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Air Pollution in Bogotá, Colombia: A Concentration-Response Approach*

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Abstract

Most of the evidence regarding the association between air pollution and health comes from studies in the USA. Nevertheless, air pollution has become a concern also for local authorities of Latin-American cities and Bogotá, Colombia is no exception. This paper will develop a model to define a concentration-response function between three of the most important air pollutants in Bogotá and the daily respiratory hospital admission counts in the city during the year of 1998. This article pretends to further work on this area by giving the first step towards a more detailed estimation of the costs of air pollution in Bogotá.

Key words: Air Pollution, Health, Respiratory Hospital Admissions, Bogotá

JEL classification: Q52, Q53, I12

Resumen

La mayor parte de los estudios que analizan la relación entre contaminación del aire y salud han sido realizados en ciudades de los Estados Unidos. Sin

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embargo, a medida que la calidad del aire en ciudades latinoamericanas se deteriora, este se ha convertido en un tema relevante para ciudades como Bogotá. Este artículo presenta una función de concentración-respuesta que define la relación entre admisiones hospitalarias diarias por enfermedades respiratorias y lo tres principales contaminantes en Bogotá para el año de 1998; también pretende dar un primer paso hacia la estimación de los costos asociados a la polución del aire en Bogotá.

Palabras clave: polución aérea, salud, admisiones hospitalarias respiratorias, Bogotá.

Clasificación JEL: Q52, Q53, I12.

Introduction

Air pollution has become one of the most important concerns of the local authorities of Latin-American cities. Bogotá, like as other urban centers in South America such as Sao Paulo, Mexico City and Santiago de Chile, shows significant levels of air pollution, levels that may represent a high risk for the population's health and certainly a reduction in the quality of life of its inhabitants. Bogotá, capital of Colombia, is one of the largest cities of Latin America; with a population of around 6.5 million and an annual growth rate of 2.08[1] percent it is the largest urban center in Colombia; it also has the highest rates of environmental deterioration of the country. Air pollution has increased dramatically lately, due mainly to the uncontrolled increase in the number of vehicles in the city[2].

Although air pollution has been monitored in Bogotá since 1967, it wasn't until 1990 that the monitoring stations were spread widely throughout the city. At that time the Secretary of Health of the District with the collaboration of the Japanese International Cooperation Agency (JICA) pursued a study in order to determine the air quality of the city. This study concluded that the most important source of pollution in Bogotá was automobiles; 70% of the pollution could be attributed to cars. Another very important source of

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1 Departamento Administrativo Nacional de Estadísticas, *www.dane;gov.co*.

2 It has been estimated that the number of vehicles increased by 8% in a period of three years (1996-1999), *www.dama.gov.co*.

pollution was found to be bricks and battery plants, among others[3]. The study conducted with the support of JICA identified for the first time the composition of air pollution in Bogotá and its principal components. These were identified to be the following: Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_x), Total Suspended Particles (TSP), Carbon Monoxide (CO), Hydrocarbons (HC), and Ozone (O_3). It was estimated that 75% of the pollutants' annual emissions correspond to Particulate Matter[4]. The study determined that the levels of CO, HC, SO2 and Particulate Matter were not above the limits defined as safe by the WHO. This led to JICA 's conclusion that: in 1990-1991 air pollution in Bogotá did not reach levels of concern to the local authorities. Nevertheless, the rapid growth in the number of cars in Bogotá during the last decade originated additional interest in this matter. The JICA pointed out in 1996 that the number of cars registered in Bogotá had increased from 324.902 in 1991 to 570.000 in 1996; this meant that around 40% of the cars of the whole country were circulating in Bogotá.

Currently, half of the localities of the city where the monitoring stations are exceed the emission limits stated as safe by the WHO, with Particulate Matter (PM10) and ozone levels being the major problems. Most of the largest cities in Latin America also share this problem. In Mexico, Santiago de Chile, and Sao Paulo vehicles account for almost all of the carbon monoxide emissions, between 50 to 90 percent of hydrocarbons, at least three-quarters of NOx and around 40 percent of suspended particulate matter (PM10)[5]. The great concern around pollution levels stems from the connection that has been found between exposure to these kinds of gases and human health problems; inhalation of these gases in certain concentration levels may cause serious respiratory illnesses as well as injuries to the neural system, especially in children.

Most air pollutants have effects on human health although their effects are different. Consider first Carbon Monoxide. This pollutant reduces the level of oxygen in the blood forcing the heart to work harder. At high exposure

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3 CAVALLAZI, Marcelo (1996). "Contaminación atmosférica en Bogotá". *Revista Cámara de Comercio de Bogotá,* no. 97 (sept.).

4 *Ibid.*

5 BLEVISS, Deborha Lynn (1999).

levels it may affect the capacity of thinking, reduce the reflexes and cause nausea, dizziness, unconsciousness and even death. On the other hand, a pollutant such as nitrogen dioxide will affect mainly persons susceptible to respiratory infections, especially children. Nevertheless, a strong and direct effect on human health from exposure to this pollutant has not been proven to exist yet. On the contrary, there is strong evidence of the effect of sulfur dioxide on human health with long as well as shorter time exposure to it Recent studies have associated changes in the 24-hour average exposure to SO_2 to lung function, increase in the incidence of respiratory symptoms and diseases, and even risk of death.

Particulate matter is another main pollutant that presents serious health effects on humans. Epidemiological studies have shown that the presence of particulate matter in the environment may affect the human respiratory apparatus causing a notorious reduction in lung function. Lead is also present in the air in most urban centers and its presence has been proven to be a serious problem especially for children. Lead may cause loss of memory, reading and spelling difficulties, vision problems, and deficiencies in perception among others. Finally, there is ozone, the principal component of smog. This gas has been associated with an increase in respiratory illnesses, eye problems and a reduction of lung activity.

The strong connection between air pollutants and health problems described in the previous paragraphs has, under these circumstances, become a concern for Bogotá's authorities. Statistics of the Secretary of Health showed that for 1998 and 1999 9.6% of the visits to the hospitals were related to respiratory problems. The evidence is even stronger for the infant population where 24.3% of the visits to the hospitals for children between zero and one years of age, were associated with Acute Respiratory Illnesses (ARI).

Local authorities now face the challenge of supporting the growth and development of the city and at the same time minimizing the adverse effects of the associated air pollution and its consequences on health. In order to find the best way to do so, cost-benefits analysis can take a very important role. Economists would suggest that policy makers, when making decisions on air pollution regulation, should weight the costs and benefits associated with the different options they have; therefore, it is essential to estimate the effect of air pollution on human health to estimate the benefits related to human health of a reduction in air pollution. This article gives a first step in this direction by estimating a concentration-response function for the city of Bogotá setting up the basis for a future benefit-cost analysis. Even though previous studies have estimated this type of functions there are few studies that use data for developing countries and in particular, to the best knowledge of the author there are no previous studies that look at the relation between Respiratory Hospital Admissions and air pollution in Bogotá, Colombia.

The remainder of this paper is organized as follows: Section I gives a general description of the data used and the sources from where they are extracted. Section II presents the model that will be estimated and section III gives a short description of the status of air pollution in Bogotá. The results of the econometric models estimated are presented in section IV, and finally the conclusion of this article is stated in section V.

I. The Data

The data used in this study come from two main sources and can be classified into two main categories: *environmental* data and *morbidity* information. The *environmental* data was provided by the Administrative Department for the Environment (DAMA). They include information from thirteen environmental stations that are part of the net of environmental quality of Bogotá. For all of them we have geographical information such as station address, latitude, altitude, precipitation, and temperature readings. The information on pollutants is not uniform across the different stations; measures for PM10, SO_2, and NO_2 are collected in nine stations while measures for CO and O_3 are gathered in only six of them. The information on these measures comes in an hourly basis, for daily records for the year of 1998.

The *morbidity* information available for this study consists of counts of daily Hospital Admissions. The information was gathered by the Secretariat of Health for the District and comes from the reports that each Hospital in the city fills on a daily basis. The Respiratory Hospital admissions were taken from the original dataset and aggregated in order to obtain the total number of daily respiratory hospital admissions for the city in 1998. The original dataset contained information for each individual that was received at each hospital: date of admission (day, month, year), code of the hospital at which the individual was admitted; sex and age; neighborhood where the person lives; type of "visit" to the hospital (external, domestic or emergency); whether or not the person has been previously admitted to the hospital and if so, if this is the first time this year; is the person new in the year; referred patient; and type of insurance that the patient uses. Given the nature of this study however, only the daily number of respiratory hospital admissions is useful.

