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Effects of fine particles on children's hospital admissions for respiratory health in Seville, Spain

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This study analyzes the influence of fine particles $PM_{2.5}$ on nonprogrammed children's hospital admissions that occurred in the city of Seville between 2007 and 2011, and makes an economic assessment of the cost of the children's hospital admissions for respiratory causes due to particle pollution. The $PM_{2.5}$ dose-response functions for each type of hospital admission were used to quantify the cost of the hospital admissions. It can be concluded that the $PM_{2.5}$ concentrations have negative effects on bronchiolitis, pneumonia, asthma, and bronchitis and other causes. A reduction of the daily average annual $PM_{2.5}$ concentration from the existing levels to $10 \mu\text{g}/\text{m}^3$ would show an annual average reduction of children's hospital admissions due to respiratory diseases of 0.09 cases. This paper shows that the daily average cost for children hospital admissions due to respiratory reasons in the city of Seville, associated with daily average annual levels of $PM_{2.5}$ above $10 \mu\text{g}/\text{m}^3$, was almost 200€.

Implications: Elevated $PM_{2.5}$ concentrations in Seville have negative effects on children's bronchiolitis, pneumonia, asthma, and bronchitis and other causes. A reduction of the daily average annual $PM_{2.5}$ concentration from the existing levels to $10 \mu\text{g}/\text{m}^3$ would suppose an annual mean reduction of children's hospital admissions due to respiratory diseases of 0.09 cases.

Introduction

Concern over the health effects of air pollution in cities acquires an ever-increasing importance in Europe. Specifically, one of the first studies to analyze the effects of atmospheric pollution on health at European level was the APHEA Project (Katsouyanni, 2001). In addition to generating reliable results, this study developed a common and standardized methodology that has been used in a generalized manner throughout Europe. More recently, attention has been drawn to the APHEKOM (Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe) project that studies the consequences of air pollution on human health in 25 European cities (Pascal et al., 2013). The APHEKOM project is the continuation of another, called APHEIS Project (Air Pollution and Health, A European Information System), that was implemented in 1999. In Spain, the EMECAM project (Spanish Multicenter Study on the Relationship Between Air Pollution and the Death Rate: Background Data, Participants, Objectives and Methods; Ballester, 1999) can be highlighted among the pioneering research studies. This was a multicenter study that included 14 Spanish cities, with different sociodemographic, climatic, and environmental situations.

The APHEIS and APHEA projects, applied to European cities, and the EMECAM project, applied to Spanish cities, analyze the relationships or short-term acute effects between air pollution and health. For the European case, for example, daily increments of $10 \mu\text{g}/\text{m}^3$ in the levels of particles with diameter less than $10 \mu\text{m}$ (PM_{10}) are followed by an increase in the number of daily deaths of about 0.6%. In Spain, the analysis has disclosed a 1.5% increase in the number of hospital admissions due to cardiac causes. In the APHECOM project, benefits associated to a reduction in the levels of microparticles and ozone pollution, to the established values in the World Health Organization (WHO) 2005 Guidelines, have been estimated, both economic and for health. The most important benefit would result from a reduction in the average annual levels $PM_{2.5}$ to the recommended annual $10 \text{mg}/\text{m}^3$ level, achieving an increase in the quality of life of 22 extra months.

The conclusions derived from main published studies that analyzed the impact of air pollution on health, between 2005 and 2012, have been summarized by the World Health Organization (WHO) in Europe in the report "Review of Evidence on Health Aspects of Air Pollution" (REVIHAAP) (WHO, 2013). The conclusions show that the mean limit values set in the WHO 2005 Guidelines should continue to serve as a reference point for all the countries. Also, the REVIHAAP report (WHO, 2013)

concluded that in the cases of particulate matter, ozone, and nitrogen dioxide, the harmful effects for health can occur at air pollution concentrations lower than those that served to establish the WHO 2005 Guidelines. The REVIHAAP report (WHO, 2013) recommends a review of the European Union policies on the matter of air pollution that updates the limits of the main pollutants harmful to health.

The studies on the impact of urban pollution on health take different pollutants as the base of their research. Nevertheless, a recent database produced by the WHO on air pollution in cities (WHO, 2014a) uses the annual mean concentrations of PM₁₀ and PM_{2.5} particles in suspension as indicators to measure this pollution. It is increasingly frequent for urban pollution studies to choose these pollutants as indicators, but especially, studies consider the PM_{2.5} particles because they have an anthropogenic origin, with an estimated 70–80% deriving from the combustion of diesel fuel in vehicles, which makes them a more reliable indicator of city pollution directly related to human activity.

