
F	(11,388) = 26.020		(10,389) = 13.685	

*Statistically significant at the 0.05 level of the one-tailed t-test.

**Statistically significant at the 0.05 level of the two-tailed t-test.

[a] ABSN refers to the frequency with which the individual missed work for reasons other than illness.

[b] HMPN refers to annual hours of home production, e.g., car repairs, house additions and repairs, etc.

Table 5.13b

Two-Stage Least Squares Estimates
of Chronic Illness Expressions
(LDSA)

Sample / Variable	(1) 1970 β	(1) 1970 s	(2) 1971 β	(2) 1971 s
RISK	-0.030	0.052	-0.016	0.048
AGEH	0.029*	0.006	0.031*	0.005
INSR	-1.475*	0.257	-0.553*	0.170
CHEM	-6.804*	2.479	0.268	0.703
CITY	0.052	0.129	0.050	0.134
POOR	0.500*	0.150	0.345*	0.135
FEDU	-0.036	0.044	-0.028	0.046
ICTR	-0.17×10^{-3} *	0.05×10^{-3}	-0.80×10^{-4} *	0.16×10^{-4}
TSPN	0.0021	0.0020	0.0039*	0.0010
SULN	-0.001	0.004	-0.0007	0.0014
WAGE	0.005*	0.002	0.005*	0.001
Constant	0.521		0.033	
S.E.	1.168		1.193	
F	(11,388) = 9.733		(11,388) = 13.250	

*Statistically significant at the 0.05 level of the one-tailed t-test.

**Statistically significant at the 0.05 level of the two-tailed t-test.

coefficient for CHEM in expression (1) is undoubtedly an anamoly since only one person worked in the chemicals and metals manufacturing sector. Those respondents who were poor when growing up demand less chronic illness avoidance, perhaps because their health status is initially less and they therefore must invest more to reach a given health status level. WAGE, and therefore $\widehat{WAGE}$, is defined here as the individual's marginal hourly earnings. This need not be his hourly earnings without overtime on his primary job.

In Table 5.13b, only expression (2) possesses a statistically significant air pollution coefficient. Assuming as in previous sections that each unit of LDSA is slightly more than two years, or 830 days, in length, that each of these days is a potential workday, and that the average workday is eight hours long, then an additional unit of TSPN in expression (2) of 5.13a causes the individual's utility-maximizing number of days of chronic illness to increase by 3.25 days over his lifetime. We have no idea, however, how these additional days will be distributed over his lifetime, nor can we treat 3.25 additional days for someone who is already chronically ill as similar to 3.25 additional days for someone who is not now chronically ill. Assume our representative individual currently has no chronic illness, and further assume that perpetual exposure to an additional unit of TSPN will cause him to acquire immediately a "chronic" illness. The arithmetic mean for $\widehat{WAGE}$ in 1971 is $3.72 per hour. Since our representative individual works eight hours per day, and since he will now find that 3.25 days of his worktime will at some time no longer be available, he would be willing to pay an undiscounted amount of $96.72 in a single lump sum. The arithmetic mean of TSPN in sample (2) is 156.185, and 127.574 units of TSPN is two standard deviations removed from this mean. Assuming the validity of a linear exprapolation of the preceding marginal (= average) willingness to pay to avoid the chronic illness induced by perpetual exposure to an additional unit of TSPN, we find that the representative respondent would be willing to pay an undiscounted lump sum of approximately $25,000 ($24,678) to avoid the chronic illnesses associated with spending the rest of his life in an extremely high TSPN location as opposed to an extremely low TSPN location.

5.7 Overview of Empirical Results

We view the empirical results of this chapter as tentative and ongoing rather than as definitive and final. The SRC interview data that we employ is a random sampling of the civilian, noninstitutionalized population of the United States. Extrapolations of results to the entire population are therefore fairly reasonable, even though we have not employed the SRC sampling weights. However, caution must be exercised in doing so: our measures of illness are substantially less than ideal. In particular, the measure of chronic illness is rather discrete and its uppermost value is unbounded. Moreover, individuals who died between the reference year of the interview and the time of interview are not included. Both factors probably cause the health impact of air pollution to be underestimated. Nevertheless, we feel that we have provided an example of some of the things that can be done with microepidemiological data on health status, endowments, and time and budget allocations. In the bulk of the dose-response expressions we have estimated, most of which were estimated from distinct random samples, air pollution is associated with increased time spent being acutely and/or chronically ill.

