

**Air Pollution and Health Effects:
A Study of Respiratory Illness Among Children in Santiago, Chile**

March 1998

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The authors gratefully acknowledge: (1) the collaboration of Carlos Aranda in the early stages of this research; (2) receipt of data from Sistema de Monitoreo Epidemiologico (supported by the UNICEF/Chile and Sociedad Chilena de Pediatria) and from Servicio de Salud Metropolitano del Ambiente, and (3) financial support from the World Bank's research committee, grant number RPO 678-48. The findings, interpretations, and conclusions expressed in this paper are entirely those of the author. They do not necessarily represent the views of The World Bank, its Executive Directors, or the countries they represent.

Short abstract:

In a study adding significantly to internationally available evidence, air pollution is found to contribute to respiratory disease among children in Santiago, Chile. Reductions in a range of symptoms from coughs to bronchitis will be among the benefits if the city is successful in reducing concentrations in the air of small dust particles (PM10).

Longer abstract:

The authors have previously argued that existing dose-response functions for the health effects of air pollution can be adjusted and transferred when local estimates are not available (Ostro, 1992, Ostro et al, 1996). They have also argued that local estimations in developing countries are needed both to test this approach and in order to enrich the literature in general, to produce better estimates under a wide range of conditions.

In Ostro et al, 1996, it was found that the association between air pollution, measured by small dust particles (PM10), and premature mortality, was significant in Santiago and consistent with what one would expect based on studies in industrialized countries.

This study estimates dose response functions for respiratory disease among children based on data from public clinics in Santiago. Respiratory disease is found to be significantly affected by air pollution measured as PM10. The effect, for children under 15 (and subgroups) is robust to the inclusion of a wide range of covariates and alternative specifications, and thus is not due to confounding with other variables. In some model specifications, ozone, another pollutant measure, is also found to have an effect on respiratory clinic visits.

The study contributes to the literature in several ways. Internationally, morbidity effects have typically been found in cross-section studies, or in prospective studies following a panel of predisposed children, such as asthmatics. This study is important in finding such an effect for a larger population of children

with more general characteristics. Apart from helping to learn about the underlying epidemiological relationships, such results are useful demand if one wants to conduct cost-benefit analysis of air pollution control, since this requires estimation of health effects for the general population.

Secondly, the study adds to much needed evidence on the benefits of pollution control in developing countries. Increasingly, cities and countries in the developing world realize that environmental management involves benefits, not only costs. Evidence on health effects will be one of the inputs that can strengthen the policy making process. To date, only few studies involving children have been made internationally.

This study, and Ostro et al. (1996) was initiated by operational support to an environmental study in the LAC region, and was given additional funding from the World Bank's research committee when a need for research was argued, and promising data and collaborators were found. The LAC study completed cost benefit analysis of air pollution control in Santiago, and found that modestly estimated health benefits exceeded pollution control costs by more than 50 percent (Report 13061-CH).

I. Introduction

The 4.5 million inhabitants of Santiago, Chile, are exposed to high levels of air pollution during a significant part of the year. Located in the western side of South America, the city frequently confronts strong anticyclonic conditions which cause a thermal inversion layer at a height of 600 to 900 meters above sea level. The city is in the middle of a valley at an average altitude of 570 meters above sea level, and is surrounded by two mountain ranges: the Andes mountains and the Cordillera de la Costa. These geographic conditions restrict ventilation and dispersion of air pollutants within the valley. Such features explain why Santiago, with emission levels similar to those in other cities, experiences high atmospheric contamination levels.