As mentioned above, the daily Respiratory Hospital Admissions for all hospitals in the city were extracted from these data and aggregated to daily counts. These data were combined with the environmental information in order to create a dataset with daily information on RHA as well as on pollution levels and meteorological data in order to estimate the concentration-response function for selected air pollutants in Bogotá, Colombia.

II. The Model

Different types of models have been used to establish the relation between human health and air pollution. A broad classification of these models could be based on the unit of observation that they use[6]. The first group uses the individual as its observation unit. Among these studies there are cross-sectional ones, which look for a relation between health outcomes and different levels of exposure to pollutants at a specific moment in time. Usually the levels of exposure are differentiated by the geographical distribution of individuals among the area in study. Cohort studies would be included in this group. These are very similar to cross-sectional studies but include also variation of exposure in time; cohort studies allow to include more exposed and less exposed individuals as cross-sectional studies, but also account for changes in exposure over time. They result very useful in analyzing which accumulating effects of exposure through time are to be studied. Nevertheless, they require the collection of individual level data through time, which makes them very expensive and lengthy to complete.

On the other hand, there are studies whose unit of observation is a group of people rather than the individual. These are known as ecological studies; they study the relation between pollutants and health, as the exposure to air pollution occurs in the community. These models were first developed for

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[6] From SAMET *et al.* (1999).

the analysis of mortality incidence of air pollution, and then expanded into the area of its morbidity effects. Epidemiological analysis is very common among morbidity studies because the information that it uses is in most cases easily accessible. Measures of morbidity traditionally used in these studies are the number of hospital admissions or visits to the emergency room. The fact that epidemiological models are based on previously collected morbidity data and pollution measures makes these models the most inexpensive to complete.

British investigators are responsible for the development of ecological models[7]. Their studies showed that pollution, measured as particles and sulfur oxides, was associated with excess mortality as well as with morbidity indicators such as respiratory symptoms and infections, reduced lung function and exacerbation of chronic respiratory diseases. In the USA, ecological studies grew in number in the seventies, with the establishment of the US EPA. Studies such as Ferris et al. (1979) concentrated on large datasets that included several cities. As time passed ambient pollution levels have declined and these large-scale studies have been changed for studies that look for relatively smaller effects of air pollution. Another change in the studies developed in this area has been the inclusion of indoor pollution in the analysis. In the beginning, only outdoor pollution measures were used, but some studies published in the eighties and nineties have showed that outdoor pollution also affects indoor measures, and moreover, that indoor pollution also has additional sources (such as cooking) that are of great interest in morbidity studies. It has been shown that indoor sources are an important source of individuals' exposure to particles, nitrogen dioxide and ozone[8]. For developing countries indoor pollution has been proven to be especially high from domestic fires used for cooking and heating[9] in poorly ventilated households[10]. For morbidity, the fit of the models measured as the R^2, increases dramatically when indoor pollution measures are included in the analysis[11].

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7 SHY *et al.* (1978); SAMET (1989).

8 SAMET, J and JAAKKOLA, J (1999).

9 STATON and HARDIN (2000).

10 CHEN *et al.* (1990).

11 WALLACE (1991).

Another concern in epidemiological studies is the measurement of exposure levels. Indirect as well as direct instruments have been used in this effort. Direct instruments are based on individual monitoring systems for each person involved in the study that collect information both on pollutant levels and on exposure times. These are not only expensive but are sometimes also difficult to carry out. Indirect techniques to account for exposure usually collect information on concentrations of pollutants over time in different locations, and if possible, they estimate exposure time of the population; with this information, individuals at similar locations are assigned the concentration measure that corresponds to that area, say the place where they live[12]. The use of either exposure or ambient concentrations leads to the distinction between dose-response and concentration-response functions. Since this study will use pollution measures that come from monitoring stations and assign those levels to individuals, it is clear that the model falls within the latter.

Ecological models have also used several measures of morbidity. Among these there are work loss days; school loss days; days of restricted activity, rates of utilization of outpatient medical services and facilities, visits to the emergency room and hospitalizations[13]. There are two groups of ecological models: cross-sectional and time-series studies. The first group usually compares pollution and morbidity measures from different locations at one point in time; the second group is usually limited to a single location that is followed through a period of time, i.e. a year. Time series designs have the advantage of avoiding problems that are driven from the generalization of results and findings from groups to individuals, especially if they use a short period of collection of the data, say a day. The principal advantage of following a single population over time is that it is not necessary to control for individual-level confounding factors such as education, income or percentage of smokers, as long as they stay roughly constant over time[14].

Ecological models also have limitations, and it is in the best interest of this article to identify them. Long-term cycles of pollutant and morbidity measures may cause wrong associations and give biased estimates for pollutants'

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12 LUNN *et al.* (1967) and DETEL *et al.* (1987).

13 LVOVSKY (2000).

14 ITO, Kazuhiko and THURSTON, George (1999).

health risk. These wrong associations may come from shared seasonal trends, driven for example from the transition from winter to summer. Addressing seasonal cycles in respiratory disease time- series is therefore important. Different modeling options have been used to model the seasonal behavior of morbidity and pollutants relation. Among these there are Fourier techniques that fit sine/cosine waves to the data; auto regression methods; and the use of dummy variables that account for changes in time (day of the week, month or a specified season). Some recent studies show that no matter which method is used, the coefficient of the pollution variable does not change much, as long as seasonality is taken into account[15].

The model of this article is an application of the ecological approach, since it examines the relation between air pollution in Bogotá-Colombia, and a health outcome –daily respiratory admissions to hospitals (RHA). The concentration level is measured as the average of daily maximums across the whole city. Geographical or individual distinctions are not taken into account due to data limitations. A concentration-response model relating respiratory admissions in hospitals in Bogotá and air pollutant levels will be constructed. The daily number of RHA in Bogotá is assumed to be a function of 4 pollutants and some meteorological variables such as rain and temperature; seasonal factors related to weather, pollen and diseases such as the flu and colds are taken into account by including a dummy variable for each quarter of the year. The model to be estimated is:

$$\ln(RHA) = f\,(rain\,, temp\,, pollutants\,, dummy\ for\ season) \qquad (1)$$

A semi-log specification is used to define the relationship between the health outcome (RHA) and pollution. All pollutants are expected to have a positive relationship with the number of respiratory hospital admissions in the city, and therefore the expected sign of each coefficient is positive. The expected signs of the meteorological variables are not clear a priori. One would expect a negative sign of the coefficient of rain, since rain acts as a cleaning device for the environment. Higher levels of rain will then result in lower respiratory hospital admissions, as rain reduces pollution in the air. By contrast, the expected effect of the daily average temperature in Bogotá is

15 KINNEY *et al.* (1995); LIPFERT (1994) in THURSTON and ITO (1999).

unclear. On one hand, most pollutants are the result of chemical processes that take place with solar radiation, which suggests a positive association with the dependent variable. On the other hand, cold weather is usually associated with illnesses such as cold and flu and hence respiratory illnesses. In developed cities, special warnings are issued on warm summer days in order to discourage people from exercising outdoors and getting exposed to pollutants such as ozone. This self-defensive attitude may lead to a decreasing effect of temperature on the dependent variable. With the aim of further investigating this issue, a quadratic term for temperature is included in the model.

Dummy variables have been a common way to avoid the problems associated with the presence of seasonality in morbidity to identify seasonal behavior of morbidity. One modeling option useful to separate seasonality is the inclusion of dummy variables that account for the different relevant periods (seasons). Bogotá is located in the tropics and therefore it is very difficult to clearly divide the year in seasons, as it has been done in several studies for the U.S.A and Canada. Four dummy variables are created in this article; one accounting for each quarter of the year, as an attempt to identify some pattern of seasonality in Bogotá.

The pollutants covered in this study are PM10, NO_2, and O_3. SO_2 is not included in this study because for the year analyzed most of the monitoring stations did not have measures for this pollutant for the second part of the year. Although the possibility of including CO was considered, the relationship between this pollutant and health outcomes is left to future research; CO is related with heart diseases rather than with respiratory illnesses, which are the main concern of this article.

In order to determine the relevance of the pollutants selected for this study, the first step will be to estimate what will be referred to as single *pollutant models*. In this first step, for exploratory purposes models will be run that relate the dependent variable to only one of the air pollutants here examined. In this case the weather variables and seasonal dummy variables will still be included in the model. After a series of exercises of this type, the full model will be estimated.

