EXTERNAL HEALTH COSTS OF A STEEL MILL

MICHAEL R RANSOM and C. ARDEN POPE III*

Intermittent operation of a steel mill in a mountain valley in central Utah provides a unique opportunity to measure the external health costs of air pollution. A nearby valley provides a control. This paper analyzes data on hospital admissions and daily deaths for the two valleys, using negative binomial regression models of daily hospital admissions and deaths. Hospital admissions for respiratory diseases increase significantly when the mill is in operation. Mortality also increases during mill operation. Estimated excess hospitalization costs are about 2 million dollars per year, and the increased cost of mortality exceeds 40 million dollars per year.

I. INTRODUCTION

This study estimates some of the external health costs associated with the operation of an integrated steel mill in Utah Valley. The mill is the largest source of particulate air pollution in Utah Valley and was closed for about a year during the period of the study. When the steel mill is in operation, the valley has relatively high wintertime particulate pollution levels. Cache Valley, a neighboring valley that is unaffected by the mill's pollution, provides an excellent comparison or control.

The study evaluates temporal associations between acute care hospital admissions for respiratory diseases and the operation of the steel mill. Mortality data for both Utah County (which contains Utah Valley) and Cache County are from Utah State vital statistics. Analysis involves comparing hospitalization and mortality rates across periods when the mill was operating and across periods when the mill was closed.

II. STUDY AREA

Utah Valley is a mountain valley in Utah County of north-central Utah (figure 1). According to the Census, the county's population was about 264,000 in 1990. The most densely populated part of the county contains several adjoining cities including Provo and Orem. In 1990, these cities' combined population of approximately 223,000 was crowded into a 5–9 km wide corridor between a large fresh water lake on the west and mountains on the east. This study refers to this populated area as Utah Valley. A large, integrated steel mill is located near the center of the valley. The valley has a dry, four-season climate with temperature inversions common during winter months. During temperature inversions, the air becomes stagnant, trapping pollutants near the valley floor.

In Utah Valley, extremely small, inhalable particles become highly concentrated in the air during these inversions. Because of the health risks associated with fine particles, the Environmental Protection Agency (EPA) set standards directed at particles with a diameter less than or equal to 10 micrometers (PM_{10}). PM_{10} standards include a 24-hour standard of 150 micrograms per cubic meter ($\mu g/m^3$), and allow no more than one expected exceed-

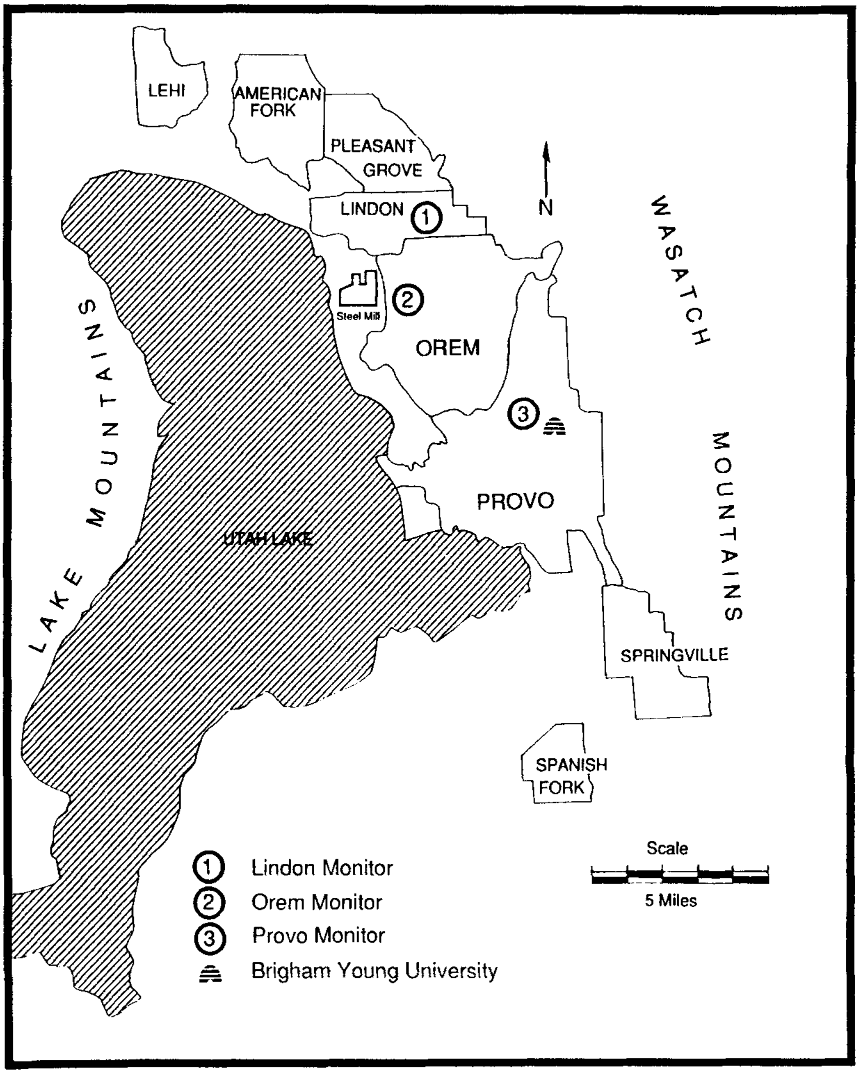
*The authors are faculty in the Department of Economics, Brigham Young University, Provo, Utah 84602.