Air pollution, in addition, appears to influence labor productivity, where the reduction in productivity is measured in the earnings lost due to reductions in salable skills and in work-time. The reduction in productivity due to air pollution-induced chronic illness seems to overwhelm any reductions due to air pollution-induced acute illness.

The following examples involve linear extrapolations of estimated labor productivity effects and willingnesses-to-pay at arithmetic mean air pollution concentrations. The linear exprapolations extend two standard deviations from the means of the frequency distributions of these concentrations. Geographical locations residing in the upper tails of these distributions might reasonably be regarded as extremely dirty while those along the extended portion of the lower tails are bathed in extremely clean air. The representative individual who is instantaneously and painlessly removed from an extremely dirty location to an extremely clean one might expect to acquire about $20 (in 1970-71 dollars) in additional annual earnings from reductions in air pollution-induced acute illnesses. This same individual would annually acquire several hundred 1970-71 dollars (approximately $100 to $600 in our empirical tests) by the reduction in chronic illness he would obtain from a similar removal. Both these results assume that wage rates are not adjusted in response to a cleaner environment.

The willingness of the representative individual to pay for the annual hours of acute illnesses he could avoid by being in a clean rather than a dirty environment is, for the two samples for which we obtained estimates, between $300 and $500 annually in 1970-71 dollars. For chronic illness avoidance, we calculated, under <u>some extremely crude assumptions</u> and on the basis of <u>only a single sample</u>, that representative individual would be willing to pay an undiscounted lump sum of $25,000 to be in the clean rather than the dirty environment.

FOOTNOTES

1/ The Survey Research Center possesses the exact addresses of the sample families, but does not include them in its data tapes.

2/ This "errors in variables" problem is usually handled by using instrumental variables which are highly correlated with the variable measured with error but are uncorrelated with the error. We were unable to think of a variable having these properties.

3/ SRC interviews for 1973 behavior and status include a three-digit occupational code corresponding to the coding used in U.S. Bureau of the Census, 1970 Census of Population Alphabetical Index of Industries and Occupations, Washington, D.C.: USGPO (1971). This means that information is available in the SRC data set on nearly the exact kind of job held by the family head and/or his wife. This rather magnificent store of information obviously has many research possibilities which remain completely unexploited in this study.

4/ Other measures of ill-health are available in the SRC data set, particularly the severity of the disability, if any, and the number of weeks missed from work due to sickness. Because of its qualitative nature, the decision was made to use the first of these entirely as an explanatory rather than as a dependent variable.

5/ Expressions of discomfort with the reductionist perspective are now fairly common in the biomedical literature. See, for example, Syme and Berkman (1970) and Engel (1977). More importantly, there is empirical evidence that variations in self-reported health status reflect correct variations in clinically objective measures of health. See Grossman (1975, p. 168) for a review of this literature as well as some additional empirical evidence.

6/ The literature which views children as an investment is surveyed in several papers in a supplement to the March/April 1973 issue of the Journal of Political Economy.

7/ The 18th century French jurist and philosopher, Montesquieu (1947, p. 245), succinctly stated the central theme of much of this literature: "The nations of hot countries are timorous like old men, the nations in colder regions are daring like youngsters." Recent efforts have been considerably less elitist and self-congratulatory.

8/ A fair amount of work appears to have been done to ascertain the discrepancies, if any, between self-reported and clinically evaluated health status. Survey Research Center (1977, pp. 7-10) states that the bulk of studies conclude: (1) as the time between an interview and an event lenghtens, there is increased underreporting about the magintude of the event; (2) important events are less likely to be incompletely and inaccurately reported; and (3) self-reported events are likely to be biased in what the respondent considers to be a socially acceptable direction. Marquis (1978), however, disputes these conclusions because all studies either check self-reported health status against clinical records or check clinical records against status. He shows that a statistically correct test of bias requires both checks. When he performed this check with a sample of individuals from Dayton, Ohio, he found that "...there is little or no average reporting bias in hospital admission/discharge data obtained by household interviews." (p. 42).