III. Pollution Levels in Bogotá

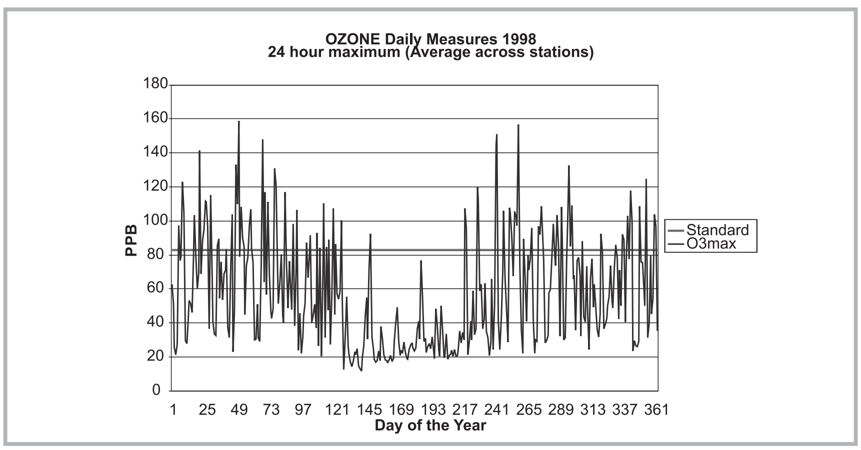
Table 1 describes the pollutants of interest for this study measured by the monitoring stations in Bogotá, showing their mean, maximum and minimum values, as well as the standards that those pollutants must satisfy. For this study maximum daily values for all stations were used to obtain a citywide average for Bogotá. Basic statistics for the measures taken by monitoring stations in Bogotá are presented in Table 1.

Table 1. Basic Statistics of Pollutants and Climate Measures.

Pollutant (Max value in 24 hours)	Units of Measure	Standard Imposed by Regulation	Mean	Standard Deviation	Minimum	Maximum
PM-10	mg/m^3	0.170	0.113	0.031	0.054	0.204
NO_2	Ppb	121	35.75	15.16	11.87	89.26
O_3	Ppb	65	57.38	32.24	11.90	158.95
RAIN	cm^3	——	3.12	5.66	0	43.83
TEMP	ºC	——	13.25	1.01	10.48	16.08

A first glance at Table 1 shows that two out of the four pollutants included in this study, were above the standard imposed by the law in at least one occasion during 1998. Graphs 1 through 4 depict the behavior of the pollutants throughout the year. For the case of ozone it is clear from the average throughout stations of maximum daily values that ozone levels were above the standard in several occasions. See Graph 1.

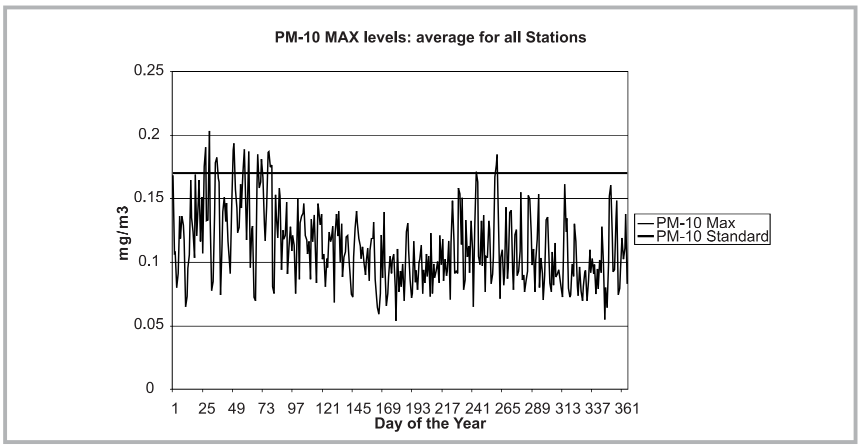
Graph1.



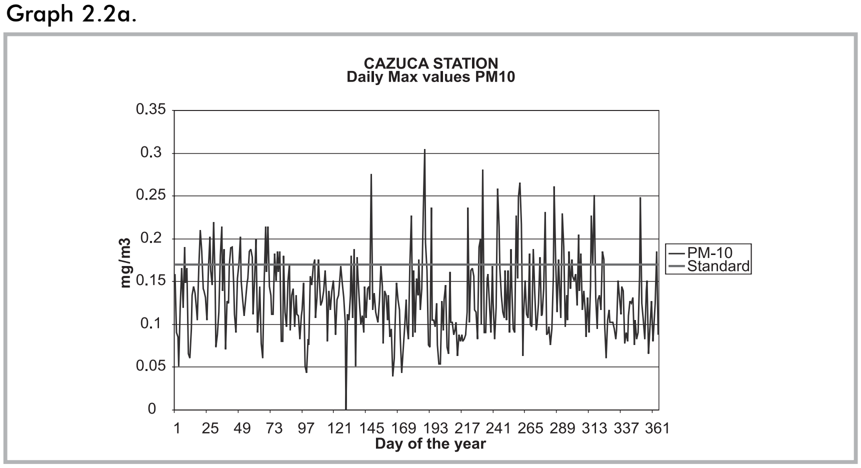
For the other pollutants it might also be interesting to look at the pollutant levels at individual stations before averaging the values across the city in order to confirm that the standard was violated more than once. For example, in the case of particles, when looking at the average across stations we see that indeed some of the daily measures are above the standard, as shown in Graph 2.1.

The violation of the standard can be seen more clearly if we look at each monitoring station separately. Graphs 2.2a and 2.2b show the daily average of hourly maximum values for two monitoring stations where the standard is violated.

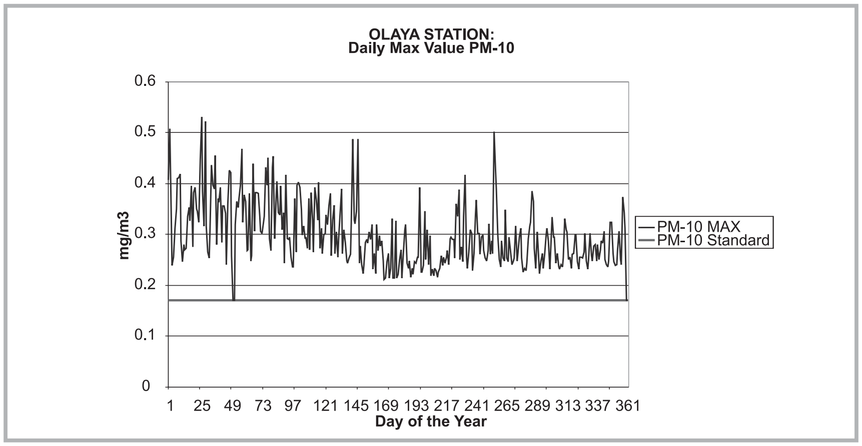
Graph 2.1.



Graph 2.2a.

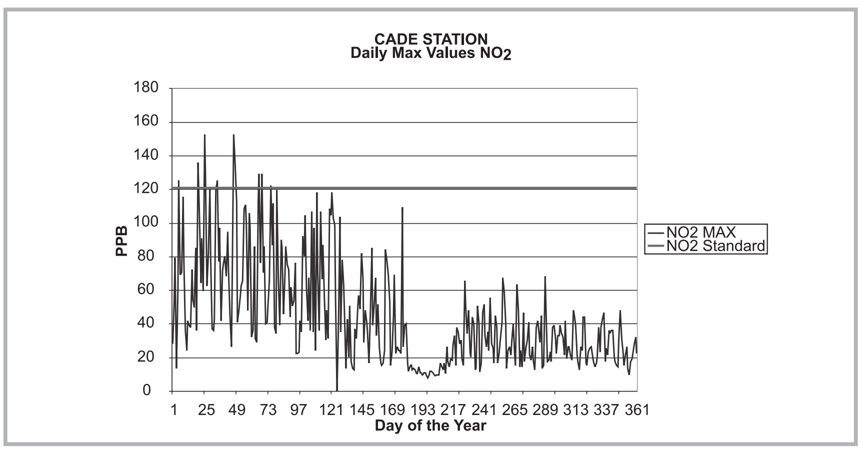


Graph 2.2b.