Among the health effects of air pollution due to fine particles, Pope and Dockery (2006) show these are not only related to cardiovascular health effects but also there is a link between PM exposure and cardiopulmonary morbidity and mortality. The effects of particles in suspension on respiratory health through conditions such as asthma, bronchitis, and other respiratory diseases have been corroborated by the WHO in its reports on air quality (WHO, 2014b). Additionally, these effects are still more serious in the case of children, whose physical characteristics make them more vulnerable to urban pollution. The reason is that children are a more vulnerable population due to their defense mechanisms that are still developing and because they inhale a greater air volume in relation to their weight than adults (Salvi, 2007).

In the case of Spain, there are some papers that analyze the effects of fine particles (PM₁₀ and PM_{2.5}) on health: Guerrero and Monzón (2004) and Lechón, Cabal, Gómez, and Sánchez Sáez (2002) for Madrid, Pérez, Sunyer, and Künzli (2009) for Barcelona, and Boldo et al. (2011) for the whole country. But in the particular case of children, there is a lack of published papers for the Spanish case. To the best of our knowledge the most recent one is Linares and Díaz (2009). They analyzed the emergency hospital admissions of children due to all causes, except trauma, in Madrid and found that the only primary pollutant statistically significant was the PM_{2.5} concentration, and the relative risk associated with an increase of 10 µg/m³ in PM_{2.5} concentration was 1.03 for children less than 10 years old. In other countries, the impact of fine particle on children health, and specifically on children's respiratory health, has been analyzed by Dockery et al. (1989), Lin et al. (2005), Schwartz and Neas (2000), Ilabaca et al. (1999), Barnett et al. (2005), and Magas et al. (2007). These latter papers led to the conclusions that first, the results provide further evidence that the rates of respiratory illnesses and symptoms are elevated among children living in cities with high particulate pollution (particularly fine particulates). Second, relatively low levels of PM₁₀ and PM_{2.5} concentrations and gaseous pollutants, such as NO₂, have a detrimental effect on children's hospitalization due to respiratory infections. And third, they also suggest that children with hyperreactive airways may be particularly susceptible to other respiratory symptoms when exposed to these pollutants.

Additionally to the analysis of the effects of urban pollution on human health, it is increasingly frequent that these effects are translated into monetary values. The latest objective of these economic assessments is to quantify the medical cost of treating the diseases associated with urban pollution. Thus, the policymaker has an additional tool with which to undertake appropriate prevention measures. Not only is the direct cost of its implementation assessed but also the benefit in the form of medical cost saving that its execution can mean for society, in addition to its contribution to improving the quality of life and human health, by putting emphasis on prevention measures and not only on those of mitigation.

Recent studies, such as the one published by the French Ministry of Ecology, Sustainable Development, and Energy (2013), put the accent on the costs of urban pollution for the government, considering its effect on the increase of cases affected by respiratory and cardiovascular diseases and even cancer. The study estimated that urban pollution in France can cause an approximate medical cost of between 0.8 and 1.7 million euros per year. In this study, the monetary valuation of the impact of air pollution on health was made using the cost of illness (COI). In a more particular way, Pérez, Sunyer, and Künzli (2009) made an estimation of the effects that a reduction of urban pollution in Barcelona would have on human health and the associated economic benefits of that measure. Specifically, this study estimated that the total monetary benefit of reducing urban pollution to WHO recommended levels was 6,400 million euros. In this evaluation, the value to attach to a reduction of the risk of death and other endpoints were based on the willingness-to-pay (WTP) approach.

The objectives of the present work are twofold. First, the influence of PM_{2.5} particles on nonprogrammed children's hospital admissions is measured, distinguishing between the different groups of respiratory diseases that occurred in the city of Seville between 2007 and 2011. Second, this work makes an economic assessment of the cost of the child hospital admissions for respiratory causes due to particle pollution above the limit levels set by the WHO.

The research highlights three novel aspects. First, it deals with an analysis for the case of the city of Seville and for PM_{2.5} microparticle pollution along the lines of previous works such as that of Ballester et al. (2008), but estimating a dose-response function for the case of Seville and extending the period of study between 2007 and 2011. Second, the work is focused on one of the population groups more sensitive to urban pollution, the child population, and specifically on the nonprogrammed hospital admissions for respiratory conditions. Third, the economic benefits found by a reduction of urban pollution to WHO recommended levels are quantified.