9/ This high proportion of non-whites is probably caused by the fact that 40 percent of the original 1967 sample was composed of families previously interviewed by the U.S. Bureau of the Census for the 1966 Survey of Economic Opportunity.

10/ Wallace (1977) has surveyed a number of recently evolved tests enabling the investigator to ascertain the extent to which Selvin's and Stuart's (1966) data-dredging alter the trustworthiness of later estimates. We have disregarded the Wallace (1977) tests in this study in favor of drawing entirely new samples each time a new expression is estimated.

11/ There is another alternative: each of the following structural expressions could be estimated:

a) DSAB = f (Air pollution, lifestyle, . . ., etc.)

b) LDSA = $g(\widehat{DSAB}, \ldots)$

where the $\widehat{DSAB}$ in expression (b) is the estimated value of DSAB. However, since DSAB is measured in ordinal and discrete terms, either a multinomial logit or a basic logit specification using maximum likelihood estimation methods would have to be employed. In the latter case, four different versions of (a) would have to be estimated since DSAB involves four discrete ordinal measures.

12/ See, for example, Grossman and Benham (1973), Thaler and Rosen (1975), and Parsons (1977).

13/ A review of recent work is available in Lave and Seskin (1977).

14/ In Grossman's (1972) notation, the sick time production function is:

$$TL_t = b_0 + b_1[I_t + \delta)H_{t-1}]$$

where TL represents chronic or acute sick time, H is the stock of health capital, I_t is current health investments, and δ is the rate at which the health stock decays. The term in parentheses is the stock of health capital written in terms of the past stock of health capital and current investment in health. Thus, for example, we treat such variables as POOR, DSAB, and FEDU as determinants of H_{t-1}, and FOOD, NCIG, TSPM, etc., as components of I_t and δ. Grossman (1972) chosses a multiplicative form for this expression, whereas we adopt a linear form. Most inportantly, Grossman (1972) makes both the wage rate and the health state endogenous by making the former a function of the latter and the latter a function of the former. We treat the health state as exogenously determined while retaining the dependence of the wage upon the health state.

15/ This currently lesser productivity could readily be due to past discrimination in the labor market and/or education as well as fewer past opportunities for investment in physical health.

16/ In this case it is unlikely that multicollinearity has seriously inflated the standard errors of the air pollution variables. The highest simple correlation coefficient between an air pollution variable and another explanatory variable was $r_{TSP \cdot SULM} = 0.65$. All other simple correlation coefficients were less than 0.20.

17/ The 830-day interval is a weighted arithmetic mean established by taking the midpoint of each of the time equivalents of the SRC index measures for LDSA and weighting by the proportion of the entire SRC sample in 1971 having a particular LDSA index value. Ten years was treated as the midpoint for the uppermost LDSA index.

18/ See Crocker and Horst (1977).

19/ Ideal generalization of this model would have: (1) the flow of health services rather than the stock of health entering the individual's utility function; and (2) the opportunity cost of time not be assumed equal to the wage rate but rather derived from the model to be equal to the wage rate weighted by the shadow price for expenditures on inputs into the production of health and the composite commodity.

20/ The time expenditure at which fatugue and/or boredom sets in on a particular job and the rate at which it changes is itself likely to be a function of the individual's state-of-health and education. We have not tried to capture this either in this model or in the subsequent empirical effort that accords with it. One might argue that various attitudinal measures such as job satisfaction, aspiration and ambition, and others readily available in the SRC data would serve as adequate proxies for fatugue and boredom.

21/ Simultaneity is implied by the model in the demand for acute illness. In particular, although we considered it only in passing, the time expended in other work activities is an endogenous variable, which, in turn, implies that work time is endogenous. We have, infact, tested this sumultaneity by treating work as endogenous and estimating the systme by two-stage least squares. The results, which we do not bother to report here, differed only trivially from the ordinary least squares estimates that we do report.

22/ The reader should be aware that by adopting a TSLS estimation procedure, we are giving up some efficiency in estimation in order to enhance the consistency of our estimation. The cruelty of this tradeoff is due to the quite low coefficients of determination involved in OLS estimates of the freedom from chronic illness demand function.