Data from the Chilean Health Service show that the standard for the 24-hour average of particulate matter below 10 microns in diameter (PM10), $150 \mu\text{g}/\text{m}^3$, is exceeded throughout the winter. The average annual concentrations of PM10 exceed Chile's standard of $50 \mu\text{g}/\text{m}^3$ by a factor greater than two. The one-hour standard for carbon monoxide is exceeded in 20% of the data collected during the winter time, while one-hour ozone often exceeds 0.09 ppm during the summer (Escudero and Cofre, 1993). These levels of atmospheric pollution are likely to cause health effects among the population of Santiago. Recent research used time series data to examine the association of PM10 and daily mortality between 1989 and 1991 in Santiago (Ostro et al. 1996). The results obtained suggest a strong association between these two variables even after controlling for several potential confounders including temperature, season, month and day of the week. However, there have been few studies completed in Chile on the effects of PM10 pollution in relation to respiratory illness in Santiago. In addition, on a world-wide basis, there are only a few epidemiologic studies of the effects of air pollution on the health of children and infants (Penna and Duchicade, 1991; Bobak M, Leon M, 1992; Woodruff et al., 1997). Studies in the developing world are important because the extent to which findings from industrialized countries can be extrapolated to other areas is uncertain (Ostro, 1992).

This paper examines how weather conditions and air pollution influence the risk

of respiratory diseases among children in Santiago. Data on morbidity due to respiratory diseases among children under 15 years of age have been collected from a group of public primary health clinics. In Chile, almost 75% of the population are members of the public health care system, which serves primarily the lower 70% of the population income distribution

II. Morbidity, Air Pollution and Weather Data

In Santiago there are about 70 primary health care centers (clinics) of the public health care system. On average, they provide service for infants with 10 to 20 doctor hours per day per clinic. During 1992, there were close to 1,830,000 medical visits for pediatric morbidity in the metropolitan area excluding well child and annual physical examinations (Aranda et. al., 1993).

The Infant Respiratory Disease Program was developed by The Chilean Ministry of Health in order to provide effective care at the clinics and to evaluate the epidemiology of pediatric illnesses. A monitoring program for infant respiratory disease provides information from 12 primary health provision centers, designated as sentinel clinics (UNICEF, 1991). The present research uses information from 8 sentinel clinics between July 13, 1992, and December 31, 1993. These clinics serve 12% of the child population in the province ($n = 153,548$) (INE, 1989).

Santiago is divided into six Public Health Services Areas. The clinic selection process followed a criterion that allowed choosing at least one clinic in each Health Service Area. Three of the twelve clinics were excluded because of missing values or insufficient information. An additional clinic was excluded because it was more than 12 km from the nearest air pollution monitoring station. With the eight remaining clinics, each of the city's six Health Service Areas was represented.

Using a standardized form, the total number of child medical visits and respiratory morbidity diagnoses were collected every day. Doctors working at each clinic prepared the diagnoses. The researchers of the infant respiratory disease program trained the record-keeping staff at each clinic to group the diagnoses observing the

following classification: (a) non-respiratory visits, (b) respiratory visits due to upper respiratory illness (ARI), (c) respiratory visits due to lower respiratory illness (LRI). In this case, upper respiratory illness included inflammation processes that affected the respiratory tract above the larynx such as pharyngitis, common cold, adenoiditis, sinusitis, tonsillitis and otitis media. Lower respiratory illness included inflammatory processes affecting the larynx, trachea, bronchus or lungs such as bronchitis, pneumonia, broncho-pneumonia, bronchial asthma, acute obstructive bronchitis, acute laryngitis, and acute tracheitis. When there were two or more simultaneous diagnoses, the most serious one was recorded. Classification separated the children in two age groups: less than 2 years old and children from 2 to 14 years old. For each day, the number of medical visits with each diagnosis was totaled across clinics.

The clinics are only open during working hours Monday through Friday. However, the number of doctors attending to patients at the clinics (in "pediatric hours") varies from day to day. This fact implies that the supply of medical attention varies accordingly. Some patients do not seek medical attention because of the limited hours of clinic operation, and also because of clinic capacity restrictions (as evidenced by lines). While the extent of unsatisfied demand cannot be known with certainty, each clinic made daily record of the number of pediatric hours available for morbidity visits.