Experimental Methods

The target population are the children under 14 years old who live in the city of Seville and have been admitted to one of the public hospitals that are in Seville. The children of Seville city represented almost 15% of the total population, considering that the population of Seville city has varied from 699,000 people in 2007

to 703,000 in 2011, according to the National Statistics Institute (IEA, 2014). The hospital admissions considered are unscheduled ones (not programmed) and limited to respiratory disease reasons (excluding the admissions for pneumonitis due to inhalation of food or vomit). The period of analysis is from January 1, 2007, to December 31, 2011. These data have been provided by the Directorate General for Health Care of the Andalusian Health Service, subordinate to the Regional Ministry of Health of the Regional Government of Andalusia.

The public hospitals are three, Virgen del Rocío University Hospital, Nuestra Señora de Valme University Hospital, and Virgen Macarena University Hospital. The hospital admissions in public hospitals are considered representative because the Spanish Health System covers 100% of population and pediatric attention in private hospitals represents less than 20% compared with public hospitals.

The hospital admissions (dependent variable) have been classified, noting their cause, into four categories: admissions for bronchiolitis, asthma, pneumonia, and bronchitis and other causes. Table A.1 shows the grouping of the diseases with their code details.

First, the independent variable used is the daily average concentration of particulate material of diameter less than 2.5 μm ($\text{PM}_{2.5}$) in a year. The values for this pollutant have been provided by the Andalusian Air Quality Monitoring and Control Network of the Directorate General for Prevention and Environmental Quality of the Regional Ministry of the Environment of the Regional Government of Andalusia.

Also, the meteorological variables have been taken into account, including the daily average temperatures and the daily degree of relative humidity in the city of Seville. The values were provided by the Andalusian Environmental Information Network and the Environmental Climatology Information Subsystem of the Regional Government of Andalusia. Additionally, some annual time variables are included in the model by creating dummies. Also, monthly time dummies for adjusting for time of year have been included initially in the model. Slow population shifts through splines have not been included because, according to data provided by the National Statistics Institute (INE, 2014), the pediatric population has not undergone significant changes over the years analyzed. The first step of the analysis was the accomplishment of scatter plots between the independent and dependent variables, which allowed the determination of possible thresholds. These scatter plots were adjusted by means of Lowess type smoothing.

Subsequently, lagged variables were created, as the effect between the independent and dependent variables may not be simultaneous in time (Morgenstern et al., 2007). This variable was constructed by totaling the hospital admissions over 5 days because some of the admissions can occur first through the emergency department and then to hospitalization, mainly at the weekends. Other delays of the variables were initially considered. According to the Akaike information criterion, 5-day delays were chosen. The estimation results gave significant estimated beta coefficients for all the respiratory causes when using this lag. However, the estimation results with 4 days of delays are similar. The months of July and August were excluded from the analysis, as during these months the

population in Seville is considerably reduced due to the vacation period, especially evident in the case of the child population.

A final step of the analysis was to create Poisson and negative binomial (NB) regression models, as the sample of hospital admissions data displays a high number of zeros, to quantify the association between the hospital admissions due to respiratory causes and the independent variables. Vuong tests were used to try for zero inflated models. Nevertheless, as the z -value was not significant in all cases, Poisson and NB models were used instead.

In general, the following equation is estimated for each of the causes considered:

$$E(Y/X_1 \dots X_3) = \exp\left(\beta_{\text{year}} + \beta_T X_1 + \beta_H X_2 + \beta_{\text{PM}_{2.5}} X_3\right) \quad (1)$$

where Y is the dependent variable that indicates the hospital admissions (unscheduled) over 5 days due to one of the respiratory causes considered. Alternatively, Y has been considered as hospital admissions in the same day of the admissions. The variable *year* is a dummy variable for each respective year, X_1 is the daily average temperature, and X_2 the daily degree of relative humidity. Finally, X_3 is the daily average concentration of particulate matter of diameter less than 2.5 μm ($\text{PM}_{2.5}$) in a year. $\beta_{\text{PM}_{2.5}}$ is the change in the average 5-day hospital admissions per unit of increase in the concentration of $\text{PM}_{2.5}$. Regressions were carried out in stages in order to take into account the possible multicollinearity between exogenous variables. Initially, a dummy variable for each of the 10 months under review was included in the model. However, this dummy variable was finally excluded due to collinearity problems with the variables, temperature and humidity, and the lack of significance that arose. Likewise, Akaike information criterion has been used to compare whether the inclusion of the X variables improves the model.