Chapter VI

AN ESTIMATE OF NATIONAL LOSSES IN LABOR PRODUCTIVITY DUE TO AIR POLLUTION-INDUCED MORBIDITY

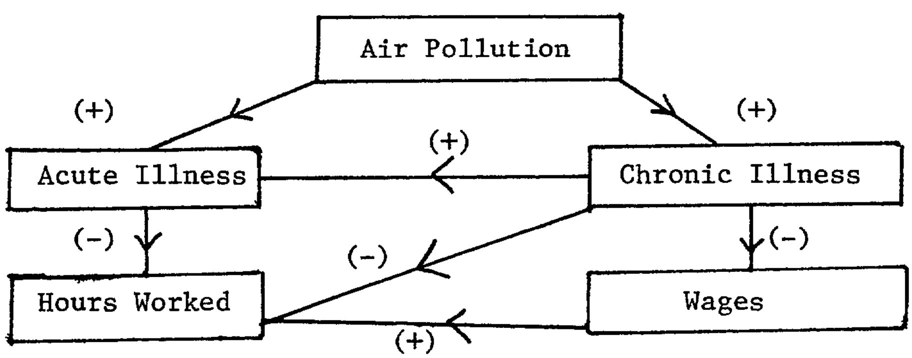
6.1 Introduction

In this brief chapter, we use what we consider to be the most representative of the recursive labor supply estimates in Table 5.10 to speculate what the aggregate gains in U.S. labor productivity could be from a reduction in air pollution-induced acute and chronic morbidity. Due to the preliminary and exploratory nature of our work, we are most anxious that the reader wishing to employ or to communicate these calculations be careful always to make highly visible the set of assumptions in which the calculations are embedded. Otherwise, he will be unable to make an informed judgment about the extent to which the world represented in the text corresponds to reality.

Figure 6.1 is a hueristic representation of the structure forming the basis of our estimate. Air pollution is viewed as increasing directly both chronic and acute illness. In addition, it causes an indirect increase in acute illness via its positive effect on chronic illness. Acute illness reduces hours worked, but, because of its passing nature, it has no impact upon the worker's long-term productivity that determines the level of his wages. However, chronic illness, which does reduce long-term productivity, exerts a direct negative influence on both wages and hours worked. It also influences hours worked in an indirect manner through its effect upon wages.

Figure 6.1

A Representation of the Effect of Air Pollution Upon Labor Productivity



6.2 The Assumptions

Table 6.1 is a succinct list of the major assumptions underlying our empirical implementation of the structure depicted in Figure 6.1 and its extrapolation to a national aggregate. We divide these assumptions into four classes: specification, measurement, estimation, and aggregation. The table also indicates the probable direction of bias, if any, the assumption introduces. However, we do not now know the sensitivity of our estimates and calculations to any particular assumption or to the entire set of assumptions. Upon reviewing Table 6.1, the judicious reader will immediately become aware that our listing is sufficiently strenuous to raise some questions about whether our estimates and calculations are yet sufficiently compelling to warrant their serious use.

In spite of the lengthy listing of assumptions, we emphasize that our treatment of the system in Figure 6.1 has several positive distinguishing features. To balance any negative impressions established from Table 6.1, we list these positive features in Table 6.2. Our estimates of the system in Figure 6.1 is presented in Table 6.3. As a result of a one-unit ($\mu g/m^3$) increase in air pollution, we estimate that the representative person in Table 6.3 will have his annual work hours reduced by 0.547 hours. Of this reduction, only 0.046 hours will be due to acute illness. The loss in labor productivity suffered by this person can be calculated by (where A stands for change):

$$\frac{\Delta(\text{Work hours} \cdot \text{Wage})}{\Delta(\text{pollution})} = \frac{\Delta(\text{Work hours})}{\Delta(\text{Pollution})} \cdot \text{Wage} + \frac{\Delta(\text{Wage})}{\Delta(\text{Pollution})} \cdot \text{Work hours}$$

Upon performing this calculation, we obtain:

$$= (0.547)(\$3.225) + (\$0.071)(1560.895)$$

$$= \$2.86$$

That is, a one-unit reduction in air pollution would have increased this representative person's 1970 earnings by \$2.86. Only \$0.15 of this sum represents the gain from a reduction in acute illness.

