The Health Benefits of Air Pollution Control in Delhi

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An important reason for controlling air pollutants such as particulate matter or sulfur dioxide is the damaging effects they have on human health. These effects include premature death as well as increases in the incidence of chronic heart and lung disease. Estimates of the health damages associated with air pollution are important because they can provide both an impetus for environmental controls and a means of evaluating the benefits of specific pollution control policies.

To estimate the health damages associated with air pollution in developing countries, policy makers are often forced to extrapolate results from studies conducted in industrialized countries. These extrapolations, however, may be inappropriate for two reasons. First, it is not clear that the relationships found between pollution and health at the relatively low levels of pollution experienced in industrialized countries hold for the extremely high pollution levels witnessed in developing countries. Levels of particulate matter, for instance, are often three to four times higher in developing countries than in industrialized ones. Second, in developing countries, people die at younger ages and from different causes than do people in industrialized countries, implying that extrapolations of the impacts of air pollution on mortality may be especially misleading.

This paper reports the results of a study relating levels of particulate matter to daily deaths in Delhi, India, between 1991 and 1994. We focus on Delhi, the capital of India, because it is one of the world's most polluted cities. Between 1991 and 1994, the average total suspended particulate (TSP) level in Delhi was 375 micrograms per cubic meter—approximately five times the annual average standard of the World Health Organization (WHO). Levels of TSP in Delhi during this time period exceeded WHO's twenty-four-hour standard on 97% of all days on which readings were taken. Although particulate matter—produced by motor vehicles, smelters, the burning of refuse, and two coal-fired power plants—is Delhi's main air pollution problem, levels of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) are below U.S. limits.

Also, the distributions of deaths by age and by cause in Delhi are very different from those in the United States. Whereas 70% of all deaths occur before age sixty-five in Delhi, with 20% occurring before age five, 70% of all deaths in the United States occur after age sixty-five. Furthermore, 45% of all nontrauma deaths in the United States are attributable to cardiovascular disease, compared to only 23% in Delhi. Because the main effects of acute exposure to air pollution on daily deaths occur through impacts on cardiovascular and respiratory disease for which age is a known risk factor, we expect these differences to affect the relationship between pollution and health.

Our estimates of health damages have policy implications for pollution control in Delhi and permit us to compare extrapolations from U.S. studies with actual pollution impacts. We find that a given reduction in TSP reduces nontrauma deaths in Delhi by a smaller percentage than predicted by U.S. studies. Indeed, the percentage decrease in deaths corresponding to a 100-microgram reduction in TSP is 2.3%—about one-third of the effect found in the United States. On the other hand, because the age distribution of impacts vary from Delhi to the United States, so do the number of life-years

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saved. The largest impact of particulates on daily deaths in the United States occurs among persons sixty-five and older. In Delhi, the largest impact occurs in the fifteen-to-forty-four age group, implying that for each death associated with air pollution, more life-years will be saved, on average, in Delhi than in the United States.

Estimating Concentration-Response Relationships for Delhi

The relationship between air pollution and premature mortality is most often studied using time-series analysis of daily observations of number of deaths and pollution levels. These studies capture the effects of short-term exposure to pollution on the probability of dying. The underlying assumption is that there is a distribution of susceptibility to the effects of air pollution in any population. People who are in a weakened physical state or who have a history of chronic obstructive pulmonary disease (COPD) or cardiopulmonary problems are thought to be the most vulnerable. In the case of a sharp rise in pollution, the most vulnerable people are more likely to die.

Clearly, this type of analysis does not capture all the effects of pollution exposure. Long-term exposure can also reduce life expectancy by altering lung function and increasing susceptibity to COPD. However, measuring the effects of chronic exposure requires a long-term prospective study in which a sample population is followed long enough for the chronic effects to manifest themselves. Because of cost considerations and time constraints, our work focuses on the acute effects of air pollution.

Because time-series studies focus on a given geographic location over a number of years, factors that are often thought to influence the health of the population, such as percentage of smokers, income level, occupational exposure to pollutants, access to medical care, and age distribution, need not be incorporated into the analysis as they are considered to remain relatively constant within the study area over time. Typically, the only other factors aside from pollution included in these models are weather variables and seasonal controls.

In measuring the effects of air pollution, most attention has been focused on particulates, especially those measuring less than 10 microns in diameter (PM_{10}), which penetrate the lungs more readily. Although particulate matter tends to be the pollutant most strongly associated with premature mortality, the presence of other pollutants, such as SO_2 and NO_x, may be important as well.

The Data

Mortality data for the years 1991–94 were obtained from the New Delhi Municipal Committee (NDMC), one of the three regions that comprise the National Capital Territory.[1] Because the NDMC houses a large concentration of Delhi's hospitals, approximately one fourth of the 60,000 deaths in Delhi each year occur in the NDMC even though only 4% of the population resides there. However, the geographic distribution of the Delhi residents who died because of nontraumatic causes in the NDMC mirrors the geographic distribution of the population.