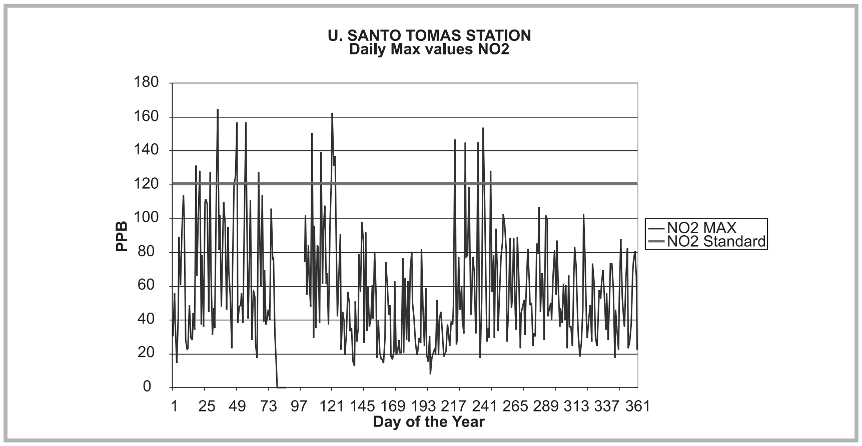
Similarly, looking back at Table 1 the reader would be tempted to conclude that there were no violations of the standard for the case of NO_2 during 1998. Nevertheless, a more careful look at the values per station would suggest a different conclusion. As an example, Graphs 3.1a and 3.1b show the level of nitrogen dioxide at two monitoring stations, which is certainly above the standard in several occasions.

Graph 3.1a.



Finally, there is sulfur dioxide, which is excluded from the model due to the poor quality of the data; for several stations there were no measures for the second half of the year.

Graph 3.1b.



In order to better understand the behavior of the pollutants that are included in this study, Tables 2.1 through 2.4 presents descriptive statistics of the variables included in the model, showing their behavior in each quarter of the year separately.

Table 2.1. Descriptive Statistics of Pollution Measures: First Quarter of the Year.

Pollutant (Max value in 24 hours)	Units of Measure	Mean	Standard Deviation	Minimum	Maximum
PM-10	mg/m^3	0.136	0.035	0.065	0.204
NO_2	Ppb	45.15	17.25	12.41	89.27
O_3	Ppb	72.30	32.01	21.50	158.95
RAIN	cm^3	2.13	5.56	0	38.32
TEMP	ºC	13.74	0.922	10.91	15.22

Table 2.2. Descriptive Statistics of Pollution Measures: Second Quarter of the Year.

Pollutant (Max value in 24 hours)	Units of Measure	Mean	Standard Deviation	Minimum	Maximum
PM-10	mg/m^3	0.108	0.023	0.054	0.149
NO_2	Ppb	34.30	14.90	11.87	71.38
O_3	Ppb	41.61	26.78	11.90	110.41
RAIN	cm^3	3.68	6.77	0	43.83
TEMP	ºC	13.96	0.858	11.85	16.09

Table 2.3. Descriptive Statistics of Pollution Measures: Third Quarter of the Year.

Pollutant (Max value in 24 hours)	Units of Measure	Mean	Standard Deviation	Minimum	Maximum
PM-10	mg/m^3	0.106	0.027	0.065	0.185
NO_2	Ppb	32.42	14.38	13.30	77.48
O_3	Ppb	50.56	33.32	18.71	156.49
RAIN	cm^3	2.36	4.17	0	20.96
TEMP	ºC	12.58	0.643	11.09	13.97

Table 2.4. Descriptive Statistics of Pollution Measures: Fourth Quarter of the Year.

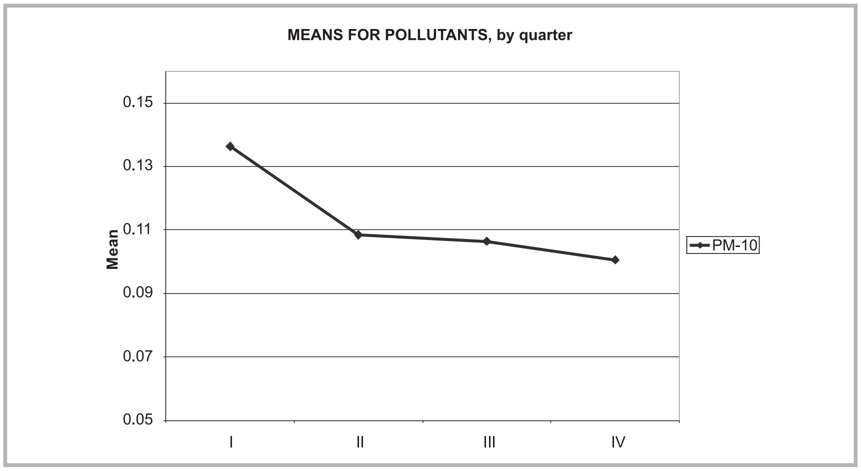
Pollutant (Max value in 24 hours)	Units of Measure	Mean	Standard Deviation	Minimum	Maximum
PM-10	mg/m^3	0.1006	0.025	0.055	0.162
NO_2	Ppb	31.32	9.03	16.76	53.40
O_3	Ppb	65.20	27.55	23.37	132.65
RAIN	cm^3	4.31	5.64	0	22.58
TEMP	ºC	12.74	0.828	10.48	15.32

From Tables 2.1 through 2.4 it is clear that on average the highest levels of pollutants are seen in the first quarter of the year, but no dramatic changes are observed from the second to the fourth quarter, except perhaps for ozone. Graph 4 depicts the behavior of the means of all pollutants in the different quarters of the year.

It looks as if nitrogen dioxide and particles share a similar behavior throughout the year, showing the higher values at the first quarter and then decreasing as the year goes on. On the other hand, ozone shows a different behavior, with its lower levels occurring during the second quarter of the year. Using a different measure of the pollutants daily value, such as the average throughout stations of the daily average rather than of the daily maximum, would obscure important information by reducing the variability in the pollutants' readings. Since standards are defined for any one measure it is more accurate to look for violations to the standards by looking at the highest pollution measure of each day instead of looking just at averages.

The dependent variable in the econometric model is the number of respiratory admissions per day in Bogotá. It is described in Table 3 and will be referred hereafter as *count*.

Graph 4.



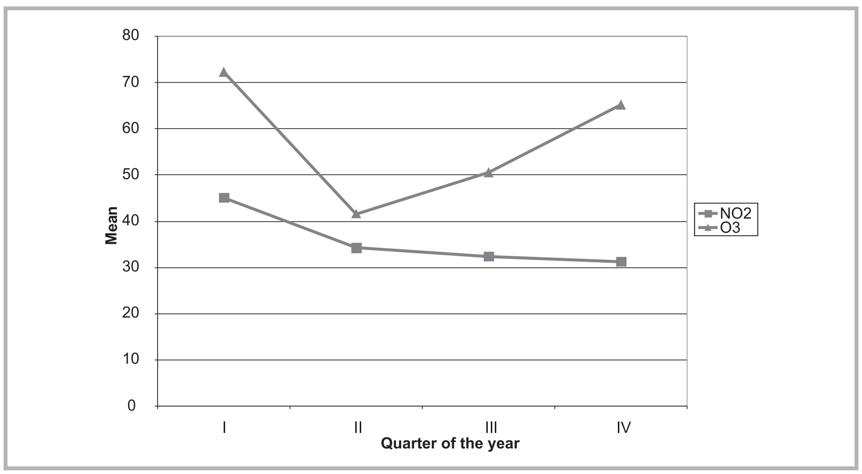


Table 3. Basic Statistic for RHA.

Daily RHA	Mean	Standard Deviation	Minimum	Maximum
Count	112.405	558.0207	209	3335
Count (males)	415.4767	199.2339	78	1201
Count (females)	696.6301	360.4465	116	2134
Count (ages 0-6)	257.0438	134.4673	43	966
Count (ages 7-17)	185.1945	97.39358	22	585
Count (ages 17-34)	325.7616	150.3889	72	948
Count (ages 35-50)	159.3397	85.99064	19	511
Count (ages 51-65)	92.89041	62.46427	5	480

The large average for daily respiratory hospital admissions leads us to the decision of estimating a semi-log function of the model rather than leaning towards a Poisson specification.

IV. Results

Single pollutant models were estimated for the following pollutants: PM_{10}, NO_2, and O_3. The results for the OLS semi-log regressions using as dependent variable the logarithm of daily respiratory hospital admissions are presented in Table 4.

Table 4. Single Pollutant Models.