The above \$2.86 sum represents our "best" estimate at this point of the representative person's gain in 1970 earnings from a one-unit reduction in air pollution. Lower and upper bounds for this estimate can be established by making use of the confidence intervals for the effect of pollution on chronic and acute illness; that is, we wish to calculate the gain in earnings when the pollution coefficient in (1) is 0.0028 ± 0.0011, and when the pollution coefficient in (2) is 0.623 ± 0.317. At least for the chronic illness expression, this confidence interval captures nearly all the range of the values for the pollution coefficients in the chronic illness expressions estimated in the previous chapter. Upon performing this calculation for the lower bound, we obtain \$1.88, and for the upper bound, we obtain \$3.84.

Assume that the average exposure of the U.S. 1970 urban population to annual geometric mean total suspended particulates was 100 $\mu g/m^3$ and that

Table 6.1

Major Assumptions Limiting Generality of Results

Specification

1) Air pollution affects only the duration of chronic illness. Our inattention to the severity of chronic illness tends to reduce the estimated impact of air pollution on labor productivity.

2) Occupational exposures to hazards and environmental pollutants other than air pollution do not influence either acute or chronic illness. If air pollution is moderately and positively associated with these hazards and pollutants, this assuption tends to increase the estimated impact of air pollution on labor productivity.

3) Annual geometric mean ambient concentrations of total suspended particulates serve as an adequate proxy for all forms of air pollution. The effect of this assumption upon the estimated effect of air pollution on labor productivity is unknown.

4) All relationships depicted in Figure 6.1 are linear. It is unknown what effect this assumption has on the estimated effect of air pollution on labor productivity.

5) Air pollution-induced health effects do not cause the voluntary substitution of leisure for work. This assumption tends to reduce the estimated impact of air pollution on labor productivity.

Measurement

6) Air pollution exposures for each individual in the sample are adequately represented by a single annual average of ambient concentrations obtained at a single monitoring station within the individual's county of residence. Since pollution monitoring stations in the early part of the 1970's were predominantly in downtown urban locations, individuals' air pollution exposures probably tend to be exaggerated. This will reduce the estimated health effects of air pollution.

7) The duration of any air pollution-induced chronic illness cannot exceed ten years. This will reduce the estimated effect of air pollution upon the duration of chronic illness.

8) Housewives, retirees, and students, who together constitute about twenty percent of our samples, do not contract air pollution-induced acute illnesses. This assumption will tend to reduce the estimated impact of air pollution upon labor productivity.

9) Air pollution-induced chronic and acute illnesses are a constant proportion of all illnesses. The effect of this assumption is unknown.

(continued)

Table 6.1

(continued)

10) The quantity of preventive and ameliorative medical care an individual consumes is adequately measured by whether or not he has medical insurance. This assumption has an unknown effect upon our estimates.

11) Relative air pollution concentrations across the U.S. have been fairly constant. This assumption has an unknown effect upon our estimates of air pollution-induced chronic illness.

12) When interviewed, the individuals in the sample had no incentive to bias their answers nor did they have difficulty accurately recalling their personal medical histories of the previous twelve to sixteen months. The effect of this assumption upon our estimates is unknown.

13) No individual who would otherwise have been included in the sample died between the time for which information was to be gathered and the time of the interview. In fact, about five percent of the potential respondents died each year. The effect of this assumption is to reduce the effects of air pollution upon labor productivity.

Estimation

14) With the available data, classical linear regression procedures provide consistent and unbiased estimates of the structure depicted in Figure 6.1. The effect of this assumption upon our estimates is unknown.

Aggregation

15) The response of the health state of each individual in the U.S. to any given change in ambient air pollution is a constant. The effect of this assumption upon the calculation for the aggregate effect of air pollution upon labor productivity is unknown.

16) The response of the health state of every individual in the U.S. to ambient air pollution changes is identical. The effect of this assumption upon the calculation for the aggregate effect of air pollution upon labor productivity is unknown.

Table 6.2

Distinguishing Features that Enhance the Generality of Results

1) The acute illness and chronic illness dose-response estimates used to calculate the aggregate impact of air pollution-induced morbidity upon U.S. labor productivity are representative of estimates obtained from many different independent samples drawn from the same data set. In effect, substantial quasi-replication of the dose-response estimates has been performed.

2) The system is estimated only for people who have always lived in one state. We believe this restriction enhances the extent to which we capture the effect of the history of air pollution exposures upon the chronic illness dose-response function.