It should be noted that the recorded data reflect medical visits in general and do not discriminate between first visits or follow-up visits; consequently, the data capture the number of visits and not the number of illness episodes. Out of the 370 planned days of observations (excluding weekends and holidays), there were information for 352 days from the 8 clinics; the remaining days were not included because there were fewer than 8 clinics fully functioning. In addition, nine days were excluded as outliers because they were holidays or because of labor disputes. Table 1 provides the general descriptive statistics of the data. There was an average of 565 visits per day among the 8 clinics surveyed. Sixty-three percent of all medical visits of children under fifteen years old were for respiratory illness. Among these, 60.3% were for lower respiratory illness.

Table 1. Summary statistics for the 8 clinics, air pollution and temperature data during study sample period July 13, 1992 to December 31, 1993.

	<i>Daily Mean</i>	<i>Max-Min Values</i>
Total visits	565.0	859 - 376
Total visits < 2 years old	221.9	316 - 136
Total visits for respiratory illness	357.1	704 - 166
Total visits for respiratory illness < 2 years old	152.8	310 - 66
Total visits for lower respiratory illness	215.4	440 - 71
Total visits for lower respiratory illness < 2 years old	104.3	202 - 42
Total visits for upper respiratory illness	141.6	290 - 69
Total visits for upper respiratory illness < 2 years old	48.5	80 - 24
PM10 (24-hour ave., $\mu\text{g}/\text{m}^3$)	108.6	380 - 18.5
Ozone (1-hour maximum, ppb)	56.2	176 - 10
Temperature (24-hour ave., C°)	15.8	23.7 - 5.4

Daily data for temperature, PM10 and ozone were available from the Metropolitan Environmental Health Service. The average of the four stationary monitors located downtown within a 12 km² quadrilateral were used to obtain the daily concentrations of PM10 and ozone. The correlations of PM10 with ozone and temperature were -0.1 and -0.45, respectively, while that for ozone and temperature was 0.67.

This data set is comprised of clinic visits, rather than illness episodes. The health endpoints studied represent children who are successful in obtaining a doctor's attention, and who are then diagnosed with respiratory illness. Assuming that diagnoses are without error (or with errors independent of the pollutant and temperature variables), some parents will not seek treatment for their children, some will take them to hospital emergency rooms, and some who take them to clinics may be unsuccessful in obtaining a doctor's attendance due to lack of

capacity. These actions may result in an attenuation or flattening of the estimated dose-response function at the higher pollution concentrations.

III. Methodology

Examination of the daily counts for reported visits for upper and lower respiratory disease for infants below age 2 (“young”) and between ages 2 and 15 (“older”) supports distributional assumptions allowing ordinary least squares (OLS) as the principal statistical analysis (the counts show no truncation and appear normally distributed). Each age group was examined separately for both upper and lower respiratory visits for a total of four different models. To develop our regression model, we determined the best fit of several covariates prior to the entry of air pollution into the model. In turn, we examined the association of each outcome with daily average temperature (lagged up to four days), day of the week, season (or month) and year of the study. Day of the week was likely to be important since the clinics were closed on weekends. Visual inspection of the data indicated clear seasonal patterns. Once the covariates with the strongest association were determined, PM10 was entered into the model. Contemporaneous exposure and lags up to 4 days were examined. All models were corrected for autocorrelation using AUTOREG in SAS (SAS, 1997).

Since preliminary analysis revealed that temperature and season (month) were relevant covariates, additional sensitivity analyses were conducted. First, the model was re-run using a locally weighted (loess) smooth of time using a general additive model (GAM) in S-Plus (Cleveland and Devlin, 1988; StatSci, 1993). The loess smoothing technique can accommodate nonlinear and nonmonotonic patterns between temperature and the health outcome, offering a more flexible nonparametric modeling tool. Typical modeling of temperature would utilize a linear and/or quadratic term. Others have used several binary variables to represent different temperature strata. In using the loess smooth, the observed values are replaced by a series of predicted values, generated by connecting the central points over a series of weighted regressions for a given span of the data (Hastie and Tibshirani, 1990.). For our purposes, we chose a span that included 20 percent of

the data. However, we also tested the sensitivity of the results to alternative spans.