ABBREVIATIONS

EPA: Environmental Protection Agency
IHC: Intermountain Health Care
PEF: Peak Expiratory Flow

Contemporary Economic Policy
(ISSN 1074-3529)
Vol. XIII, April 1995

FIGURE 1



ance per year. The annual PM_{10} standard is an arithmetic mean of less than 50 $\mu g/m^3$ (Environmental Protection Agency, 1987). Daily monitoring of PM_{10} occurs at three sites in the valley (figure 1).

The principal source of particulate pollution in Utah Valley is an integrated steel mill built in the 1940s. During severe winter temperature inversions, the mill contributes 50–70 percent of total PM_{10} pollution (Utah Bureau of Air Quality, 1990). On August 1, 1986, a labor dispute shut down the mill. A new owner reopened the mill on September 1, 1987. When the mill was open, winter PM_{10} levels were approximately twice as high as when the mill was closed. Violations of the 24-hour PM_{10} standard occurred an average of 12.6 times per year when the mill was open and never when it was closed.

Cache Valley, also in Utah, serves well as a control (Archer, 1990). It is approximately 150 miles north of Utah Valley, had a population of about 70,200 according to the 1990 Census, and is unaffected by the steel mill's pollution. Both Utah and Cache Valleys are mountain valleys at approximately the same elevation with populations centered around universities. Both valleys have similar climates and both commonly experience severe temperature inversions during winter months. Cache Valley has slightly cooler temperatures.

Both Utah and Cache counties have low smoking rates. Based on an unpublished 1986 Utah State Department of Health survey, 5.5 percent of persons 18 years or older in Utah Valley smoke, and 9.6 percent of persons in Cache Valley smoke. These low smoking rates are due largely to the fact that the high percentage of the population in both counties are members of the Church of Jesus Christ of Latter-day Saints (Mormons), which teaches against smoking. Additionally, both counties have similar housing characteristics and use natural gas as the primary source of residential heating.

The counties also are demographically similar, with relatively young populations including a large university student population between the ages of 18 and 24. In both counties, 12.8 percent of the population was under the age of six in 1990. Between the 1980 and 1990 Censuses, the population of Cache county grew by 22.8 percent and the population of Utah county grew by 20.9 percent. Archer (1990) gives additional demographic comparisons.

A major difference between Utah and Cache counties is their air pollution levels. Although Cache Valley has had limited air quality monitoring, it has never recorded a violation of EPA ambient air quality standards. Vehicles, space heating, fireplace and wood stove burning, and other sources combined produce PM_{10} concentrations that are approximately one-third to one-half the levels found in Utah Valley.

III. EFFECTS OF PARTICULATE POLLUTION ON RESPIRATORY HEALTH AND MORTALITY

Many studies have implicated particulate pollution in the incidence and severity of respiratory disease (e.g., American Thoracic Society, 1978; Dockery et al., 1989). Sulfate and nitrate particles, which may contain sulfuric and nitric acids, are of specific concern (Spektor et al., 1989; Schlesinger, 1989). Fine particulate pollution is especially damaging to respiratory health because it contains more toxic substances such as acid sulfates and trace metals and because it is more likely to bypass the defense mechanisms of the respiratory system (Ozkaynak and Spengler, 1985; Lippmann, 1977).

Various studies associate respiratory disease and particulate pollution. Dockery et al. (1989), for example, indicates that the relative risks of bronchitis, chronic cough, and chest illness are 2.3 to 3.7 times higher for children living in cities with air pollution levels similar to and often lower than levels in Utah Valley, as compared with cities with little air pollution. Studies also associate decreases in pulmonary function with particulate pollution (Dockery et al., 1982; and Schwartz, 1989).

Observers note strong associations between respiratory hospital admissions, PM_{10} pollution, and the operation of the steel mill in Utah Valley. For example, Pope (1989, 1991) reports that in-patient admissions of children for bronchitis and asthma were about twice as high during periods when the mill was operating than when it was not.

In two cohort studies of children in Utah Valley, Pope et al. (1991) and Pope and Dockery (1992) observe that elevated levels of PM_{10} pollution were associated with a significant decline in lung function as measured by Peak Expiratory Flow (PEF), by increases in symptoms of respiratory disease, and by the use of asthma medication.