3) Our estimated expressions for wages and hours worked are very similar to those obtained by other economists.

4) We include more information on life-styles and genetic and social endowments than is usually included in dose-response expressions estimated from epidemiological data.

Table 6.3

Estimated Expressions to be Used to Calculate the Effect of Air Pollution-Induced Illness on Labor Productivity[a]

(1) 830 day years chronically ill = 2.980 + 0.554 (illness severity)** +
(0.035)
0.005(age in years) + 0.013(years of school) - 0.044(father's years of
(0.004) (0.029) (0.037)
school) - 0.069(poor when growing up) + 0.072(Caucasoid) + 0.139(male)
(0.103) (0.488) (0.114)
- 0.902(diet adequacy) - 0.454(has medical insurance)* - 1.645(works
(0.975) (0.129) (0.575)
in chemicals/metals industries)[b] + 0.0028(mean total suspended
(0.0011)
particulates)*

R^2 = 0.525; S.E. = 0.964; F(11,388) = 38.920.

(2) Annual hours acutely ill = 165,208 + 39.52(years chronically ill)*
(13.34)
-1.421(age in years) - 16.92(male) - 0.086(cigarette expenditures) -
(1.312) (39.16) (0.118)
78.47(gets strenuous exercise)* - 0.105(diet adequacy)* - 38.44(degree
(40.11) (0.033) (13.26)
of risk aversion)* + 187.70(has medical insurance)** - 85.56(works in
(47.47) (191.20)
chemicals/metals industries) + 0.623(mean total suspended particulates)*
(0.317)

R^2 = 0.195; S.E. = 204.462; F(10,389) = 5.721.

(3) Wage in cents = -132.318 - 25.930(years chronically ill)* + 24.070(years
(14.440) (8.578)
of school)* + 15.370(illness severity) + 26.880(family size)* + 42.380
(18.260) (6.079) (6.138)
(cost-of-living)* = 52.950(years on current job)* - 7.163(often late
(22.130) (33.88)
for work) + 66.090(union member)* + 47.60(Caucasiod)
(34.580) (34.22)

R^2 = 0.408; S.E. = 258.908; F(11,388) = 24.28.

(continued)

Table 6.3

(continued)

(4) Annual hours worked = 1266.68 - 163.90(years chronically ill)* + 0.354
(27.22) (0.130)
(wage in cents)* + 44.26(family size)* + 519.80(male)* - 0.272(dollars
(16.68) (80.27) (0.022)
Of transfer income)* + 23.06(cost-of-living) - 0.074(annual hours
(15.20) (0.031)
acutely ill)*

R^2 = 0.551; S.E. = 663.196; F(6,393) = 80.41.

[a]Exact variable definitions are available in Table 5.1.

[b]The number of people in these industries was too small for this coefficient to be meaningful

*Statistically significant at the 0.05 level of the one-tailed t-test.

**Statistically significant at the 0.05 level of the two-tailed t-test.

the standard deviation of these exposures was 30 $\mu g/m^3$. Throughout this study, total suspended particulate measures have been highly correlated with other air pollutants so that total suspended particulates probably serve as an adequate proxy for all air pollution. Further assume that the national urban population is approximately 150 $\times 10^6$ people, each of whom is or will be a family head. After age 20, each of these family heads has a life-span of 50 years and any air pollution-induced chronic illnesses he contracts are distributed rectangularly over the 50 years. The earnings he loses due to the presence of an acute or chronic illness do not vary over the years. Given these and earlier assumptions, a 60 percent reduction in air pollution would, in June 1978 dollars, increase the value of 1970 U.S. labor productivity by the amounts shown in Table 6.4. Most of the gain would accrue due to reductions in air pollution-induced chronic illness.

It must be strongly emphasized that the magnitudes exhibited in Table 6.4 are extremely sensitive to the assumptions we have made. Nevertheless, given any reasonable set of assumptions about air pollution exposures, size of the population exposed, etc., the estimates of labor productivity gains in Table 6.4 are much larger than previous estimates of all types of annual gains from air pollution control in the United States. No gains in labor productivity, via reductions in air pollution-induced health effects, have previously been developed. It thus appears that the economic gains from the morbidity effects of air pollution control have been greatly under-valued, perhaps because most prior research efforts have concentrated upon mortality rather than morbidity.

