AIR POLLUTION IN BOGOTÁ, COLOMBIA:
A Concentration-Response Approach

Air pollution has become one of the most important concerns of the 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 won't concentrate on the estimation of the costs but rather will motivate further work on this area by giving the first input needed for that type of analysis.

I. 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 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

---

[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

[3] CAVALLAZI, Marcelo. "Contaminación Atmosférica en Bogotá" *Revista Cámara de Comercio de Bogotá* No. 97 (Sept. 96)

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 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 1996 around 14% of the visits to the hospitals were related to respiratory problems. The evidence is even stronger for the infant population where 30% of the visits to the hospitals were associated with Acute Respiratory Illnesses (ARI).

---

[4] Ibid.

[5] Bleviss, Deborha Lynn (1999)

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 weigh 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 paper does not concentrate on the benefit-cost analysis but gives a first step towards this final objective by estimating a concentration-response function for several pollutants using information available for Bogotá, Colombia.

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

II. 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.

III. 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 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

---

[6] From Samet et al. (1999)

[7] Shy et al. 1978 ; Samet (1989)

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 morbidity, the fit of the models measured as the R^2, increases dramatically when indoor pollution measures are included in the analysis.[9]

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.[10] 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[11].

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.[12]

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' 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

---

[8] Samet, J and Jaakkola, J (1999)

[9] Wallace (1991)

[10] Lunn et al. (1967) and Detel et al. (1987)

[11] Lvovsky (2000)

[12] Ito, Kazuhiko and Thurston, George (1999)

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.[13]

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:

$$\ln(RHA) = f\,(rain\,, temp\,, pollutants\,, dummy\ for\ season) \qquad \textit{Eq. 1}$$

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 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.

---

[13] Kinney et al. (1995); Lipfert (1994) in Thurston and Ito (1999)

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.

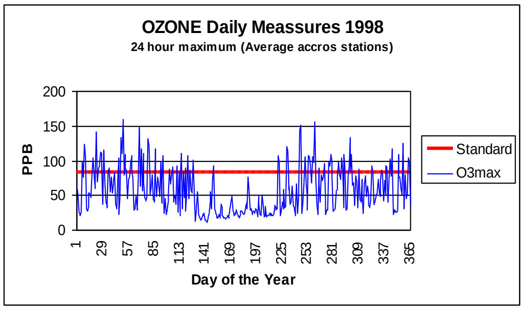
IV. Pollution Levels in Bogotá

Table 2 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

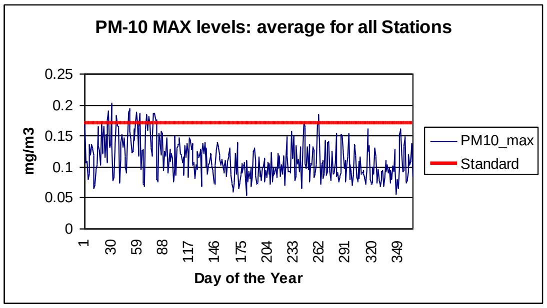
Pollutant (Max value in 24 hours)	Units of Measure	Standard Imposed by Regulation	Mean	Standard Deviation	Minimum	Maximum
PM-10	mg/m^3	0.170	0.1128	0.0307	0.0536	0.2036
NO$_2$	Ppb	121	35.7503	15.1618	11.8707	89.2646
O$_3$	Ppb	65	57.3771	32.2421	11.9043	158.9532
RAIN	cm^3	----	3.1225	5.6568	0	43.8349
TEMP	^{o}C	----	13.2495	1.0142	10.4809	16.0826

A first glance at Table 1 shows that two out of the four pollutants included in this study, were above the norm 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.



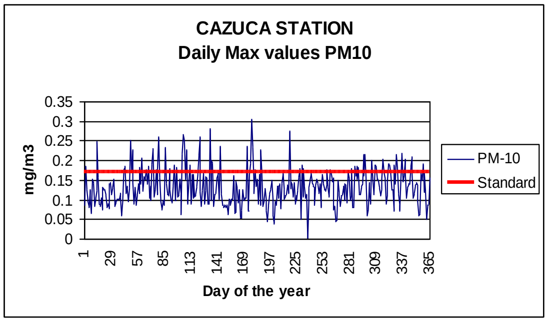
Graph 1.