A second and third sensitivity analysis involved re-running the model after dropping the days with the highest 5% of PM10 concentrations ($PM_{10} > 235 \mu\text{g}/\text{m}^3$) and the coldest 5% of the days (Celsius temperature < 8 degrees). Fourth, we re-ran the GAM model without the monthly binary variables since these variables are correlated with PM10 levels and their inclusion may result in “over correction”. Fifth, the regression was re-run for only the eight month non-summer period, by excluding November through February from the analysis of this southern hemisphere city. Finally, we examined the models after inclusion of a second pollutant, ozone, was added to the specification.

IV. Results

In general, the best fit for the ordinary least squares model included average temperature (lagged one-day, although same-day temperature performed almost as well), day of the week, and dichotomous variables for each month and year. As expected, for lower respiratory illness, the numbers of visits were highest on Monday and Friday. For upper respiratory illness, the differences by day of week were modest. Three of the four outcome measures (i.e., young lower, older lower and older upper illness) peaked during the winter months. Upper respiratory visits for those below age 2 had a less distinct seasonal pattern with some peaks in March, April and May. For the older subgroup, there was no evidence of serial correlation in the error terms, while for the younger subgroup, a two period correction effectively reduced the serial correlation, based on the Durbin-Watson statistics. As summarized in Table 2, there was a statistically significant association between PM10 and lower respiratory illness in both the young and older cohorts, between PM10 and upper respiratory illness in the older cohort, and between ozone and lower and upper illness in the older cohort. The models explained about 80 percent of the variation in lower respiratory visits, about 70 percent of the variation

in upper respiratory visits in older children, and about 20 percent of the variation in the upper respiratory visits of infants.

Table 2. Ordinary least squares regression results for clinic visits for upper and lower respiratory symptoms in young (age<2) and older (age 2 to 15) children (estimated beta coefficient with standard error in parenthesis).

	<i>Young, Lower</i>	<i>Young, Upper</i>	<i>Old, Lower</i>	<i>Old, Upper</i>
PM10	0.049 (0.020)*	0.0014 (0.012)	0.066 (0.027)*	0.053 (0.021)*
Ozone	0.041 (0.036)	0.0034 (0.021)	0.157 (0.050)**	0.103 (0.037)**
PM10 and Ozone	0.060 (0.022)** 0.027 (0.036)	0.002 (0.012) -0.006 (0.023)	0.042 (0.029) 0.151 (0.051)**	0.033 (0.023) 0.093 (0.041)*

* p < 0.05; ** p < 0.01; *** p < 0.001.

Model also includes daily average temperature (one-day lag), binary variables for day of week, month, year, and corrections for autocorrelation. PM10 and ozone are unlagged and expressed in terms of $\mu\text{g}/\text{m}^3$ and ppb, respectively.

Table 3 summarizes the results for different lags using the GAM, where a smooth of time is used in place of dichotomous variables for month and year. This model generated stronger associations between the clinic visits and PM10, relative to the model using ordinary least squares. For lower respiratory illness in both cohorts, a 3-day lag demonstrated the strongest association, but the differences between alternative lags were not large. However, for upper and lower respiratory visits in the younger cohort and for upper respiratory visits for the older cohort, a 5 day moving average (days 0 through day 4) generated much larger and stronger

associations with PM10.

Table 3. Sensitivity Analysis: Alternative lags for PM10 using general additive model with gaussian distribution for clinic visits for upper and lower respiratory symptoms in young (age < 2) and older (age 2 to 15) children. (estimated beta coefficient with standard error in parentheses).