Given the apparent impact of the mill's pollution on respiratory morbidity, one might expect that chronic exposure to the same pollution would result in elevated risks of mortality. Respiratory deaths in Utah County equal approximately 130 deaths per year. Approximately 25 percent of these deaths are due to respiratory cancer. The remaining 75 percent of respiratory deaths are due to nonmalignant causes, including pneumonia, influenza, and various types of chronic obstructive pulmonary disease (U.S. Department of Health and Human Services, 1980–1988). Pope et al. (1992) observe statistically significant associations between daily mortality and PM_{10} pollution levels. The association was strongest for deaths caused by respiratory diseases, next strongest for cardiovascular deaths, and not significant for other causes of death.

Archer (1990) compares age adjusted death rates for malignant and nonmalignant respiratory disease across Utah and Cache Counties. Because Utah and Cache Counties were so similar until the steel mill was constructed in Utah County, Archer estimates the number of respiratory deaths due to air pollution and observes that malignant respiratory death rates were slightly lower in Utah County versus Cache County until approximately 15 years after the steel mill was built in Utah County. Since that time, respiratory death rates in Utah County have been significantly higher than in Cache County. Archer estimates that approximately 38 percent of all respiratory deaths in Utah County, or 50–60 deaths per year, were attributable to air pollution.

Archer may underestimate the impact of air pollution on respiratory mortality because Utah County has lower smoking rates, has a younger age distribution, has slightly warmer weather, and changed from coal and wood burning for cooking and space heating to natural gas sooner than did Cache County. Furthermore, Archer does not account for deaths where respiratory disease was a secondary cause of death nor for impacts air pollution may have on non-respiratory disease such as heart disease.

Population based cross-sectional mortality studies associate death rates and air pollution (Lave and Seskin, 1977; Ozkaynak and Spengler, 1985; and Evans et al., 1984). Death rates are most strongly associated with the sulfate component of particulate pollution. These studies yield regression estimates for sulfates that typically are approximately three deaths/year/100,000 persons per $\mu g/m^3$. In Utah County, depending on estimates of exposure levels and the steel mill's contribution of both primary and secondary sulfates, this translates into 20–75 excess deaths per year associated with the steel mill's emissions of sulfate and sulfate precursors.

IV. ESTIMATING EFFECTS OF MILL'S OPERATION ON DISEASE

Previous research links respiratory disease and mortality to the type of pollution associated with the steel mill's operation. However, this study uses the natural experiment provided by the mill's temporary closure and directly observes the closure's effect. This approach might capture some effects of the mill that studies based on measured pollution levels do not. For example, if the particles associated with the operation of the mill are more toxic than others, measurement of particulate pollution would underestimate the impact of the mill. On the other hand, this brief experiment probably will miss the impact of chronic exposure, which is especially likely for the analysis of mortality effects.

The analysis involves collecting hospital admissions for respiratory diseases (ICD-9 codes 460-519) and cardiovascular diseases (ICD-9 codes 390–459.9) for 73 months, from April 1, 1985 through April

30, 1991. These data are from Intermountain Health Care (IHC), the largest provider of hospital care in Utah. The data include admissions to eight major acute care IHC hospitals in Utah, Salt Lake, and Cache counties, including all three acute care hospitals in Utah Valley, and the only hospital in Cache Valley. Patients' zip codes indicate which patients are residents of either Utah Valley or Cache Valley. The analysis also groups admissions by date of admission and by International Classification of Disease Codes (Revision 9) (U.S. Department of Health and Human Services, 1980). Pope (1991) gives a detailed description of a similar data set.

The analysis here aggregates the hospital admissions data into four groups of diseases: bronchitis and asthma (ICD-9 466.0, 466.1, 490–491.1, 493.9 and 493.91), pneumonia (ICD-9 480–486), all other respiratory diseases excluding bronchitis, asthma, and pneumonia (ICD-9 460–519.99), and diseases of the heart and circulatory system (ICD-9 390–459). Data for pneumonia and for bronchitis and asthma include hospital admissions for preschool children (defined as those under age 6).

Analyzing daily deaths in Utah and Cache counties involves obtaining mortality data files for 1985 through 1989 from the Utah State Department of Health. The analysis excludes deaths from accidents (ICD-9 $\geq$ 800) and deaths of nonresidents of Utah county or Cache county.

Table 1 reports daily averages and standard errors for data for both Utah and Cache valleys for periods with the mill open and closed. (The mill was closed from August 1, 1986 through August 31, 1987.) Compare average hospital admissions during the period the mill is closed against the period the mill is open. The first column shows that hospital admissions for asthma and bronchitis in Utah Valley increased by 0.188 per day (about 69 admissions per year)—an increase of 25.5 percent in the admission rate—when the mill was open versus when it was closed. In contrast, Cache Valley hospital admission rates for the same diseases actually declined slightly (7.2 percent) during the period the mill was open.