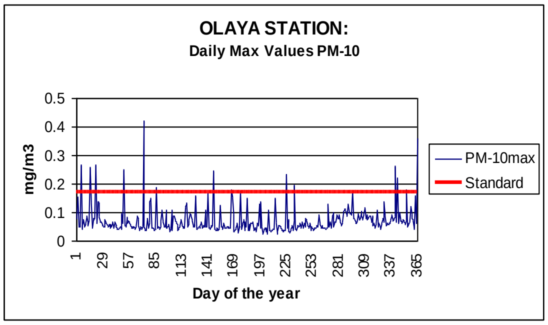
For the other pollutants it might also be interesting to look at the pollutant levels at individual stations before averaging the values across the city in order to confirm that the standard was violated more than once. For example, in the case of particles, when looking at the average across stations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



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.

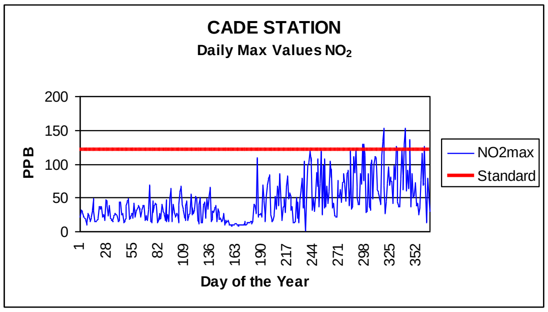


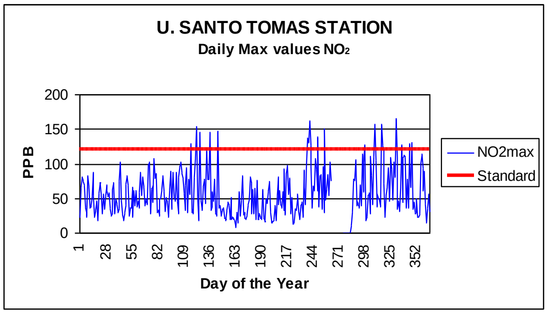


Graph 2.2a

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 3.2a

Graph 3.2b

The story is very similar when looking at the information gathered on NO_2. It is only when we look at the values reported for each monitoring station individually that we observe violations of the standard. Graph 3.1 shows the behavior of mean values across stations, while Graph 3.2 and 3.3 show the behavior of the pollutant at two of the stations where the standard was violated.

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.

In order to better understand the behavior of the pollutants that are included in this study, Table 3 presents descriptive statistics of the variables included in the model, showing their behavior in each quarter of the year separately.

Table 3.1 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	0.1363	0.0347	0.0646	0.2036
NO_2	Ppb	45.1473	17.2522	12.4119	89.2646
O_3	Ppb	72.2968	32.0111	21.5010	158.9532
RAIN	cm^3	2.1247	5.5607	0	38.3199
TEMP	^oC	13.7394	0.9217	10.9050	15.2146

Table 3.2 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	0.1084	0.0226	0.0536	0.1497
NO_2	Ppb	34.3009	14.9025	11.8707	71.3766
O_3	Ppb	41.6051	26.7770	11.9043	110.4111
RAIN	cm^3	3.6776	6.7685	0	43.8349
TEMP	^oC	13.9573	0.8580	11.8518	16.0862