<i>PM10 lag</i>	<i>Young, Lower</i>	<i>Young, Upper</i>	<i>Old, Lower</i>	<i>Old, Upper</i>
0 (days)	0.12 (0.02)***	0.01 (0.01)	0.20 (0.04)***	0.06 (0.02)**
1	0.15 (0.02)***	0.00 (0.01)	0.20 (0.04)***	0.05 (0.02)**
2	0.15 (0.02)***	0.01 (0.01)	0.20(0.04)***	0.06 (0.02)**
3	0.19 (0.03)***	-0.01 (0.01)	0.28 (0.04)***	0.05 (0.02)*
4	0.15 (0.03)***	-0.01 (0.01)	0.20 (0.04)***	0.01 (0.02)
0 to 4 moving average	0.25 (0.03)***	-0.00 (0.01)	0.36 (0.05)***	0.14 (0.03)***

***= significant at $p < 0.001$.

Model also includes daily average temperature (one-day lag), binary variables for day of week, and a loess smooth of time.

Table 4 summarizes the results of different sensitivity analyses using the GAM. In the basic model, PM10 was statistically associated with lower respiratory visits in the young and older children. The results appeared relatively insensitive to the length of the span chosen. A monthly dichotomous variable was entered back into the model since it remained significant, even after the smooth of time was included. With these additional covariates in the model, the magnitude of the effect dropped significantly. For example, for lower respiratory visits for the younger cohort, the regression coefficient dropped from 0.19 to 0.05. Visual inspection of residual and autocorrelation function plots indicated absence of any remaining serial correlation. The general results did not appear sensitive to either high PM10 concentrations or low temperature. One-hour maximum ozone concentrations were associated with upper and lower respiratory visits in the older cohort. In the multi-pollutant model, PM10 remained significantly associated with lower respiratory

visits in both cohorts, while ozone was associated with lower and upper respiratory visits in the older cohort. The magnitude of the effect was slightly higher than that predicted from the ordinary least squares models. For example, for PM10, among the younger cohort, the coefficient for lower respiratory visits was 0.049 in the OLS model versus 0.052 in the GAM, while for upper respiratory visits, the coefficients were 0.066 versus 0.083, respectively. When monthly dichotomous variables were dropped from the GAM specification, the effects were much larger, more than tripling in magnitude. Additional smoothers of temperature did not alter the results for any of the endpoints.

Table 4. Sensitivity Analysis: General additive model regression results for clinic visits for upper and lower respiratory symptoms in young (age < 2) and older (age 2 to 15) children (estimated beta coefficient with standard error in parentheses).

	<i>Young, Lower</i>	<i>Young, Upper</i>	<i>Old, Lower</i>	<i>Old, Upper</i>
PM10	0.052 (0.024)*	- 0.021 (0.014)	0.083 (0.033)**	0.008 (0.026)
PM10, less top 5% (< 235 $\mu\text{g}/\text{m}^3$)	0.059 (0.026)*	-0.011 (0.016)	0.046 (0.035)	-0.004 (0.028)
PM10, less coldest 10% (> 8° C)	0.052 (0.023)*	-0.019 (0.015)	0.086 (0.033)**	0.006 (0.027)
PM10, non-summer months	0.039 (0.026)	-0.025 (0.17)	0.082 (0.030)**	0.0116 (0.029)
PM10, no month variable	0.186 (0.025)***	0.0003 (0.011)	0.279 (0.036)***	0.183 (0.028)***
PM10, no month variable, 5-day moving average	0.140 (0.021)***	-0.003 (0.013)	0.263 (0.030)***	0.144 (0.026)***
Ozone	0.033 (0.034)	0.022 (0.020)	0.120 (0.047)**	0.123 (0.035)***
PM10 and Ozone	0.045 (0.024)* 0.025 (0.038)	-0.023 (0.014) 0.020 (0.020)	0.082 (0.032)** 0.154(0.046)***	0.008 (0.026) 0.131 (0.037)***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Model also includes daily average temperature, binary variables for day of week and month, and a loess smooth of time.