	Model I PM-10	Model II NO_2	Model III O_3
Constant	-2.7842 (3.9951)	0.3929 (4.0712)	1.6435 (4.3639)
Rain	-0.02123 (0.00105)**	-0.0323 (0.0108)***	-0.0296 (0.0119)**
Rain 2	0.0006 (0.00038)	0.0008 (0.0003)***	0.0008 (0.0004)**
Temperature	1.2341 (0.6018)**	0.7989 (0.6145)	0.6622 (0.6583)
Temperature2	-0.0431 (0.0226)*	-0.0258 (0.0231)	-0.0202 (0.0247)
Pollutant	8.3202 (0.9522)***	0.0143 (0.0019)***	0.0012 (0.001)
R^2	0.2227	0.1792	0.0616
Adjusted R^2	0.2118	0.1677	0.0485

*** Significant at the 1% level
** Significant at the 5% level
* Significant at the 10% level

It is suggested in the literature that the relationship between temperature and health outcomes might not be linear but rather a "U-shaped" one. This means that higher mortality would be seen in extremely high and low temperatures[16]. Rain may be associated in a quadratic function with the

16 THURSTON, G.D. and ITO, Kazuhiko (1999).

dependent variable. Table 4 shows that this relationship is only confirmed for rain accumulation in the model for nitrogen dioxide, but not for temperature measured in Celsius degrees. As mentioned above, rain acts as a cleaning device that helps to clean the air from pollutants. Extremely high levels of rain however will also be associated with high morbidity. For the three models presented above, the sign for temperature coefficients is contrary to this hypothesis. At any rate the coefficients on temperature and temperature square are insignificant in the NO_2 and O_3 equations. As reported in Table 1, the maximum value of daily hourly measures for temperatures in Bogotá is 16.08 while the minimum value is 10.48, with the standard deviation being 1.01. The small variation in temperature throughout the year might explain the fact that temperature seems to be not significant for pollutant models in Bogotá. Studies are conducted usually in the U.S., Canada or if it is in South America, in Chile. All of these countries experience seasons and therefore temperature varies very much throughout the year. These differences may explain the results obtained for Bogotá. The coefficients for the pollutants show the expected positive sign; as pollution increases more people tend to visit the hospital with respiratory illnesses and symptoms. For the case of particles and nitrogen dioxide, the coefficients show to be highly significant, confirming the strong relation between air pollution and human morbidity. On the other hand, for the case of ozone the coefficient for the pollutant is not significant. Several problems arise when modeling ozone's effect on health. Ozone is usually moderately to strongly associated with ambient temperature; ozone tends to show peak concentrations on high temperature days, when many of O_3 precursors are emitted at higher rates and their conversion to ozone is faster. Therefore, it has been a concern in previous papers that if inadequately addressed, correlation between temperature and this pollutant might confound the evaluation of the effect of ozone on human health. Other studies have found correlations for ozone and temperature ranging from 0.06 to 0.90 (Us EPA 1996). For Bogotá, the correlation between these two is -0.0714, which is not only lower than the lower bound value from other studies, but also negative rather than positive. This might suggest that the relation between these two variables for Bogotá is different from that suggested at other locations, and it might be necessary to account for other factors that are beyond the scope of this study.

A linear relationship was also considered between the meteorological variables and health endpoint, but although the signs of the coefficients were consistent with the model reported in Table 4, the effect of ozone was still not significant. It is also important to consider that ozone is a reactive pollutant and therefore its indoor concentrations are much lower than those outdoors; given the greater amount of time spent by most people indoors, personal ozone exposures tend to be more related to indoor ozone concentrations than to outdoor levels. Additional collection of data would be necessary to develop an accurate model for the relation between ozone and human health; the lack of this data may present a mayor drawback for the present model. Although this study did not find a relationship between ozone and RHA, the consistent positive relation found in other locations suggests the importance of continuing to study ozone[17]. Therefore, ozone will be included in the full model only for exploratory purposes.

The full model estimated includes the same meteorological variables that were included in the single pollutant models, but now puts together all pollutants to estimate the total effect of these three pollutants on the health outcome. The results from this model are reported in Table 5.

Table 5. Full Model.

Variables	Regression Coefficients
Constant	-1.2354 (3.8439)
Rain	-0.0069 (0.0106)
Rain ^{2}	0.00013 (0.00038)
Temperature	1.0191 (0.5788)*
Temperature^2	-0.0357 (0.2179)
PM-10	7.9119 (1.4609)***
NO_2	0.0116 (0.0032)***
O_3	-0.0069 (0.0012)***
R^2	0.2912
Adjusted R^2	0.2773

*** Significant at the 1% level
** Significant at the 5% level
* Significant at the 10% level

17 *Ibid.*; SCHLESINGER (1999).

In the full model the meteorological variables lose significance but the pollutants seem to be very significant. The coefficients for particles and nitrogen dioxide are positive and of similar magnitude to those from the single pollutant models. On the other hand, the coefficient of ozone is negative for the full model. It is suspected that this stems from the high correlation between ozone and particles. In order to explore more about the reasons for this behavior, a model was constructed in which the residuals from a regression of ozone on particles were included on the full model instead of ozone. The results from this model stay in the same line as those from the full model. The effect of particles on daily respiratory hospital admissions remains strongly significant, and of very similar magnitude as for previously mentioned models. On the other hand, the effect of ozone is negative and significant at the 1% level. This would confirm what was mentioned above about the problems related to ozone measures and would also agree with the conclusion that further research and data collection need to be done in order to accurately measure the effects of ozone on the health outcome.

In an effort to account for the interaction between pollutants, additional models were estimated that included an interaction term for particles and ozone. In these models the coefficients are similar in significance and magnitude to those shown in Table 5, the interaction term being insignificant. Furthermore, several alternative econometric models were specified. A first alternative model included a dummy variable for each quarter of the year. The dummy variables were insignificant for all quarters except for the third one for the single pollutant models as well as for the full model. For the case of ozone the first, second and third quarter dummies appear to be significant at the 1% level. Colombia is a tropical country and does not experience seasons like the Northern Hemisphere, but rather has only “rainy” and a “dry” season. The difference between these “seasons” is not as big as it would be for a country like the US anyway. It is important to note that this seasonal effect, if any, is already being captured by the rain and temperature coefficients, and therefore the inclusion would be making reference to seasonality factors of the illnesses. The coefficients for other variables as well as their significance level remain very similar to the original model, confirming in this case the robustness of the model. Interaction terms between these “seasons” and the pollutants were also included in the model but were not significant in any case.

As a final step and one additional way to check how strong the results for the model are, counts were computed for men and women and by age group. When comparing results for males and females one may conclude that there is not much difference on the incidence pollutants have on the health outcome of each particular group. Nevertheless, the coefficients of pollutants for males were consistently (but only slightly) smaller than those obtained for females. For the case of age groups, the population was organized in six groups: age less than or equal to six, from 7 to 17, from 18 to 34, from 35 to 51, from 51 to 64 and 65 and over. From these regressions it is possible to conclude that the elder population faces shows a larger health response to the air pollutants included in this study, since the coefficients for these variables appear to be higher for the population over 51 years old, and in some cases also the population above 35. As an example, for the single pollutant model for particles, the effect of the pollutant on the health outcome is 7.2737 for the age group 17-34 and jumps to 9.1345 for people in the range 35-50. On the other hand, the coefficient of ozone in the single pollutant model remains insignificant. The other coefficients of the model are stable. The full model confirms these findings showing higher coefficients for people above 51. It is interesting that it is always elder people who seem to be more affected than younger cohorts. Very young children have always been identified as a population at high risk when exposed to air pollutants. Nevertheless, looking at the coefficients of the models we would be tempted to conclude that air pollution in Bogotá is affecting more the older groups rather that the younger ones. A more careful analysis would suggest looking at the predicted values for daily respiratory hospital admissions in Bogotá driven from the full model. These predicted values are shown in Table 6.1 and 6.2. In order to get an idea of the effects that increases in pollutants would have on the population, we estimated the RHA that would occur if the pollutants were to double their actual levels (third column) or if they were to increase by 25% (fourth column).

As it can be seen in Table 6.1, the conclusion above seems to be appropriate. Although the number of RHA per day seems to be higher for people between 17 and 34 years old, the increase in the health outcome that would occur in the event that particulates doubled their 1998 levels, would cause the highest effect on the health outcome of the population of ages between 51 and 64. Against what would have been expected, the youngest cohort is the less affected when the concentration levels of particles double the 1998 levels. It is interesting to note that the effect for people from 35 to 50 is also high, showing increases in the RHA of 141%. It is not only the elder group that is most affected but also younger adults, which might have important consequences when conducting a cost-benefit analysis since the effect on these younger groups –working age group, will have to be associated with productivity losses if a costs approach is taken. It is also important to note that women seem to be more affected by increases in particulate matter than men.