For the preschool age group, the effect of the mill's operation is dramatic. Admissions for bronchitis and asthma in Utah Valley *more than doubled* during the periods when the mill was open compared with the period when the mill was closed. By comparison, admissions in Cache Valley were virtually constant. Operation of the mill increased preschool admissions by about 60 per year. Thus, most of the response observed in admission rates for bronchitis and asthma for all age groups was due to the preschool group.

One also can observe an increase in pneumonia in Utah Valley when the mill was open. However, pneumonia cases also were low in Cache Valley when the mill was closed. Admissions for "other respiratory diseases" increased sharply when the mill was open. Cardiovascular disease admissions changed little during periods when the mill was closed compared to when the mill was open.

In Utah county, there were 0.083 more deaths per day (30 deaths per year) during the period the mill was open versus the period during which the mill was closed. This represents an increase of about 3.2 percent in the death rate. When the mill was open, deaths in Cache county were actually lower by almost 8 percent. However, these differences are small compared with the day-to-day variation in death rates.

V. REGRESSION MODELING

One can characterize hospitalization and mortality as independent and random occurrences across time—variations that classically have been modeled as a Poisson process. If daily admissions or mortality counts follow a Poisson process, then they will have Poisson distributions. That is, if Y_t is the number of admissions on day t, then

TABLE 1
Summary Statistics of Hospital Admissions and Mortality Data for Utah and Cache Valleys with Steel Mill Open and Closed

	Utah Valley		Cache Valley	
Average Daily Hospital Admissions	Mill Open	Mill Closed	Mill Open	Mill Closed
Bronchitis and Asthma (All Ages)	0.925 (0.025)	0.737 (0.045)	0.220 (0.011)	0.237 (0.026)
Bronchitis and Asthma (Preschool Ages)	0.322 (0.014)	0.152 (0.020)	0.079 (0.007)	0.073 (0.014)
Pneumonia (All Ages)	1.237 (0.030)	1.010 (0.056)	0.534 (0.018)	0.376 (0.030)
Pneumonia (Preschool Ages)	0.336 (0.016)	0.255 (0.027)	0.148 (0.010)	0.129 (0.018)
Other Respiratory Diseases	0.837 (0.022)	0.586 (0.039)	0.322 (0.013)	0.280 (0.027)
Cardiovascular Diseases	3.964 (0.050)	3.904 (0.110)	1.509 (0.030)	1.505 (0.069)
Number of Days (Hospitalization)	1825	396	1825	396
Mortality	2.697 (0.048)	2.614 (0.079)	0.776 (0.025)	0.8409 (0.0470)
Number of Days (Mortality)	1340	396	1340	396
Population 1990	223,800		70,200	

(1) $$Prob(Y_t = r) = \exp(-\lambda_t)\frac{(\lambda_t)^r}{r!},$$

where λ_t is the expected number of admissions on day t. (For a more detailed discussion of the Poisson process and distribution, see DeGroot, 1986.)

Assume that hospital admissions and mortality are generated by a non-stationary Poisson process. This process is non-stationary because λ_t need not be constant across the entire period of observations but will be influenced by seasonal changes, changes in the level of particulate pollution, and possibly other factors. Therefore, assume that λ_t are dependent on the explanatory variables,

(2) $$\ln\lambda_t = X_t B,$$

where X_t is vector of variables and **B** is a vector of coefficients to be estimated. The model implied by (1) and (2) is called the Poisson regression model. (See Maddala, 1984.)

Estimate regression models of the form:

(3a) $$\ln(\lambda_t^U) = \beta_0^U + \beta_1^U D_t + \beta_2^U Z_t,$$

(3b) $$\ln(\lambda_t^C) = \beta_0^C + \beta_1^C D_t + \beta_2^C Z_t,$$

where D_t is a dummy variable indicating that the mill is open and Z_t represents all other covariates. Superscripts U and C indicate Utah Valley and Cache Valley, respectively. The logarithmic form of the regression model implies that variables will have a proportional effect on admission rates. Besides a variable indicating that the mill is open, the model also includes season indicators because respiratory disease is strongly seasonal and a trend variable because of the increasing populations in the two valleys.

Let δ represent the proportional increase in admission rates that results from the operation of the mill. The "experimental" effect observed in Utah Valley is

$$(4) \qquad \ln(1+\delta) = \ln(\lambda_{open}/\lambda_{closed}) = \ln(\lambda_{open}) - \ln(\lambda_{closed}) = \beta_1.$$

Therefore,

$$(5) \qquad \delta = \exp(\beta_1) - 1.$$

Unusually severe weather or an outbreak of contagious disease could have altered admission and death rates during the experimental period whether or not a mill operated in the valley. Since the mill's operation does not affect Cache Valley, Cache Valley provides an estimate of what might have occurred in Utah County if no mill existed there. Thus, a difference-in-differences comparison is called for. The corresponding proportional increase in admissions, δ^*, is

$$(6) \qquad \ln(1+\delta^*) = \ln\left[\frac{\lambda^U_{open}/\lambda^U_{closed}}{\lambda^C_{open}/\lambda^C_{closed}}\right]$$

$$= \ln(\lambda^U_{open}/\lambda^U_{closed}) - \ln(\lambda^C_{open}/\lambda^C_{closed}) = \beta^U_1 - \beta^C_1.$$