PM10 is lagged 3 days and ozone is unlagged and expressed in terms of $\mu\text{g}/\text{m}^3$ and ppb, respectively.

Table 5 summarizes some of the model results indicating the percent changes in clinic visits for lower respiratory visits for young and older children, based on the GAM model. For children under age 2, a 50 $\mu\text{g}/\text{m}^3$ change in PM10 (about half of the mean concentration) is generally associated with a 3% increase, increasing up to 9% in the model without month variables. For children age 2 to 15 years, the lower respiratory effects are in the range of 2 to 4% for a 50 $\mu\text{g}/\text{m}^3$ change in PM10 (increasing to 13% in the model without month variables) and 5%

per 50 ppb change in ozone. Finally, for clinic visits attributed to upper respiratory visits, a 50 $\mu\text{g}/\text{m}^3$ change in the 5-day moving average of PM10 is associated with a 7% increase.

Table 5. Percent change in clinic visits for lower respiratory symptoms predicted from alternative models. (percent change and 95% confidence interval associated with 50 $\mu\text{g}/\text{m}^3$ change in PM10 and 5 ppb change in ozone).

	<i>Young, Lower</i>	<i>Old, Lower</i>
PM10	2.5 (0.2, 4.8)	3.7 (0.8, 6.7)
PM10, less top 5% (235 $\mu\text{g}/\text{m}^3$)	2.8 (0.4, 5.3)	2.1 (-1.0, 5.2)
PM10, less coldest 10% (8° C)	2.5 (0.3, 4.7)	3.9 (1.0, 6.8)
PM10, non-summer months	1.9 (-0.6, 4.3)	3.7 (1.0, 6.3)
PM10, no month variable	8.9 (6.6, 11.3)	12.6 (9.4, 15.7)
Ozone	1.6 (-1.6, 4.8)	5.4 (1.3, 9.6)

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Regression results are based on General Additive Model which includes daily average temperature, binary variables for day of week and month, and a loess smooth of time. PM10 is lagged 3 days and ozone is unlagged.

V. Discussion

The analysis indicates that PM10 is associated with clinic visits for lower respiratory visits in children aged 2 to 15 and those under age 2. A prior study in Santiago, reported a strong and consistent association between acute exposure to PM10 and mortality (Ostro et al., 1996). The association existed for all-cause mortality as well as mortality associated with either cardiovascular- or respiratory-specific mortality. Prior to the current study, only a few efforts have been

reported in the epidemiologic literature linking air pollution to either mortality or morbidity among young children in particular. For example, several ecological studies have reported an association between particulate matter and neo-natal or infant mortality (Penna and Duchiage, 1991; Bobak and Leon, 1992;. Knoebel et al., 1995; Woodruff et al., 1997).

Morbidity effects of particulate matter on children with asthma or asthma-like symptoms also have been reported from several panel studies using daily time-series data (Ostro et al., 1995; Roemer et al., 1993; Pope and Dockery, 1992). Among panels that were not entirely composed of asthmatics, several studies have reported an association between PM10 and lower respiratory symptoms (Schwartz et al., 1994; Braun-Fahrland et al., 1992; Ostro et al., 1993). Air pollution effects on children have also been demonstrated from daily data on emergency room visits (Delfino et al., 1997; Bates et al., 1990).

As in all studies, our use of the Santiago data had both advantages and disadvantages. One of the principal advantages was that the health care professionals in the clinics included in our study were specifically trained in filling out the special diagnostic forms. Studies that use data on hospital admissions or emergency room visits often face difficulties in terms of accuracy and consistency of coding and compliance. An additional advantage was that for the subpopulation being served (lower and moderate income residents), these clinics are the primary provider of health care services. Therefore, the possibility of behaviors complicated by competing servers, health plans, insurance and accessibility is minimized.