Using these data, we calculated counts of total nontrauma deaths[2] for each day during the study period as well as counts for deaths due to selected causes (respiratory illness[3] and cardiovascular disease[4]) and deaths by age-group. Because of problems associated with pinpointing the precise cause of an individual's death, counts of total nontrauma deaths are most often used for time-series analyses of this type, even though the links are strongest between air pollution and both cardiac and respiratory disorders. We expect that the youngest and oldest segments of the population will be more susceptible to air pollution.

Daily counts of total nontrauma deaths display a marked seasonal pattern in Delhi, with the highest number of deaths occurring during the rainy monsoon season. To control for variations in weather, we obtained data on average daily temperature, maximum and minimum temperature, mean daily dew point temperature, rainfall, and visual range measured at Delhi's international airport.

The Central Pollution Control Board (CPCB) provided daily data on air pollution levels collected at the nine monitoring stations located throughout the city. Readings of TSP, SO_2, and NO_x are taken at each station on a rotational

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[1] Although registration of vital statistics became mandatory in the National Capital Territory in 1957, only the NDMC maintains a sufficiently detailed, computerized database suitable for time-series analysis of this type.

[2] Deaths due to traumatic causes, such as fire or automobile accidents, are routinely omitted because they are not thought to be affected by pollution levels.

[3] Respiratory deaths include ICD8 460–519, excluding 463, 464, and 474.

[4] Cardiovascular deaths include ICD8 390–448.

basis approximately every three days; however, the monitors are not in operation on weekends or holidays. Daily means of TSP, SO_2, and NO_x were calculated using all available readings on a given day.

The Econometric Model

Daily mortality counts are considered counts of rare events and are therefore often modeled using Poisson regression analysis. We fit Poisson regressions to the Delhi mortality data using the method of maximum likelihood. Formally, the log likelihood function is

$$\log L = \sum_{t=1}^{T} [-\lambda_t + y_t \log \lambda_t - \log(y_t!)]$$

where y_t is the count of deaths occurring on day t, $\lambda_t = \exp(X_t\ \beta)$ is both the mean and the variance, $\mathbf{X}_t$ is a matrix of covariates on day t, and $\boldsymbol{\beta}$ is a vector of regression coefficients. Our model is a variation of the Poisson model above that allows for serial correlation of the observations using the generalized estimating equation approach devised by Liang and Zeger.

We fit the Poisson model to total nontrauma deaths and to deaths by selected cause (respiratory and cardiovascular deaths) and age-group. Our modeling strategy is to first account for the variability in the number of deaths using seasonal/cyclical terms, a time trend, and weather variables and then to add pollution to see whether it has any additional explanatory power. The independent variables include temperature and dewpoint measured on the same day as deaths, dummy variables indicating whether the day was among the hottest 10% of all days or among the most humid 10% of all days, trigonometric terms for cycles ranging from 1 year to 2.4 months, dummy variables for each year of the study, and a daily time trend; TSP enters the model with a two-day lag.

Results

The pollution coefficients for this model for eight specifications of the dependent variable, including total nontrauma deaths, cardiovascular deaths, respiratory deaths, and deaths in each of five age-groups, are reported in table 1. Air pollution is a statistically significant determinant of daily deaths for all categories of deaths except those among the very young (zero to four years) and the very old (sixty-five and over).

Table 1. Percentage Increase in Mortality per 100 $\mu g/m^3$ Increase in TSP: Delhi versus Philadelphia

Mortality End Point	Delhi	Philadelphia
By selected cause		
Total deaths	2.3*	6.7*
CVD	4.3*	9.2*
Respiratory[a]	3.1*	Pneumonia: 10.2
		COPD: 17.8*
By age-group (yrs.)		
0–4	2.4	
5–14	2.6*	
15–44	4.3*	2.7
45–64	2.0*	
≥65[b]	0.8	9.1*

Source: Delhi results from the Poisson model with trigonometric terms, weather, year, and trend. Philadelphia results from Schwartz and Dockery.
[a] Schwartz and Dockery computed dose response functions for pneumonia and chronic obstructive pulmonary disease. [b] Schwartz and Dockery divided deaths into two age-groups: <65 and ≥65.
* Significant at the 95% confidence level.

Sensitivity analyses of these models are reported in Cropper et al. We note here that the magnitude of the pollution coefficients and their standard errors are generally unaffected by (*a*) adding SO_2 to the model; (*b*) using monthly dummies instead of trigonometric terms to control for seasonality; (*c*) adding dummy variables to control for the monitoring stations used to compute average TSP; and (*d*) correcting the serially independent Poisson model for overdispersion, which, when ignored, can result in unrealistically low standard errors (Agresti).