Therefore,

$$(7) \qquad \delta^* = \exp(\beta^U_1 - \beta^C_1) - 1.$$

A restriction of the Poisson regression model is that the conditional variance must be equal to the conditional mean. If the conditional mean, equation (2), contains a stochastic element

$$(8) \qquad \ln(\lambda_t) = X_t B + \varepsilon_t,$$

then the conditional variance may exceed the conditional mean. A Poisson regression model with an omitted explanatory variable also would result in "overdispersion." A more general statistical model, the negative binomial regression model, is useful in cases where such overdispersion of the data is present. The negative binomial can be motivated as a compound distribution of the Poisson, where λ_t follows a gamma distribution. Cameron and Trivedi (1986) provide a detailed discussion of the negative binomial regression model and its relationship to the Poisson regression model. Since the Poisson model is a special case of the negative binomial model, one can test the adequacy of the Poisson model with a likelihood ratio test.

Table 2 presents the negative binomial regression estimates of the effect of steel mill operation on hospital admissions and mortality. One observes strong positive, statistically significant effects in "bronchitis and asthma" and "other respiratory diseases." Intertemporal comparison for pneumonia in Utah Valley also indicates a rather large, statistically significant response. However, pneumonia in Cache Valley has an effect of approximately the same magnitude, so the difference-in-differences approach suggests no effect on pneumonia. The mill's effect on cardiovascular disease admissions is small.

Table 2 also reveals the strong seasonal nature of respiratory disease admissions. These seasonal effects are qualitatively similar across the different respiratory categories and are remarkably similar in the two valleys. The trend coefficient usually is not statistically significant and sometimes is negative.

TABLE 2
Negative Binomial Regression
Estimates of Effect of Steel Mill Operation on Hospital Admission and Deaths

	Daily Hospital Admissions												Daily Deaths	
	Bronchitis & Asthma (All Ages)		Bronchitis & Asthma (Preschool Children)		Pneumonia (All Ages)		Pneumonia (Preschool Children)		Other Respiratory Diseases (All Ages)		Cardiovascular Disease		Non-accidental Deaths	
Variable	Utah Valley	Cache Valley	Utah Valley	Cache Valley	Utah Valley	Cache Valley	Utah Valley	Cache Valley	Utah Valley	Cache Valley	Utah Valley	Cache Valley	Utah Valley	Cache Valley
Intercept	−0.859	−2.125	−2.858	−3.457	−0.503	−1.578	−2.043	−2.494	−0.643	−1.531	1.387	0.331	0.847	−0.316
	(0.087)	(0.161)	(0.187)	(0.286)	(0.073)	(0.113)	(0.150)	(0.200)	(0.084)	(0.128)	(0.035)	(0.055)	(0.046)	(0.083)
Mill Open (β_1)	0.205	−0.152	0.687	−0.103	0.124	0.149	0.162	0.005	0.374	0.164	0.051	−0.042	0.022	−0.099
	(0.070)	(0.125)	(0.144)	(0.224)	(0.061)	(0.096)	(0.120)	(0.166)	(0.075)	(0.108)	(0.032)	(0.050)	(0.037)	(0.067)
Fall	0.627	0.829	1.055	0.950	0.267	0.401	0.147	0.309	0.207	0.415	0.034	−0.027	0.109	0.147
(Sep, Oct, Nov)	(0.080)	(0.154)	(0.159)	(0.265)	(0.071)	(0.102)	(0.151)	(0.194)	(0.072)	(0.117)	(0.033)	(0.052)	(0.043)	(0.079)
Winter	0.971	0.000	1.475	1.093	0.822	0.721	1.190	0.804	0.310	0.607	0.010	0.019	0.219	0.261
(Dec, Jan, Feb)	(0.076)	(0.151)	(0.153)	(0.259)	(0.064)	(0.097)	(0.129)	(0.178)	(0.071)	(0.113)	(0.033)	(0.052)	(0.044)	(0.079)
Spring	0.667	0.677	1.085	0.591	0.688	0.594	0.855	0.511	0.112	0.287	0.067	0.068	0.152	0.091
(Mar, Apr, May)	(0.079)	(0.156)	(0.157)	(0.278)	(0.065)	(0.098)	(0.132)	(0.184)	(0.072)	(0.118)	(0.032)	(0.050)	(0.043)	(0.081)
Time Trend	−0.044	0.054	−0.008	0.223	0.070	0.258	0.090	0.097	−0.062	−0.100	−0.076	−0.087	0.003	0.038
(x1000)	(0.038)	(0.077)	(0.065)	(0.133)	(0.034)	(0.052)	(0.065)	(0.097)	(0.037)	(0.062)	(0.019)	(0.030)	(0.031)	(0.058)
Variance/Mean	1.11	1.02	1.07	1.04	1.13	1.07	1.16	1.12	1.05	1.00	1.16	1.09	1.07	1.06
LR Test Statistic	11.30	0.40	4.72	1.15	18.08	4.47	17.72	11.27	2.29	0.00	25.61	7.22	4.09	2.83
Experimental Effects														
Differences														
$[\exp(\beta_1^{Utah}) - 1] \times 100$	**22.8%**		**98.7%**		**13.1%**		**17.7%**		**45.4%**		**5.3%**		**2.25%**	
95% CI	**[7.26–40.6]**		**[50.1–162.9]**		**[3.7–27.6]**		**[7.3–49.2]**		**[25.7–68.1]**		**[−1.2–12]**		**[−4.7–9.7]**	
Differences-in-Differences														
$[\exp(\beta_1^{Utah} - \beta_1^{Cache}) - 1] \times 100$	**43.0%**		**120.2%**		**−2.5%**		**17.0%**		**23.4%**		**9.7%**		**12.9%**	
95% CI	**[7.5–90.0]**		**[29.7–274.0]**		**[−21.6–21.3]**		**[2.1–73.6]**		**[−4.4–59.3]**		**[−2.8–23.8]**		**[−2.6–30.8]**	