These models have been tested for the hospital admissions caused by each one of the four causes shown in Table A.1. They have been applied with time lag, and in the cases when independent control variables were not significant ($p < 0.05$), they were suppressed. Once the Poisson and NB functions were estimated for each case, the overdispersion (α) was analyzed through the likelihood ratio test such that α equals zero. It was found more advantageous to approximate an NB function for the admissions due to bronchiolitis, pneumonia, and bronchitis and other causes, and a Poisson function for the admissions due to asthma.

Finally, in addition to estimating the beta coefficient in the regressions, the marginal effect (dy/dx) that provokes a unitary increase of pollutant concentrations in the number of hospital admissions due to the different causes has also calculated. This marginal effect (dy/dx) shows the change in hospital admissions of our target population that occurs when there is a unitary increase in the fine particles pollution concentration. The statistical package used was Stata 11.

The methodology for the economic assessment of the cost of the children hospital admissions, due to respiratory causes, was as follows.

The $\text{PM}_{2.5}$ dose-response functions for each type of hospital admissions were used to quantify the cost of the hospital

admissions. Given that these estimates were made by means of Poisson and negative binomial regressions, the registered cases of hospital admissions can be given, in agreement with Kan and Chen (2004), by

$$E = e^{\beta_{PM2.5}(C-C_0)} E_0 \tag{2a}$$

where C and C_0 are the observed level of $PM_{2.5}$ particle concentration (daily average concentrations in a year) and the level set by the WHO as the value limit, respectively, and E and E_0 are the registered cases of real hospital admissions associated with the levels of pollution C and C_0 , respectively. Thus, the difference between E and E_0 represents the number of cases attributable to $PM_{2.5}$ pollution above the value limits set by the WHO (2006) in its guideline for air quality. The value $\beta_{PM2.5}$ represents the coefficient obtained from the estimations of the dose-response functions.

In this paper, C is the $PM_{2.5}$ observed (daily average concentration in a year) and C_0 is the level set by the WHO. E is the daily average children’s hospital admissions registered for each respiratory disease in Seville city during the period 2007–2011, while E_0 is equivalent to daily average children’s hospital admissions that would take place if pollution were reduced to the standard level provided by WHO (2006). E_0 is calculated reordering eq 2 as follows:

$$E_0 = \frac{E}{e^{\beta_{PM2.5}(C-C_0)}} \tag{2b}$$

Once the number of daily cases attributable to the excess pollution above the value limits was obtained ($E - E_0$), these cases were assessed on the basis of the estimated cost of each of them by disease group. This cost was estimated from the cost per process of the diagnosis-related groups (DRGs) whose bases and calculation procedures may be consulted in the initial report of the Ministry of Health and Consumption (1999). The DRGs use demographic and diagnostic variables to classify the patients into groups that can be clinically compared, with durations of stay in the hospital and with consumptions of similar resources. Therefore, the costs of treatment for the cases included in each DRG must be similar. The costs per DRG of this present study are the last available and come from the 2010 report of the Institute of Health Information (2012).

The cost of a single admission was established as a weighted average of the cost of the processes that form part of the disease group (in agreement with Table A.1). The weight used for each diagnosed process cost is the frequency of the process in relation to the frequency of the disease during the analysed period. Therefore, an average cost (AC) per process was established for the cases of bronchiolitis, pneumonia, asthma, and bronchitis and other cases.

Given the AC of a case of hospital admission due to each type of disease and the value of $E - E_0$, which represents the daily average hospital admissions due to each type of disease due to daily average $PM_{2.5}$ concentration levels in a year above those established by the WHO (2006), then the daily average costs (DC) for each disease related to the pollution are calculated as follows:

$$DC = AC \times (E - E_0) \tag{3}$$

Once the DC is obtained, as July and August months were excluded from the analysis, then a 10-month cost is calculated by multiplying the daily cost by 304 days.

Results

During the period 2007–2011, with the exception of July and August months, a total of 2130 hospital admissions of children under 14 years of age due to all respiratory causes was recorded. Of those admissions, 788 were due to bronchiolitis, 571 to pneumonia, 87 to asthma, and 687 to bronchitis and other respiratory reasons. Table 1 shows the descriptive statistics of the considered dependent and independent variables.