There are three main disadvantages of these data. First, the action of visiting a clinic is ultimately a subjective choice that can be influenced by several factors such as competing demands, parents' attention to illness, and the thresholds of the children. However, it is reasonable to assume that these factors are randomized over the range of pollution concentrations and are not likely to vary on a day-to-day basis with air pollution. Therefore, omitting these factors from the

analysis is unlikely to result in a significant estimation bias. Second, the public clinics primarily serve the lower 70% of the population income distribution, while citizens from the upper quintile are typically served by private clinics. Therefore, these estimates are not necessarily representative of all children in Santiago. If children from lower and moderate income families are more susceptible to the effects of air pollution, our estimates would have an upward bias in representing the entire population of children. Third, clinics are only open on weekdays and during normal working hours. Furthermore, though the number of attending physicians varies on a daily basis at the clinics to keep up with demand, lines at the clinics are evidenced. Therefore, some patients may be discouraged from seeking medical attention. Since the analysis indicates an association between PM10 and clinic visits, it is possible that on the higher air pollution days, visits are “artificially” reduced. This would result in a downward bias in the dose-response curve. Visual observation of the data suggests a smoothing at the higher levels of PM10. Whether this is due to discouraged demand or to other factors, such as higher PM10 days resulting from less harmful blowing dust, is unclear. As part of the analysis, other time series models were investigated in an attempt to adequately take account of the potential influence of the supply of physician hours. A particular concern was the possibility that recorded respiratory visits could be influenced causally by the availability of physicians, which in itself might be an endogenous variable if the number of physician hours varies with either pollution or meteorological variables. We used an instrumental variables approach and vector autoregressive techniques to examine the question of endogeneity. The results indicated that a capacity constraint in clinics was not a problem in the estimation.

For lower respiratory symptoms in both the infants and older children, a three-day lag in PM10 appears to be most significant among the single day lags. However, the cumulative exposure over a 5-day period generates the strongest effects. Several recent studies have reported that lags of 2 days or more are more strongly related to the health endpoint than are concurrent exposure (for example, Delfino et al., 1997; Roemer et al., 1993; Pope and Dockery, 1992). Upper respiratory symptoms in infants are more randomized throughout the year and are

more difficult to model. The lag may be due to either delays in seeking medical care or to the pathogenesis of particulate matter in its potential impact on lung clearance.

Because of concerns about potential confounding, we controlled for the effects of seasonality and temperature in several ways. The basic model included a variable representing daily temperature and dichotomous variables representing the month and year. We then analyzed the data using loess smoothers for time, with and without variables representing the month of the study. We also analyzed the data after deleting the 5 percent of the days with highest PM10 concentrations and the coldest 5 percent of the days to ensure that the results were not driven by any extreme observations. The models were also re-run after deleting the summer months. With one exception, the results did not noticeably change with any of these analyses. Dropping the dichotomous variable for month significantly increased the estimated coefficient of PM10 suggesting that some “over-correction” for season in the model may be occurring.

The problem of confounding in a multivariate model is an important one, and the inclusion of a broad array of variables - as applied here - is necessary to gain confidence both in the significance and magnitude of effects. It is worth reflecting, however, on the role of variables that are on *a priori* grounds not causal, such as 11 dichotomous variables representing each month. These may take their effect from correlated variables that are not included (or poorly measured) examples of which might be exposure to low temperatures and high air pollution. The possibility exists, therefore, that the magnitude of the effect of air pollution on morbidity visits is biased downward significantly when day-of-week, month, and smoothers are included. Taken together, a significant effect of PM10 on lower respiratory disease does not appear due to residual confounding by temperature or season. Our analysis is strongly suggestive of an association between clinic visits for respiratory illness and PM10 among the population of children age 3 to 15 and for infants.

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