These observed differences likely underestimate the total respiratory health effect of the steel mill, especially in adults. Because the steel mill was closed for only 13 months, the observed reduction in respiratory admissions only reflects the impact of acute exposure to the mill's pollution. Given preschool children's relatively short exposure to the pollution, most of their illnesses would be related to acute exposure to pollution and likely would display a larger and more rapid response to a short-term reduction of the pollution. Older individuals, however, have experienced chronic exposure to the pollution. A 13-month closure of the steel mill and subsequent reduction in pollution may be not long enough to show an alleviation of chronic effects.

The intertemporal comparisons in Utah county estimate an increase in the death rate of about 2.5 percent. The difference-in-differences estimates suggest an increase in the total death rate of about 13 percent. However, these estimated effects are not statistically significant at usual levels. It is interesting to compare the "experimental effects" here with the changes in death rates that would be expected based on exposure to the additional pollutants that the mill generates. Pope et al. (1992) did observe statistically significant associations between daily mortality counts and changes in PM_{10} pollution levels. Their results predict that when the steel mill is open, death rates should increase by 2.3 percent (roughly 22 deaths per year) based on the estimated relationship between death rates and PM_{10} exposure. This is almost exactly the experimental effect estimated in the regression here. Based on the steel mill's contribution of sulfates to the environment, the analysis here predicts an additional 20 to 75 deaths per year. These results indicate that an estimate of 20 to 25 additional deaths per year probably is conservative. Furthermore, Archer's (1990) estimate of 50 to 60 excess deaths per year is based on chronic exposure to the mill's effluent. However, one cannot observe chronic exposure in the short period that the mill was closed. Also, two recent prospective cohort studies associate increases in mortality with chronic exposure to particulate pollution (Dockery et al., 1993; Pope et al., 1995). Both studies observe larger mortality effects due to chronic exposure compared to effects observed in the acute (daily time-series) mortality studies.

Table 2 also reports tests of the adequacy of the Poisson model relative to the negative binomial model. In most cases, there is overdispersion. However, the variance usually is less than 10 percent greater than the mean, and in about one-third of the models, the likelihood ratio test can not reject the Poisson model. Furthermore, the Poisson regression model yields virtually identical results for the coefficients and standard errors reported in table 2.

One might obtain more efficient estimators by jointly estimating the regression equations for the two counties in a manner similar to the "seemingly unrelated" model of Zellner (1963). One can develop a version of the seemingly unrelated regression model for Poisson variates, as in King (1989). Although the model is rather limited, especially in this case where the base populations of the two valleys are quite different, the analysis here also estimates a seemingly unrelated Poisson regression model. Results indicate small, positive residual correlation between the two valleys for most diseases. However, the estimated coefficients and their variances differed only slightly from those reported in table 2.