Figure 1 shows the sequence graphs during the period for the hospital admissions due to different causes. These graphs show that the number of hospital admissions descends abruptly during the months of July and August (mostly no case is recorded).

Figure 2 shows the sequence graphs during the period considered for the $PM_{2.5}$. Figure 2 shows that the concentrations levels during these months are around the mean. The mean concentration level of $PM_{2.5}$ for July and August were 16.83 and 17.62, respectively. Months with lesser mean concentrations levels were March, April, and May (15.09, 13.09, and 13.43, respectively). Therefore, the hospital admissions diminishing can be related to the fact that the population of children has mainly left the city during the months of July and August, which justifies the elimination of the observations of these months from the study.

The scatter plots of the daily mean temperature do not show the V form seen in other works in which the maximum temperature is considered, such as in Morgenstern et al. (2007). This implies that is not necessary to separate the temperature variable into two groups, hot and cold days. However, the scatter plots show a negative trend for each one of the causes of hospital admissions, with the exception of the asthma cases. In these latter cases, a V form is seen until a high temperature level is reached, when it descends again. Nevertheless, highest temperatures are only reached during July and August, so we have not divided the temperature into the two groups either.

Table 1. Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Bronchiolitis	1516	0.5197889	0.9770996	0	6
Pneumonia	1516	0.3771466	0.6532492	0	4
Asthma	1516	0.0573879	0.2410199	0	2
Bronchitis and others	1516	0.4531662	0.7488935	0	5
$PM_{2.5}$	1516	17.27135	7.84691	1	62.1111
Temperature	1516	17.7752	5.7304	3	32.5
Humidity	1516	75.74967	16.52155	29.7	100

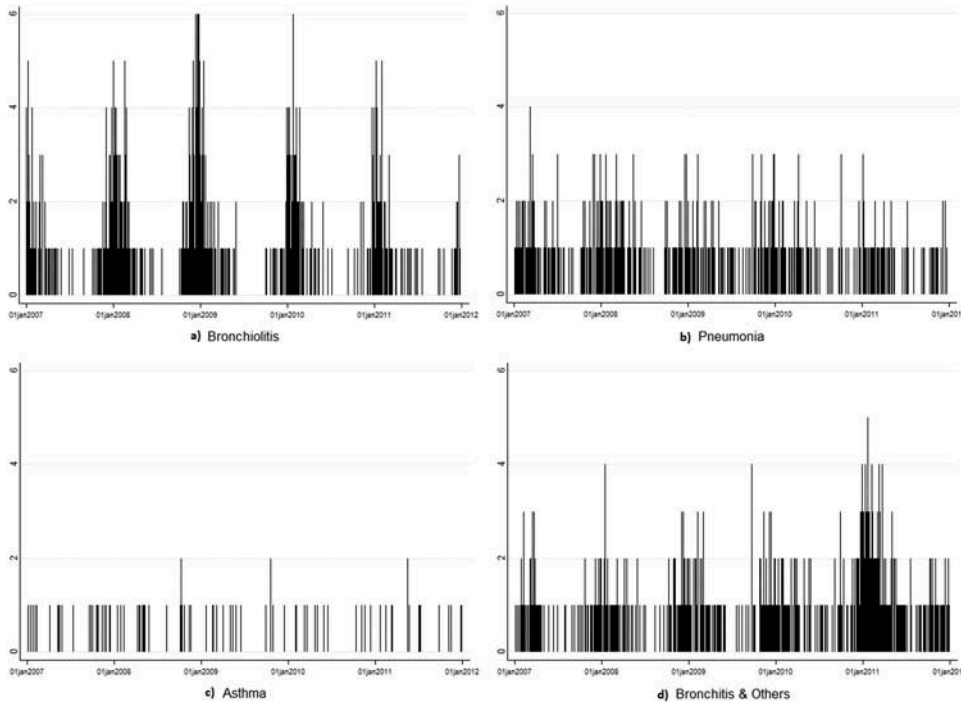


Figure 1. Sequence graphs of the daily hospital admissions of children under 14 years of age due to bronchiolitis, pneumonia, asthma, and bronchitis and other causes (January 1, 2007, to December 31, 2011).