Comparison of Results for Delhi with Other Studies

To place our results in context, we compare our estimates of the impact of TSP on mortality in Delhi with similar estimates for Philadelphia (Schwartz and Dockery), also presented in table 1. The Philadelphia results are based on an econometric model similar to ours and use TSP as the measure of air pollution. However, average TSP levels in Philadelphia during the time of the study were 300 micrograms lower on average than levels in Delhi.

The comparisons between Delhi and Philadelphia (shown in table 1) are striking. The impact of TSP on deaths in Delhi is only one third to one half the impact of TSP in Philadelphia. The difference in the impact on total

Table 2. Number of Life-Years Lost by a 100 μg/m³ Increase in TSP

<table>
<tr><th rowspan="2">Mortality End Point</th><th colspan="2">Delhi</th><th colspan="2">Philadelphia</th></tr>
<tr><th>No. Excess Deaths</th><th>No. Life-Years Lost</th><th>No. Excess Deaths</th><th>No. Life-Years Lost</th></tr>
<tr><td>By age-group (yrs.)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>0–4</td><td>278</td><td>16,680</td><td></td><td></td></tr>
<tr><td>5–14</td><td>63</td><td>3,591</td><td></td><td></td></tr>
<tr><td>15–44</td><td>651</td><td>26,040</td><td rowspan="2">370</td><td rowspan="2">13,320</td></tr>
<tr><td>45–64</td><td>268</td><td>5,092</td></tr>
<tr><td>≥65</td><td>125</td><td>0</td><td>3,149</td><td>37,788</td></tr>
<tr><td>Total</td><td>1,385</td><td>51,403</td><td>3,519</td><td>51,108</td></tr>
</table>

Source: Current Delhi study, Schwartz and Dockery.

nontrauma deaths[5] is no doubt due in part to the continued importance of infectious diseases in Delhi (accounting for close to 20% of deaths in our sample) as well as to the smaller role played by cardiovascular and respiratory deaths. The results for cardiovascular and respiratory deaths are most likely driven by differences in the nature of these illnesses and in the age distribution of deaths between the two cities. For example, pneumonia, which has a weaker association with particulate matter than COPD, comprises a larger fraction of respiratory deaths in Delhi. Furthermore, over 60% of pneumonia deaths occur before age five. This is in contrast to Philadelphia, where at least 60% occur after age sixty-five.

The differences in the effects of TSP by age are also striking. In Philadelphia, the impact of TSP on deaths before age sixty-five is not statistically significant. The main impact of TSP is on persons who die after age sixty-five. In Delhi, the impact of TSP on deaths after age sixty-five is not statistically significant. Peak impact occurs between fifteen and forty-four, and significant positive effects are also found for the age-groups five to fourteen and forty-five to sixty-four. A clear implication of this finding is that more life-years are likely to be lost per person because of the impacts of air pollution.

Policy Implications of the Results

One of the implications of our findings is that extrapolations of the mortality impacts of air pollution to developing countries from studies in the United States are likely to be misleading. If one applies the coefficients from Schwartz and Dockery's study to the population of Delhi, the number of premature deaths associated with air pollution is overestimated. As shown in table 2, deaths would increase by 1,385 in Delhi if TSP were to increase by 100 micrograms, whereas the Schwartz and Dockery coefficient predicts an increase of 3,524 deaths.

However, if one cares about life-years lost, the impacts of a 100-microgram increase in TSP in Delhi are more startling. As illustrated in table 2, weighting each of the 1,385 lives lost by remaining life expectancy implies a loss of 51,403 life-years. To put this number in perspective, we use table 2 to contrast the impact of increasing TSP by 100 micrograms in Philadelphia and in Delhi. Although the impact of the change in air pollution on total nontrauma deaths is lower in Delhi than in Philadelphia, the same increase in air pollution causes more life-years to be lost in Delhi. This is because more deaths occur at younger ages in Delhi than in Philadelphia and because the impact of air pollution on deaths is greater at younger ages in Delhi than in Philadelphia.

Conclusions

We draw two conclusions from this study: (*a*) The impact of particulate matter on total nontrauma deaths in Delhi, India, is smaller than effects found in the United States. This is due to the fact that in Delhi a greater proportion of deaths occurs at younger ages and from causes not associated with air pollution than is the case in the United States. Estimating the number of nontrauma deaths associated with air pollution

[5] TSP could have differential impacts because the size distribution and chemical composition of particles differ between the two cities. However, it appears that the ratio of smaller particles (PM_{10}) to TSP in Delhi is about the same as in the United States.

for a city in a developing country on the basis of U.S. studies may therefore yield misleading results. (*b*) The impacts of air pollution on deaths by age-group may be very different in developing countries than in the United States, where peak effects occur among people aged sixty-five and older. In Delhi, peak effects occur between the ages of fifteen and forty-four, implying that a death associated with air pollution causes more life-years to be lost.

We recognize that our results are based on data representing only 25% of the deaths that occurred in Delhi during the study period. When data for the remainder of the city become available, this study should be replicated to confirm our findings.

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