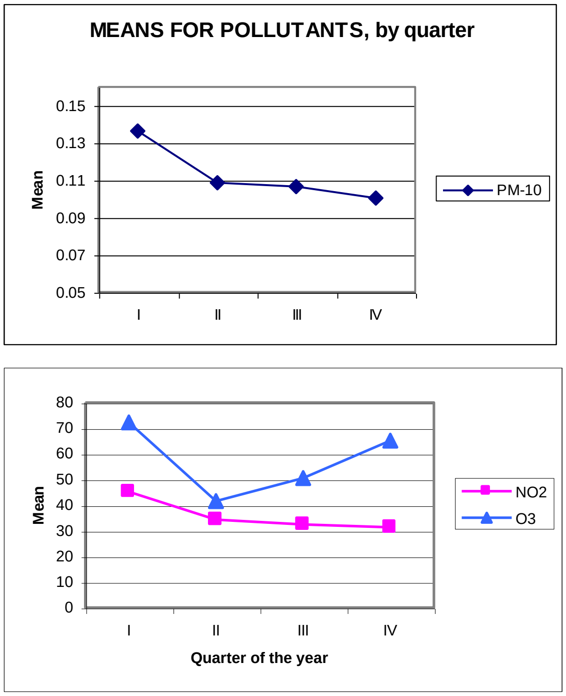
Table 3.3 Descriptive Statistics of Pollution Measures: Third Quarter of the Year

Pollutant (Max value in 24 hours)	Units of Measure	Mean	Standard Deviation	Minimum	Maximum
PM-10	mg/m^3	0.1064	0.0267	0.0648	0.1848
NO_2	Ppb	32.4219	14.3783	13.2965	77.4763
O_3	Ppb	50.5595	33.3199	18.7142	156.489
RAIN	cm^3	2.3589	4.1658	0	20.9572
TEMP	^oC	12.5769	0.6432	11.086	13.9743

Table 3.4 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	0.0246	0.0552	0.1615
NO_2	Ppb	31.3194	9.0311	16.7559	53.3982
O_3	Ppb	65.19986	27.54825	23.37078	132.6532
RAIN	cm^3	4.3130	5.6371	0	22.5814
TEMP	°C	12.7429	0.8288	10.4809	15.3184

From Tables 3.1 through 3.4 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.



Graph 4

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.

The dependent variable in the econometric model is the number of respiratory admissions per day in Bogotá. It is described in Table 4 and will be referred hereafter as *count*.

Table 4. Basic Statistic for RHA

Daily RHA	Mean	Standard Deviation	Minimum	Maximum
Count	1112.405	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
Count (ages 65 or more)	92.17534	58.73012	7	453

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.

V. 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 5.

Table 5. 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.[14] Rain may be associated in a quadratic function with the dependent variable. Table 5 shows that this relationship is only confirmed for rain accumulation in the of 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 5, 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,

---

[14] Thurston, G.D. and Ito, Kazuhiko (1999)

the consistent positive relation found in other locations suggests the importance of continuing to study ozone[15]. 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 6.

Table 6. 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

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 and very significant for the full model, while it appeared to be insignificant in the single pollutant 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. See Annex 1, Table A1. 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.

---

[15] Ibid; Schlesinger (1999)

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 6, the interaction term being insignificant. See Table A2.

In order to continue checking the robustness of the model, several alternative econometric models were specified. A first alternative model included a dummy variable for each quarter of the year. See Annex 1, Tables A3 and A4. 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 coefficient 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 that pollutants have on the health outcome of each particular group. Nevertheless, the coefficients of the 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 is more affected by the adverse effects of 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 the second column of Table 6. 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).

Table 7.1 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

As it can be seen in Table 7.1, 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 group –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 7.2 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.

Table 7.3 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 NO2 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

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 7.4 Predicted Values RHA: Decreases in Concentration of Nitrogen Dioxide

Model	Predicted RHA	Predicted RHA (If NO2 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

Ostro 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.

VI. 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. Ostro 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.

Table 8. Economic Values for a Respiratory Hospital Admission

	WTP for the US (1995 US dollars)	**WTP for Colombia** (1995 US dollars)
Cropper and Krupnic (1990)	7874.48	628.14
Lvovsky et al. (2000)	5141.30	410.11

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. Table 8 describes the Willingness to Pay encountered by literature on costs of a Respiratory Hospital Admission. The WTP for avoiding a morbidity effect in Bogotá is calculated by multiplying the values for the U.S. by Colombia's GDP per capita for 1998, and dividing afterwards by the equivalent value for the U.S. The third column of Table 8 shows then, an approximation of the cost of a respiratory hospital admission in Bogotá. It is necessary to remember that this approach may have a lot of problems since this costs were calculated based on the U.S. medical system. Using the values from Table 8 and those presented in Tables 7.2 and 7.4 the total costs avoided from reducing the pollutants by 50 and 25 percent. These values are presented in Table 9.