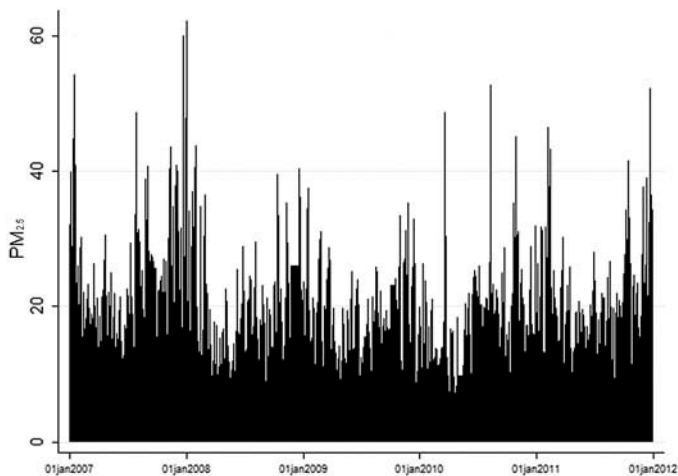


Figure 2. Sequence graph of the daily mean concentrations of PM_{2.5} (January 1, 2007, to December 31, 2011).

The scatter plots of the PM_{2.5} concentration levels display a practically constant behavior for all the causes of hospital admissions (with very few admissions) until a daily average concentration level of somewhat less than 20 μg/m³ is reached, after which the admissions increase intensely, with the exception of the admissions due to asthma, which increase smoothly after that level. This value is somewhat less than that observed in similar studies for other Spanish cities (Linares and Díaz, 2009).

Finally, Table 2 shows the beta coefficients (βPM_{2.5} estimated from the NB function or Poisson) for the different

Table 2. Estimation of NB function by diseases

Hospital admissions	Estimated coefficient	Marginal effect dy/dx
Bronchiolitis	0.0099 (2.01)**	0.013
Pneumonia	0.0073 (2.40)**	0.011
Asthma	0.019 (2.81)***	0.004
Bronchitis and other causes	0.0057 (1.2)**	0.008

Notes: The Poisson function was more suitable for estimating the effect of the polluting agents on the admissions due to asthma, and was therefore used for these cases. Significance: ***at 1% and **at 5%. Numbers in parentheses reflects z-values.

respiratory causes of hospital admissions. Lagged and control (temperature and humidity) variables and a temporal dummy variable (year) were included. The estimation results without delays gave no significant estimated beta coefficients for all the respiratory causes, except for pneumonia. In this latter case the beta coefficient had a value of 0.009 but with very little significance ($p < 0.10$).

Using eq 1 and the beta coefficients estimated, Table 3 shows that a reduction of the daily average PM_{2.5} concentration (without considering July and August) from existing levels to the target level proposed by the WHO (2006) would suppose a daily

Table 3. Daily average hospital admissions related to PM_{2.5} pollution

	Daily average level PM _{2.5} (without July and August months)	Average level of PM _{2.5} (WHO, 2006)	<i>E</i> , Daily average hospital admissions observed	<i>E</i> ₀ , Daily average hospital admissions calculated for standard level	<i>E</i> – <i>E</i> ₀
Bronchiolitis	17.271	10	0.5197889	0.483537	0.036252
Pneumonia	17.271	10	0.3771466	0.350876	0.026271
Asthma	17.271	10	0.0573879	0.049646	0.007742
Bronchitis and other causes	17.271	10	0.4531662	0.431734	0.021432

Table 4. Direct costs of hospital admissions of children under 14 years of age for respiratory reasons related to PM_{2.5} particles in Seville

Disease	Average cost of a case (Euros)	Daily average cost (Euros)	10-Month cost (Euros)
Bronchiolitis	1,800.89	65.29	19,846.59
Asthma	1,307.45	10.12	3,077.07
Pneumonia	1,932.73	50.77	15,435.47
Bronchitis and others	3,427.52	73.46	22,332.11
Total	8,468.59	199.64	60,691.23

average reduction of hospital admissions due to respiratory diseases of 0.09 cases. The greater number of cases corresponds to hospital admissions due to bronchiolitis, followed by pneumonias, bronchitis and other causes, and finally asthma.

The average costs per process of every analyzed disease and the daily and 10-month average cost are shown in Table 4. As can be seen in the last row of the third column, the daily average cost for children hospital admissions due to respiratory reasons in the city of Seville, which can be related to PM_{2.5} concentrations above those recommended by the WHO, during the analyzed period, was almost 200€, which represents a 10-month cost of 60,691.23€. During the period analyzed, from 2007 to 2011 (without the months of July and August), the value amounted to 303,456.2€.