VI. MONETARY COSTS OF HEALTH EXTERNALITIES

Data on hospital admissions also contain information on in-patient hospital fees. Table 3 summarizes estimates of excess in-patient fees charged to residents of Utah county as a result of the mill's operation. Computing the estimates involves

TABLE 3
Estimates of Annual Excess Hospitalization Cots Associated with Operation of the Steel Mill

	Differences Estimates		
	Estimate Number of Excess Admissions	Average Hospitalization Charge Per Admission (1991)	Estimated Total Excess Charges (Thousands)
Bronchitis and Asthma (Base = 269)	61.3 (19.4 - 109.2)	$4,030	$247 (78 - 440)
Pneumonia (Base = 369)	48.3 (13.7 - 101.8)	$7,725	$373 (105 - 786)
Other Respiratory Diseases (Base = 214)	97.2 (55.0 - 145.7)	$6,167	$599 (339 - 898)
Cardiovascular Diseases (Base = 1425)	75.5 (–17.1 - 173.9)	$9,883	$746 (–169 - 1,718)
Total			$1,966 (908 - 3,024)
	Difference-in-Differences Estimates		
Bronchitis and Asthma	115.7 (20.2 - 242.1)	$4,030	$466 (81 - 975)
Pneumonia	–9.2 (–79.7 - 78.6)	$7,725	–$71 (–615 - 607)
Other Respiratory Diseases	50.1 (–9.4 - 126.9)	$6,167	$309 (–58 - 783)
Cardiovascular Diseases	138.2 (–39.9 - 339.2)	$9,883	$1,366 (–394 - 3,352)
Total			$2,070 (90 - 4,050)

Note: Figures in parentheses represent 95% confidence intervals.

applying the estimated effects from table 2 to the annual rate of admissions from the period when the mill was closed and then applying the average hospitalization charge for that disease type. (Charges are based on average charge by disease type for 1991.) For example, the base annual rate of admissions for bronchitis and asthma was 269. Table 2 predicts that admissions increase by 22.8 percent when the mill is in operation. That is, the mill causes an additional 61.3 admissions. Hospitals charge an average of $4,030 for an admission for bronchitis or asthma, implying "excess" charges of about $250,000. The analysis here bases results on "differences" and our "difference-in-differences" estimators and reports 95 percent confidence intervals for excess costs in each disease category. Confidence intervals for the total cost are based on the assumption of independence of the different categories, using a Taylor series approximation for the variance of exp(β)–1. Base year admissions and charges are nonstochastic.

Both estimation approaches find additional hospitalization costs of about $2 million per year, summing across all disease groups. This value ignores all emergency room costs as well as all out-of-hospital medication and health care costs. In addition, costs associated with restricted activities are ignored. For example, Ransom and Pope (1992) find that annual school absenteeism is about 25 percent higher when the mill is operating. Hospitalization costs in the analysis here represent a lower bound, and actual total health costs probably exceed it substantially.

Other studies attempt to provide monetary estimates of the health costs of pollution (Cannon, 1990). In most of these studies, 70 to 90 percent of the health costs was due to increased risk of premature mortality. Monetary values are assigned to increased risk of premature death by estimating the individuals' "willingness to pay" to accept small changes in the risk of premature death through contingent valuation studies. "Willingness-to-accept" values are estimated based on labor market tradeoffs between wages and the risks of premature mortality. These are not estimates of the worth of an individual human being, but of a statistical life (Thaler and Rosen, 1975; Conley, 1976; Mishan, 1971). Recent willingness-to-accept estimates of the value of a statistical life range from approximately $2 to $7 million (Viscusi, 1992).

The analysis here predicts between 22 and 123 additional deaths per year. The effect on mortality is not statistically significant but is consistent with previous estimates that the air pollution from the steel mill is associated with an increase of 20 to 75 deaths per year in Utah County. Based on value-of-life estimates of 2 to 7 million dollars, the mortality costs of the steel mill's air pollution would equal between 40 and 525 million dollars per year.

VII. SUMMARY AND CONCLUSIONS

A substantial portion of respiratory morbidity in Utah county is attributable to the operation of the steel mill. A strong association between the operation of the steel mill and respiratory disease exists. Accurately quantifying all of the health costs of the steel mill's air pollution is impossible. However, the conservative estimates in the analysis here show that such costs are significant compared with other costs of operating the mill. For example, estimates of hospitalization costs alone suggest that the community bears external cost of over $1,000 per worker per year. Additionally, estimated mortality costs exceed $16,000 per worker per year.

REFERENCES

American Thoracic Society, *Health Effects of Air Pollution*, American Lung Association, New York, 1978.

Archer, Victor E., "Air Pollution and Fatal Lung Disease in Three Utah Counties," *Archives of Environmental Health*, November/December 1990, 325–334.

Conley, Byron C., "The Value of Human Life in the Demand for Human Safety," *American Economic Review*, March 1976, 45–55.

Cannon, James S., *Health Costs of Air Pollution: A Survey of Studies Published 1984-1989*, American Lung Association, New York, 1990.

DeGroot, Morris H., *Probability and Statistics*, 2nd Edition, Addison-Wesley Publishing Company, Reading, Mass., 1986.

Dockery, Douglas W., C. Arden Pope III, Xiping Xu, John D. Spengler, James H. Ware, Martha E. Fay, Benjamin G. Ferris Jr., Frank E. Speizer, "Mortality Risks of Air Pollution: A Prospective Cohort Study," *New England Journal of Medicine*, December 1993, 1753–1759.