A more conservative but equally tenuous way of calculating the effects in Table 6.4 might proceed as follows. Assume that the 75 percent, or 112 $\times 10^6$ million people of the 150 $\times 10^6$ urban population are 16 years or older. At age 16, each of these adults has a lifespan of 56 years and any air pollution-induced chronic illnesses he contracts are distributed rectangularly over the 56 years. The annual earnings he loses due to the presence of an acute or chronic illness do not vary over the 56 years. If the median household size is 2.0, there are then 56.25 $\times 10^6$ urban household heads. There is thus a \$160.88 $\times 10^6$ = (\$2.86) (56.25 $\times 10^6$) gain in the labor productivity for household heads from a one unit reduction in air pollution.

If two-thirds of the household heads are married, if 35 percent of these households have working wives, and if working wives earn 60 percent as much as their male counterparts, there would then be a \$22.58 $\times 10^6$ = (\$2.86) (0.6) (13.13 $\times 10^6$) gain in the labor productivity of working wives.

If the value of household services provided by all household members in each urban household is 40 percent of the household head, there would then be a \$64.35 $\times 10^6$ = (\$2.86)(0.4) (56.25 $\times 10^6$) gain in the household labor productivity of all urban households. Adding the results for household heads, working wives, and household labor, we obtain a \$247.81 $\times 10^6$ gain in labor productivity for a one unit reduction in air pollution. A 60 percent reduction in 1970 air pollution would then, in August 1978 dollars, increase the value of 1970 urban labor productivity by \$25 $\times 10^9$ dollars. This is a "best" estimate. Its upper and lower bounds are, respectively, \$34 $\times 10^9$ and \$16 $\times 10^9$. If one performs these identical calculations in precisely the same fashion for a 1977 U.S. total population of 216.1 $\times 10^6$, one obtains a "best" estimate of \$36 $\times 10^9$.

Table 6.4

Estimated Per Capita Aggregate Gains in 1970 U.S. Labor Productivity Due to a 60 Percent Reduction in Air Pollution

(June 1978 Dollars)

	Per Capita	Aggregate
Lower Bound	$189.50	28,426 x 10^6
"Best" Estimate	$288.29	43,243 x 10^6
Upper Bound	$387.07	58,061 x 10^6

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/5-79-001a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Methods Development for Assessing Air Pollution Control Benefits: Volume I, Experiments in the Economics of Air Pollution Epidemiology		5. REPORT DATE February 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Thomas D. Crocker, William D. Schulze, Shaul Ben-David, and Allen V. Kneese		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Wyoming Laramie, Wyoming 82071		10. PROGRAM ELEMENT NO. 1HA616 and 630
		11. CONTRACT/GRANT NO. R805059-01
12. SPONSORING AGENCY NAME AND ADDRESS Office of Health and Ecological Effects Office of Research and Development U.S. Environmental Protection Agency Washington, DC 20460		13. TYPE OF REPORT AND PERIOD COVERED Interim Final, 10/76-10/78
		14. SPONSORING AGENCY CODE EPA-600/18

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This volume employs the analytical and empirical methods of economics to develop hypotheses on disease etiologies and to value labor productivity and consumer losses due to air pollution-induced mortality and morbidity.

In the mortality work, 1970 city-wide mortality rates for major disease catagories have been statistically associated with aggregate data from sixty U.S. cities on physicians per captia, per capita cigarette consumption, dietary habits, air pollution and other factors. The estimated effect of air pollution on mortality rates is about an order of magnitude lower than some other estimates. Nevertheless, rather small but important associations are found between pneumonia and bronchitis and particulates in air and between early infant disease and sulfur dioxide air pollution.

The morbidity work employed data on the generalized health states and the time and budget allocations of a nationwide sample of individual heads of household. For the bulk of the dose-response expressions estimated, air pollution appears to be significantly associated with increased time being spent acutely or chronically ill. Air pollution, in addition, appears to influence labor productivity, where the reduction in productivity is measured by the earnings lost due to reductions in work-time.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Economic analysis Air pollution Epidemiology Public health	Economic benefits of pollution control	13B

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 175
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆U.S. GOVERNMENT PRINTING OFFICE: 1979 620-007/3769 1-3