Discussion

The daily average value in a year for PM_{2.5} concentration found during the analyzed period was 17.271 µg/m³. This value is greater than the average value guidelines of 10 µg/m³ set by the WHO for long-term effects (WHO, 2006). The daily average value in a year of PM_{2.5} concentrations that have been found is similar to that of some cities of the United States for which studies have taken place on the effects of pollutants on health, which showed a mean concentration of 18 µg/m³ (Pope, 2002; Jerret et al., 2005). The concentration is also slightly lower than the mean of 19 µg/m³ observed for Madrid, Spain (Linares and Díaz, 2009). In these studies, a negative effect of these pollution levels was observed on health. It is possible to emphasize the study of Dockery (1993), which found negative effects from

annual mean concentrations of between 11 and 15 µg/m³. Accordingly, the scatter plots of the PM_{2.5} concentration levels made in our study reveal that, from levels somewhat under than 20 µg/m³, an increasing tendency of hospital admissions is observed for children under 14 years of age, related to respiratory diseases, especially for bronchiolitis, pneumonia, and bronchitis and other causes.

Regarding the results in Table 2, it is possible to emphasize that significant estimations for PM_{2.5} were observed for all the causes of hospital admissions included in this study. Thus, those concentrations of pollutant are associated with the children's hospital admissions due to bronchiolitis, pneumonia, asthma, and bronchitis and other causes. Therefore, this study is consistent with the results shown in other similar works that relate child hospital admissions to PM_{2.5} (e.g., Linares and Díaz, 2009; Dockery et al., 1989; Lin et al., 2005; Schwartz and Neas, 2000). It is also in line with the results shown in studies that relate this pollutant to cases of pneumonia (Ilabaca et al., 1999) and bronchitis (Barnett et al., 2005), and also with those that relate hospital emergencies due to chronic obstructive pulmonary disease and asthma (Katsouyanni, 2001). The relationships between admissions due to asthma and PM_{2.5} are also shown in the study made by Magas et al. (2007).

The economic assessment results are modest compared with others (Pérez, Sunyer, and Künzli, 2009). The reasons are the following. First, the paper is focused only on children population under 14 years of age; second, the target population is exclusively limited to the residents in the city of Seville; and third, the paper is exclusively focused on nonprogrammed hospital admissions due to respiratory diseases. In summary, it is concluded that the mean 10-month economic benefit

associated with the reduction of hospital admissions of children under 14 years of age due to respiratory diseases, due to the reduction of PM_{2.5} pollution in Seville to the guideline levels of the WHO (2006), is 60,691.23€.

Study Limitations and Uncertainties

There are some uncertainties in estimating the health effects of air pollution in Seville city during 2007–2011. Given next is a brief review of some of the major uncertainties, along with suggestions for research that might be undertaken to reduce them.

First, our research deals with the daily average of PM_{2.5} concentrations. In Seville, there is just one monitoring site to measure this pollutant, and therefore, the PM_{2.5} concentration values from this monitoring site have been considered representative of Seville city. Therefore, some uncertainties appear because the spatial variation in the concentration of PM_{2.5} in the area of interest might not be captured accurately from only one monitoring station. Although the estimated annual mean of PM_{2.5} for the period in Seville (17.2 µg/m³) is quite close to the one offered by WHO (2014a) in the last available “Ambient Air Pollution database,” that is, 16 µg/m³, our results might be overestimating the respiratory cases due to PM_{2.5} concentrations. Overall, local government should make greater efforts to overcome this problem in order to provide better and more accurate environmental information.

Second, the present analysis only selects PM_{2.5} concentration as the indicator of outdoor air pollution, which would probably overlook the adverse health effects due to exposure to other air pollutants, thus underestimating the health effects attributable to total air pollution. However, this pollutant is becoming one of the most representative one for measuring the city pollution, as recently published by WHO (2014a).