Table 6.1. Predicted Values RHA: Increases in average concentration of Particles.

Model	Predicted RHA	Predicted RHA (If Particles were to double)	Percentage change in RHA	Predicted RHA (If Particles increased 25%)	Percentage change in RHA
All individuals	946.52	2086.50	120.44	1153.33	21.85
Women	586.04	1364.25	132.79	723.88	23.52
Men	358.89	725.20	102.07	427.90	19.23
Ages0-6	223.63	387.22	73.15	256.53	14.71
Ages7-16	158.72	388.61	144.84	198.54	25.09
Ages17-34	283.98	556.99	96.13	336.07	18.34
Ages35-50	131.03	316.72	141.71	163.38	24.69
Ages51-64	69.83	222.01	217.93	93.25	33.53
Ages65 or more	70.34	216.46	207.73	93.16	32.45

Table 6.2. Predicted Values RHA: Decreases in Average Concentration of Particles.

Model	Predicted RHA	Predicted RHA (If Particles decreased 25%)	Percentage change in RHA	Predicted RHA (If Particles decreased 50%)	Percentage change in RHA
All individuals	946.52	776.80	17.93	637.51	32.65
Women	586.04	474.44	19.04	384.10	34.46
Men	358.89	301.02	16.13	252.48	29.65
Ages0-6	223.63	194.95	12.83	169.94	24.01
Ages7-16	158.72	126.88	20.06	101.43	36.09
Ages17-34	283.98	239.97	15.50	202.78	28.60
Ages35-50	131.03	105.09	19.80	84.28	35.68
Ages51-64	69.83	52.30	25.11	39.16	43.92
Ages65 or more	70.34	53.11	24.50	40.10	42.99

For reductions in the pollutant the effects are similar. A 25% reduction in the 1998 levels of particles would produce a decrease in RHA for the overall population of 17.9%. It is clear again that the most benefited from such a reduction would be the elder.

On the other hand, changes in Nitrogen Dioxide seem to have a smaller effect on the health outcome than changes in Particulates. For the overall population, if concentrations of NO_2 were to double, the health outcome would increase by around 12%. Similar to the previous case, women seem to be more vulnerable to changes in the pollutant concentration than men. Nevertheless, the effects of these changes on the different age groups are not in the same line as those for particles. For changes in Nitrogen Dioxide the most affected group seems to be the younger one. Children under six years old would experience an increase of around 24.51% when the concentrations of NO_2 reach levels that duplicate those of 1998. While most of the cohorts experience changes of around 12% when this pollutant changes by 25%, children under six years old would experience an increase of 24.51% in the daily respiratory hospital admissions in Bogotá. A similar analysis may be done for reductions of 25% and 50% in the 1998 levels of Nitrogen Dioxide.

Table 6.3. Predicted Values RHA: Increases in Concentration of Nitrogen Dioxide.

Model	Predicted RHA	Predicted RHA (If Nitrogen Dioxide were to double)	Percentage change in RHA	Predicted RHA (If NO_2 increased 25%)	Percentage change in RHA
All individuals	946.52	1068.36	12.87	975.61	3.07
Women	586.04	660.64	12.73	603.86	3.04
Men	358.89	407.41	13.52	370.45	3.22
Age 0-6	223.63	278.43	24.51	236.22	5.63
Age 7-16	158.72	179.97	13.39	163.78	3.19
Age 17-34	283.98	320.20	12.75	292.63	3.05
Age 35-50	131.03	147.87	12.85	135.05	3.07
Age 51-64	69.83	76.53	9.59	71.45	2.32
Ages 65 or more	70.34	75.42	7.22	71.58	1.76

Table 6.4. Predicted Values RHA: Decreases in Concentration of Nitrogen Dioxide.

Model	Predicted RHA	Predicted RHA (If NO_2 decreased 25%)	Percentage change in RHA	Predicted RHA (If Nitrogen Dioxide decreased 50%)	Percentage change in RHA
All individuals	946.52	918.30	-2.98	890.92	-5.87
Women	586.04	568.74	-2.95	551.96	-5.82
Men	358.89	347.70	-3.12	336.85	-6.14
Ages0-6	223.63	211.70	-5.33	200.41	-10.38
Ages7-16	158.72	153.81	-3.09	149.05	-6.09
Ages17-34	283.98	275.59	-2.96	267.44	-5.83
Ages35-50	131.03	127.13	-2.98	123.35	-5.87
Ages51-64	69.83	68.25	-2.26	66.71	-4.48
Ages65 or more	70.34	69.13	-1.73	67.93	-3.42

Eskeland et al. 1998 state that reducing by around 50% the levels of particulates will reduce the number of respiratory hospital admissions by 2,500 cases a year.

V. Conclusions

Air pollution is a concern not only in Bogotá but also in most developing countries. The increasing pollution in large cities has led to changes in local government policies, such as taxes for emissions, restrictions to the use of motor vehicles, and several economic incentives to reduce the amount of air pollution. The health effects of this type of pollution have also become a concern since it has been proved that pollutants such as particulates, ozone, and nitrogen dioxide have hazardous effects on human health. This article has shown that for the case of Bogotá it is true that air pollutants show a relationship with the number of daily respiratory hospital admissions. For the cases of Particulates and Nitrogen Dioxide the relationship is clear, positive and significant in all the models developed. For Particulates, the coefficient stays between 7 and 9, depending on the model. Eskeland et al. 1998 obtained coefficients between 4.9 and 6.6, for PM-10 in the city of Santiago depending on the age group analyzed and the type of clinical visit. This study looked only at children under 15 years of age. The results for Bogotá show a slightly larger effect of particles on the health outcome. On the other hand, several studies such as Erbas et al. 2000, report coefficients of around 0.01 and 0.02 for nitrogen dioxide when defining RHA as the dependent variable for the city of Victoria, Australia. These are very similar to the effects for NO_2 found for the health outcome in Bogotá confirming the robustness of the model here presented. Finally, it is clear that in order to clearly define a relationship between ozone and health in Bogotá it is essential to gather additional information. Looking back at Graph 1 we can say that filling this information gap is essential since ozone seems to violate the safety levels several times throughout the year. Conducting further analysis on ozone and the hazards that it may imply for Bogotá's habitants should be a priority.

The result for groups of different ages is interesting; older people seem to be more affected by changes in particulate matter while younger cohorts seem to suffer more from increases in nitrogen dioxide. For the case of particles it is important to remember that it is not only the elder who are highly affected but also people over 35. This might be very useful when calculating the costs of air pollution in Bogotá, since different ages must be associated with different costs. For example, effects on people between 35 and 50 years old have to be associated with loss of productivity, while costs of people over 65 will be mostly associated with medical expenses. This is an important part of the analysis that is out of the scope of this article and will be left for future studies. Nevertheless, a first approximation to the cost analysis could be pursued using costs estimated by other authors and locations, and adjusting this value by Colombia's GDP per capita.

Different studies have used several methods in order to give monetary value to the effects of air pollution on human morbidity. A first approach is the one that establishes the willingness to pay for avoiding morbidity effects; there is also the cost of illness approach that estimates the economic costs of health and losses of output during the illness episode.

For a first and quick approximation to the costs that air pollution implies for Bogotá, this study will make reference to WTP values estimated for the U.S. The values from Cropper and Krupnic (1990) and Lvovsky et al. (2000) were used to obtain equivalent values for the city of Bogotá. The values, reported in 1990 U.S., were converted to 1995 U.S. dollars and then multiplied by the relation between Colombia's and the U.S.'s GDP per capita, also in 1995 US dollars. These gave values of US$629 and US$410 for the two studies respectively[18]. These correspond to the value of a Respiratory Hospital Admission in Bogotá. Using these estimates of the WTP and the values presented in Tables 6.2 and 6.4 the daily costs avoided from reducing particulates 1998 measures by 50% are between US$ 127,000 and US$ 194,000 depending on which study is used[19]. In a year, this means that the daily costs avoided add up to almost US$ 46 million dollars, which is around 18% of the 2004 budget of the Secretary of Health of Bogotá. Therefore, reduction of air pollution should be considered a priority by environmental as well as health authorities. Developing incentives to reduce the use of cars and promoting alternatives such as car-pooling and the use of bicycles must be a main objective in the agenda of local authorities.