Table 9. 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 NO_2**	**Cost Avoided from a 50% reduction in NO_2**
Total Costs Avoided (C&K) (US$ 1995)	106,609.72	194,102.99	17,728.20	34,927.78
Total Costs Avoided (L. et al) (US$ 1995)	69,605.04	126,729	11,574.67	22,804.20

As Table 9 shows the costs are considerable and show the importance of controlling air pollution in Bogotá. Reducing by 25% the Particulate measures would represent a total avoided cost of 106,609.72 (US$ 1995). The potential savings from reducing the levels of Nitrogen Dioxide are lower than for the case of Particles but are in no case negligible. It is important to note that these are estimates 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.

From the result of the present study, 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.

VII. References

Ackermann-Liebrich, Ursula and Rapp, Regula. (1999) "Epidemiological Effects of Oxides of Nitrogen, Especially NO2". In *Air Pollution and Health*. Holgate, Sthephen, et al. eds. Academic Press, London.

Alberini, Anna and Krupnick, Alan. (2000) "Cost-of-illness and willingness-to-pay estimates of the benefits of improved air quality: evidence from Taiwan" *Land Economics* Vol. 76 Iss.2

Bleviss, Deborha Lynn.(1999) "Urban Transportation: Challenges Facing Latin America." IADB Working Paper.

Cifuentes, Luis et al. (2001) "Assessing the Health Benefits of Uban Air Pollution Reductions Associated with Climate Change Mitigation (2000-2020): Santiago, Säo Paulo, México City and New York City" Environmental Health Perspectives, v109 supplement 3.

Erbas, Bircan and Hyndman, Rob J. (2000) "The effect of air pollution and climate on hospital admissions" in www-personal.buseco.monash.edu.au/~hyndman/papers/bircan.pdf

Jacobi, P. et al. (1999) "Governmental Responses to air pollution: summary of a study of rodizio in Sao Paulo". In *Environment and Urbanization*, Vol. 11, No 1.

Lvovsky, Kseniya et al. (2000) "Environmental Costs of Fossil Fuels: A Rapid Assesment Method with Application to Six Cities" *Environment Department Papers*, World Bank.

O'ryan, R and Díaz, M. (2000) "Risk-Cost Analysis for the Regulation of Airborne Toxic Substances in a Developing Context" *Environmental and Resource Economics* V15

Ostro, Bart D. (1983) "The Effects of Air Pollution on Work Loss and Morbidity" *Journal of Environmental Economics and Management.* v10

Ostro, Bart D. et al. (1999) "Air Pollution and Health Effects: A Study of Respiratory Illness Among Children in Santiago, Chile" *Policy Research Working Paper*, World Bank.

Özkaynak, Haluk. (1999) "Exposure Assessment". In *Air Pollution and Health*. Holgate, Sthephen, et al. eds. Academic Press, London.

Pope III, C. A. and Dockery, D.W. (1999) "Epidemiology of Particle Effects". In *Air Pollution and Health* Holgate, Sthephen, et al. eds. Academic Press, London

Samet, Johathan M. and Jaakkola, J.K. (1999) "The Epidemiologic Approach to Investigating Outdoor Air Pollution". In *Air Pollution and Health*. Holgate, Sthephen, et al. eds. Academic Press, London.

Thurston, G. D. and Kazuhiko, Ito. (1999) "The Epidemiologic Approach to Investigating Outdoor Air Pollution". In *Air Pollution and Health.* Holgate, Sthephen, et al. eds. Academic Press, London.

Wallace, LA, Samet JM and Spengler JD (eds) "Volatile organic compounds" In :Indoor Air Pollution . Ahelath Perspective. Baltimore, Maryland: Johns Hopkins University Press.

Xu, X. and Dockery, D. (1995) "Association of air pollution with hospital outpatient visits in Beijing". *Archives of Environmental Health*, Vol. 50 Issue3