Third, the sample size covers the children population hospital admissions in Seville during the period 2007–2011. There have been 2130 hospital admissions during this period, which represents 2% of the total child population in Seville. This sample size is considered representative based on the Spanish Health System, which covers 100% of the population, especially with pediatric attention, and offers accurate information and statistical data. However, some uncertainties appear as soon as the sample size only covers the most extreme cases of respiratory disease, which are when families take their children to the hospital. Meanwhile, as recently found by Janke (2014), in the case of asthmatics, if the disease is previously diagnosed, the families know the treatment, and when the asthmatic children get sick, their families adjust the dose of their reliever medicine without taking them to the hospital. This reason might explain why our results show the lowest correlation between cases of asthma and PM_{2.5} concentrations.

Fourth, this research considers that other important variables such as socioeconomic, behavioral, demographic, genetic, and environmental health risk factors have remained constant during the period analyzed and they have not been taken into consideration in the estimating. The reason why they have been considered constant is because these variables have not significantly changed during this short period (2007–2011).

However, there are other estimates that show the importance of alternative variables for explaining the a priori influence of pollution on health. Therefore, our analysis might be overestimating the health risks associated with the PM_{2.5} pollution in Seville city, although a temporal dummy variable has been included in order to show any relevant structural changes that might be explained by these other alternative variables.

Fifth, in our research, the costs of each disease are only related to the health attention that children receive when they are at public hospitals. However, there are other health effects related to air pollution, such as school absences, low or restricted activity for parents or child’s guardians, and possible long-term impact on chronic diseases, or life span decreasing. Additionally, some respiratory diseases of children, like asthma, are usually attended to at home by their parents/caretakers because they usually know the appropriate medical treatment. For that reason, the asthma cases that are registered in the public hospitals are completely extreme and do not reflect the other cases that appear at home because they are solved by the parents. Therefore, this underestimates the costs in our research.

Sixth, there are other methods of cost valuation, such as that based on the concept of willingness to pay (WTP) that implies the assessment of the value of a statistical life (VOSL) and how this is affected by air pollution. However, this latter method was not suitable for our research because there is no contingent valuation study (CVS) made previously that provides information about the WTP of our target population. In our research, we have decided to use the DRG, which is what the literature called the cost of illness (COI) that is usually employed as an alternative choice for some morbidity endpoints that could not be valued based on existing WTP literatures.

Conclusion

The incidence of admissions due to respiratory diseases of children under 14 years of age is related to the elevation of the daily average PM_{2.5} concentration in a year in the urban area of Seville, which allows us to conclude that PM_{2.5} has a possible negative effect on the health of the children population in Seville. In particular, it can be concluded that the elevated PM_{2.5} concentrations have negative effects on bronchiolitis, pneumonia, asthma, and bronchitis and other causes. A reduction of the mean PM_{2.5} concentration from the existing levels to the objective level proposed by the WHO (2006) would suppose a daily average reduction of hospital admissions due to respiratory diseases of 0.09 cases. The greater number of cases with hospital admissions corresponds to bronchiolitis, followed by pneumonia, bronchitis and other causes, and finally asthma.

These hospital admissions due to pollution generate a cost. This paper shows that the daily average cost for children hospital admissions due to respiratory reasons in the city of Seville that can be associated with levels of PM_{2.5} above those recommended by the WHO, during the analyzed period, was almost 200€, which supposes a 10-month cost of 60,691.23€. During the analyzed period, from 2007 to 2011 (without July and August months), its value amounted to 303,456.2€.

This figure represents only one part (that of the hospital admission) of the cost derived from a pollutant. Future research can extend this analysis to the economic assessment of other pollutants and other costs generated outside the hospital, such as medical visits to outpatient departments, pharmaceuticals, and other costs associated with the time used by parents and caretakers.

The analysis shows some uncertainties and limitations that have been highlighted. They imply that our results have to be balanced with the factors that might be overestimating and underestimating them. In fact, there are some variables such as socioeconomic, behavioral, demographic, genetic, and environmental health risk factors that have been omitted in the analysis, and therefore, results might be different if they were considered. Additionally, children's hospital admissions have only considered the extreme cases of respiratory disease, and therefore, other cases are excluded from the analysis. The monetary costs are collected from the hospital statistics, so they do not include other relevant costs that have to do with the treatment of respiratory diseases.

Overall, these conclusions led us to recommend that the revision of the European Union policies on the matter of air pollution should update the limits of this pollutant, PM_{2.5}, in order to lower the upper limits. The harmful effects on human health, specifically on respiratory health of children, due to PM_{2.5} concentration levels above WHO recommendations, have also an important economic cost. These results should serve the policymaker to implement measures aimed at reducing pollution limits for PM_{2.5}.

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