Dockery, Douglas W., John H. Ware, Benjamin G. Ferris Jr, Frank E. Spierzer, Nancy R. Cook, and Stanislaw M. Herman, "Change in Pulmonary Function in Children Associated with Air Pollution Episodes," *Journal of the Air Pollution Control Association*, September 1982, 937–942.

Dockery, Douglas W., Frank E. Spierzer, Daniel O. Stram, James H. Ware, John D. Spengler, and Benjamin G. Ferris Jr., "Effects of Inhalable Particles on Respiratory Health of Children," *American Review of Respiratory Diseases*, March 1989, 587–594.

Environmental Protection Agency (EPA), "Revisions to the National Ambient Air Quality Standards for Particulate Matter," *Federal Register*, July 1, 1987, 24,634–24,669.

Evans, J. S., T. Tosteson, and P. L. Kinney, "Cross-sectional Mortality Studies and Air Pollution Risk Assessment," *Environment International*, January/February 1984, 55–83.

King, Gary, "A Seemingly Unrelated Poisson Regression Model," *Sociological Methods and Research*, February 1989, 235–255.

Lave, Lester B., and Eugene P. Seskin, *Air Pollution and Human Health*, John Hopkins University Press, Baltimore, 1977.

Maddala, G. S., *Limited-Dependent and Qualitative Variables in Econometrics*, Cambridge University Press, Cambridge, 1983.

Mishan, E. J., "Evaluation of Life and Limb: A Theoretical Approach," *Journal of Political Economy*, July/August 1971, 687–705.

Moore, Michael J., and W. Kip Viscusi, "Doubling the Estimated Value of Life: Results Using New Occupational Fatality Data," *Journal of Policy Analysis and Management*, Spring 1988, 476–490.

Ozkaynak, Haluk, and John D. Spengler, "Analysis of Health Effects Resulting from Population Exposures to Acid Precipitation Precursors, *Environmental Health Perspectives*, November 1985, 45–55.

Pope, C. Arden III, "Respiratory Disease Associated with Community Air Pollution and a Steel Mill, Utah Valley," *American Journal of Public Health*, May 1989, 623–628.

———, "Respiratory Hospital Admissions Associated with PM_{10} Pollution in Utah, Salt Lake, and Cache Valleys," *Archives of Environmental Health*, March/April 1991, 90–97.

Pope, C. Arden III, Douglas W. Dockery, J. D. Spengler, and Mark E. Raizenne, "Respiratory Health and PM_{10} Pollution: A Daily Time Series Analysis," *American Review of Respiratory Disease*, September 1991, 668–674.

Pope, C. Arden III, Joel Schwartz, and Michael R. Ransom, "Daily Mortality and PM_{10} Pollution in Utah Valley, *Archives of Environmental Health*, May/June 1992, 211–217.

Pope, C. Arden III, Michael J. Thun, Mohan M. Namboodiri, Douglas W. Dockery, John S. Evans, Frank E. Speizer, Clark W. Heath, "Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults," *American Journal of Respiratory and Critical Care Medicine*, 1994, in press.

Ransom, Michael R, and C. Arden Pope III, "Elementary School Absences and PM_{10} Pollution in Utah Valley, *Environmental Research*, August 1992, 204–219.

Schlesinger, Richard B., "Factors Affecting the Response of Lung Clearance Systems to Acid Aerosols: Role of Exposure Concentration, Exposure Time, And Relative Acidity," *Environmental Health Perspectives*, February 1989, 121–126.

Schwartz, Joel, "Lung Function and Chronic Exposure to Air Pollution: A Cross-sectional Analysis of NHANES II," *Environmental Research*, December 1989, 309–321.

Spektor, Dalia M., Bai M. Yen, and Morton Lippmann, "Effect of Concentration and Cumulative Exposure of Inhaled Sulfuric Acid on Tracheobronchial Particle Clearance in Healthy Humans," *Environmental Health Perspectives*, February 1989, 167–172.

Thaler, Richard, and Sherwin Rosen, "The Value of Saving a Life: Evidence from the Labor Market," in Nestor Terleckyj, ed., *Household Production and Consumption*, National Bureau of Economic Research, Studies in Income and Wealth, Volume 40, New York, 1975.

Utah Bureau of Air Quality, *Draft Utah State Implementation Plan*, Utah State Department of Health, Salt Lake City, 1990.

U.S. Department of Health and Human Services, *The International Classification of Diseases*, 9th Revision, Clinical Modification, 2nd edition, U.S. Government Printing Office, Washington, D.C., 1980.

———, *Vital Statistics of the U.S.*, U.S. Government Printing Office, Washington, D.C., 1980–1988.

Zellner, Arnold, "Estimators of Seemingly Unrelated Regressions and Tests of Aggregation Bias," *Journal of the American Statistical Association*, June 1962, 977–992.