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18 See Annex 1, Table A9.

19 See Annex 1, Table A10 for detailed values.

It is important to note that the cost estimates shown above are given for the whole sample and no distinctions were made between sexes or age groups. As it was noted before, in order to accurately estimate the costs or benefits associated with morbidity, it would be necessary to do an analysis that would account for these differences and therefore assign different values to the RHA of each group. This study suggests that cost-benefits analysis of reducing particulate matter should concentrate on the effects on adults over 35 while a similar analysis of the effects of reducing nitrogen dioxide should put more emphasis on the younger cohort. Thus, the costs and benefits of any policy would be calculated more accurately and the target population for each policy can be clearly defined.

Several points must be kept in mind when looking at the results of this study. First, even though the results seemed to suggest that the health response for elderly is larger than for young children it is hard to interpret such difference in coefficients since they may be caused by sources other than air pollution. For example, this study does not account for the population distribution so differences in coefficients might be related to differences in the size of the population age -groups rather than in health effects; on the other hand since hospital admission data suffers from selectivity bias it might also be the case that differences in coefficients are driven by differences in access to health services rather than by different effects from air pollution. A future study should take these into account both by looking at age-adjusted rates rather than counts as well as by accounting for selectivity bias in the estimation methods.

Finally, the spatial dimension has been ignored in this article by averaging pollution levels for the whole city and ignoring the fact that people who live or work in different places are exposed to different pollution levels. At the time this paper was written the data for such analysis was not available. Future studies should make an effort to consider this important dimension of the problem.

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Annex 1

Table A1. Full Model Including Residuals from Regressing Ozone on Particulates.

Dependent Variable: Particles	Coefficient
Particles	558.0 (46.6764)***
Constant	-5.5957 (5.4586)
R^2	0.2825

The residuals from this model are called e1.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0069 ((0.0106)
Temperature	1.0191 (0.5788)*
Particles	4.0374 (1.5410)***
Nitrogen Dioxide	0.0116 (0.0032)***
e1	-0.0069 (0.0012)***
$Rain^2$	0.0001 (0.0003)
$Temperature^2$	-0.0357 (0.0217)
Constant	-1.1965 (3.8442)
R^2	0.2912

Table A2. Interaction between part and ozone.

Dependent Variable: Log(RHA)	**Coefficient**
Rain	-0.0071
Temperature	(0.0107) 1.0272
Particles	(0.5824)** 8.1586
Nitrogen dioxide	(2.2820)*** 0.0116
Ozone	(0.0116)*** -0.0064
$Rain^2$	(0.0035)** 0.0001
$Temperature^2$	(0.0003) -0.0360
Interaccion	(0.0219) -0.0038
Term (Oxone*Particles)	(0.0271)
Constant	-1.3154 (3.8909)
R^2	0.2912

Table A3. Dummy Variables Full Model.

Dependent Variable: Log(RHA)	**Coefficient**
Rain	-0.0097 (0.0107)
Temperature	0.9900 (0.5720)*
Particles	8.3082 (1.4714)***
Nitrogen dioxide	0.0121 (0.0032)***
Ozone	-0.0063 (0.0012)***
$Rain^2$	0.0002 (0.0003)
$Temperature^2$	-0.0326 (0.0216)
T 1	-0.1286 (0.0942)
T 2	-0.0084 (0.0945)
T 3	0.2222 (0.0794)***
Constant	-1.5075 (3.7955)
R^2	0.3226

Table A4. Dummy Variables: Single Pollutant Models.

Particles.

Variable: Log(RHA)	Coefficient
Rain	-0.0197
Temperature	(0.0105)* 1.2715
Particles	(0.5878)** 9.2557
$Rain^2$	(1.0267)** 0.0005
$Temperature^2$	(0.0003) -0.0436
T 1	(0.0221)** -0.0448
T 2	(0.0958) 0.1762
T 3	(0.0904)* 0.3101
Constant	(0.0799)*** 0.3391 (3.9832)
R^2	0.2717

Nitrogen Dioxide.

Dependent Variable: Log(RHA)	COEFFICIENT
Rain	-0.0297 (0.0109)***
Temperature	0.7557 (0.6020)
Nitrogen dioxide	9.2557 (1.0267)***
$Rain^2$	0.0007 (0.0003)**
$Temperature^2$	-0.0233 (0.0227)
T 1	0.0290 (0.0978)
T 2	0.1612 (0.0938)*
T 3	0.3379 (0.0823)***
Constant	0.3391 (3.9832)
R^2	0.2237

Ozone.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0227 (0.0120)*
Temperature	0.6743 (0.6458)
Ozone	0.0018 (0.0010)*
$Rain^2$	0.0006 (0.0004)
$Temperature^2$	-0.0212 (0.0243)
T 1	0.2682 (0.0984)***
T 2	0.2900 (0.1013)***
T 3	0.3881 (0.0887)***
Constant	1.3771 (4.2753)
R^2	0.1132

Table A5. Single Pollutant Models Males vs. Females.

Particulates: Females.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0223 (0.0111)**
Temperature	1.2515 (0.6345)**
Particles	8.7897 (1.0039)***
$Rain^2$	0.0006 (0.0004)
$Temperature^2$	-0.0439 (0.02389)**
Constant	-3.4031 (4.2120)
R^2	0.2076

Particulates: Males.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0197 (0.0097)**
Temperature	1.2163 (0.5572)
Particles	7.611 (0.8816)**
$Rain^2$	0.0005 (0.0003)
$Temperature^2$	-0.0421 (0.0209)***
Constant	-3.6002 (3.6990)
R^2	0.2278

Nitrogen Dioxide: Females.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0339 (0.0114)***
Temperature	0.7905 (0.6485)
Nitrogen dioxide	0.0150 (0.0020)***
$Rain^2$	0.0008 (0.0004)**
$Temperature^2$	-0.0256 (0.0244)
Constant	-0.0356 (4.2965)
R^2	0.1731

Nitrogen Dioxide: Males.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0299 (0.010)***
Temperature	0.8207 (0.5675)
Nitrogen Dioxide	0.0132 (0.0018)***
$Rain^2$	0.0007 (0.0003)**
$Temperature^2$	-0.0265 (0.0213)
Constant	-0.7154 (3.7597)
R^2	0.1888

Ozone: Females.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0314 (0.0215)**
Temperature	0.6500 (0.6942)
Ozone	0.0014 (0.0010)
$Rain^2$	0.0008 (0.0004)*
$Temperature^2$	-0.0199 (0.0261)
Constant	1.2530 (4.6016)
R^2	0.0562

Ozone: Males.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0272 (0.0110)**
Temperature	0.6888 (0.6085)
Ozone	0.0010 (0.0009)
$Rain^2$	0.0007 (0.0004)*
$Temperature^2$	-0.0211 (0.0228)
Constant	-0.7154 (3.7597)
R^2	0.0710

Table A6. Full model: Male vs. Female.

Females.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0074 (0.0112)
Temperature	1.0313 (0.6113)*
Particles	8.4270 (1.5431)***
Nitrogen dioxide	0.0119 (0.0034)***
Ozone	-0.0071 (0.0012)***
$Rain^2$	0.0001 (0.0004)
$Temperature^2$	-0.0363 (0.0230)
Constant	-1.8163 (4.0602)
R^2	0.2847

Males.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0063 (0.0098)
Temperature	1.0067 (0.5342)*
Particles	7.0965 (1.3484)***
Nitrogen dioxide	0.0114 (0.0029)***
Ozone	-0.0066 (0.0011)***
$Rain^2$	0.0001 (0.0003)
$Temperature^2$	-0.0349 (0.0201)*
Constant	-2.0919 (3.5479)
R^2	0.3003

Table A7. Single Pollutant Models: By Age Group.

Particles: Ages 0-6.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0223 (0.0098)**
Temperature	1.2489 (0.5608)**
Particles	7.2471 (0.8873)***
$Rain^2$	0.0006 (0.0003)*
$Temperature^2$	-0.0426 (0.0211)**
Constant	-4.3852 (3.7230)
R^2	0.2185

Particles: Ages 7-16.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0300 (0.0112)***
Temperature	1.6543 (0.6411)***
Particles	9.300 (1.0144)***
$Rain^2$	0.0008 (0.0004)*
$Temperature^2$	-0.0596 (0.0241)**
Constant	-7.3349 (4.2562))**
R^2	0.2343

Particles: Ages 17-34.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0196 (0.0095)**
Temperature	1.6543 (0.6411)**
Particles	7.2737 (0.8630)***
$Rain^2$	0.0005 (0.0003)
$Temperature^2$	-0.0465 (0.0205)**
Constant	-7.3349 (4.2562))
R^2	0.2033

Particles: Ages 35-50.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0229 (0.0121)*
Temperature	1.1519 (0.6921)*
Particles	9.1345 (1.0950))***
$Rain^2$	0.0006 (0.0004)
$Temperature^2$	-0.0397 (0.0260)
Constant	-7.3349 (4.2562))**
R^2	0.2047

Particles: Ages 51-64.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0192 (0.0142)
Temperature	1.2562 (0.8134)
Particles	11.2446 (1.2869)***
$Rain^2$	0.0006 (0.0005)
$Temperature^2$	-0.0451 (0.0306)
Constant	-6.0119 (5.3993)
R^2	0.2124

Particles: Ages 65 and over.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0206 (0.0141)
Temperature	1.0419 (0.8091)
Particles	10.7176 (1.2802)***
$Rain^2$	0.0006 (0.0005)
$Temperature^2$	-0.0357 (0.0304)
Constant	-4.4076 (5.3714)
R^2	0.1948

Nitrogen Dioxide: Ages 0-6.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0325 (0.0099)***
Temperature	0.8874 (0.5628)
Nitrogen Dioxide	0.0137 (0.0017)***
$Rain^2$	0.0008 (0.0003)***
$Temperature^2$	-0.0283 (0.0211)
Constant	-1.7718 (3.7287)
R^2	0.2138

Nitrogen Dioxide: Ages 7-16.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0424 (0.0116)***
Temperature	1.1663 (0.6571)*
Nitrogen Dioxide	0.0158 (0.0020)***
$Rain^2$	0.0010 (0.0004)***
$Temperature^2$	-0.0403 (0.0247)
Constant	-3.7703 (4.3536)
R^2	0.1854

Nitrogen Dioxide: Ages 17-34.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0294 (0.0098)***
Temperature	0.9192 (0.5550)*
Nitrogen Dioxide	0.0126 (0.0017)***
$Rain^2$	0.0007 (0.0003)**
$Temperature^2$	-0.0316 (0.0208)
Constant	-1.3341 (3.6768)
R^2	0.1648

Nitrogen Dioxide: Ages 35-50.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0350 (0.0124)***
Temperature	0.6722 (0.7058)
Nitrogen dioxide	0.0155 (0.0022)***
$Rain^2$	0.0009 (0.0004)**
$Temperature^2$	-0.0208 (0.0265)
Constant	-0.8487 (4.6760)
R^2	0.1623

Nitrogen Dioxide: Ages 51-64.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0339 (0.0147)**
Temperature	0.6569 (0.8354)
Nitrogen Dioxide	0.0185 (0.0026)***
$Rain^2$	0.0009 (0.0005)*
$Temperature^2$	-0.0194 (0.0314)
Constant	-1.6204 (5.5349)
R^2	0.1584

Nitrogen Dioxide: Ages 65 and over.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0345 (0.0146)**
Temperature	0.4679 (0.8300)
Nitrogen Dioxide	0.0174 (0.0026)***
$Rain^2$	0.0009 (0.0005)*
$Temperature^2$	-0.0130 (0.0312)
Constant	-0.1980 (5.4992)
R^2	0.1418

Ozone: Ages 0-6.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0295 (0.0110)***
Temperature	0.7479 (0.6069)
Ozone	0.001 (0.0009)
$Rain^2$	0.0008 (0.0004)**
$Temperature^2$	-0.0226 (0.0228)
Constant	-0.5062 (4.0231)
R^2	0.0893

Ozone: Ages 7-16.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0402 (0.0128)***
Temperature	1.0284 (0.7067)
Ozone	0.0017 (0.0010)
$Rain^2$	0.0011 (0.0004)**
$Temperature^2$	-0.0346 (0.0265)
Constant	-2.4915 (4.6846)
R^2	0.0614

Ozone: Ages 17-34.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0267 (0.0107)**
Temperature	0.7918 (0.5934)
Ozone	0.0010 (0.0009)
$Rain^2$	0.0007 (0.0003)*
$Temperature^2$	-0.0264 (0.0223)
Constant	-0.1770 (3.9332)
R^2	0.0490

Ozone: Ages 35-50.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0323 (0. 0136)**
Temperature	0.5251 (0.7512)
Ozone	0.0014 (0.0011)
$Rain^2$	0.0009 (0.0004)*
$Temperature^2$	-0.0147 (0.0282)
Constant	0.4992 (4.9797)
R^2	0.0546

Ozone: Ages 51-64.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0316 (0.0161)**
Temperature	0.5003 (0.8889)
Ozone	0.0020 (0.0013)
$Rain^2$	0.009 (0.0005)*
$Temperature^2$	-0.0128 (0.0334
Constant	0.01622 (5.8920)
R^2	0.0510

Ozone: Ages 65 and over.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0317 (0.0159)**
Temperature	0.3096 (0.8787)
Ozone	0.0017 (0.0013)
$Rain^2$	0.0009 (0.0005)*
$Temperature^2$	-0.0064 (0.0330)
Constant	1.2607 (5.8244)
R^2	0.0421

Table A8. Full Models: By Age Group.

Ages 0-6.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0102 (0.0098)
Temperature	0.9941 (0.5338)**
Particles	5.7544 (1.3474)***
Nitrogen Dioxide	0.0142 (0.0029)***
Ozone	-0.0068 (0.0011)***
$Rain^2$	0.0001 (0.0003)
$Temperature^2$	-0.0337 (0.0201)*
Constant	-2.5647 (3.5454)
R^2	0.3115

Ages 7-16.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0152 (0.0114)
Temperature	1.4311 (0.6181)**
Particles	8.8767 (1.5602)***
Nitrogen Dioxide	0.0121 (0.0034)***
Ozone	-0.0072 (0.0012)***
$Rain^2$	0.0003 (0.0004)
$Temperature^2$	-0.0520 (0.0232)**
Constant	-5.7275 (4.1052)
R^2	0.2984

Ages 17-34.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0067 (0.0096)
Temperature	1.0965 (0.5238)**
Particles	6.8007 (1.3222)***
Nitrogen Dioxide	0.0109 (0.0029)***
Ozone	-0.0063 (0.0010)***
$Rain^2$	0.0001 (0.0003)
$Temperature^2$	-0.0396 (0.0197)**
Constant	-2.6460 (3.4791)
R^2	0.2756

Ages 35-50.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0073 (0.0123)
Temperature	0.9374 (0.6694)
Particles	88.8028 (1.6896)***
Nitrogen Dioxide	0.0123 (0.0037)***
Ozone	-0.0075 (0.0013)***
$Rain^2$	0.0001 (0.0004)
$Temperature^2$	-0.0319 (0.0252)
Constant	-2.7077 (4.4458)
R^2	0.2665

Ages 51-64.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0011 (0.0145)
Temperature	1.0216 (0.7908)
Particles	11.3392 (1.9961)***
Nitrogen Dioxide	0.0125 (0.0044)***
Ozone	-0.0083 (0.0016)***
$Rain^2$	0.00005 (0.0005)
$Temperature^2$	-0.0352 (0.0297)
Constant	-4.3141 (5.2522)
R^2	0.2659

Ages 65 and more.

Dependent Variable: Log(RHA)	Coefficient
Rain	-0.0022 (0.0145)
Temperature	0.8181 (0.7870)
Particles	11.0432 (1.9864)***
Nitrogen Dioxide	0.0118 (0.0044)***
Ozone	-0.0082 (0.0016)***
$Rain^2$	0.00006 (0.0005)
$Temperature^2$	-0.0282 (0.0296)
Constant	-2.7849 (5.2267)
R^2	0.2491

Table A9. Economic Values for a Respiratory Hospital Admission.

	WTP for the US (1995 US dollars)	WTP for Colombia (1995 US dollars)
Cropper and Krupnic (1990)	7874	628
Lvovsky et al. (2000)	5141	410

Table A10. Daily Costs Avoided by Reduction in Pollutants

	Cost Avoided from a 25% reduction in Particles	Cost Avoided from a 50% reduction in Particles	Cost Avoided from a 25% reduction in NO2	Cost Avoided from a 50% reduction in NO2
Total Costs Avoided (C&K) (US$ 1995)	107,000	194,000	18,000	35,000
Total Costs Avoided (L. et al) (US$ 1995)	70,000	127,000	11,600	23,000