IDB WORKING PAPER SERIES No. IDB-WP-468

The Effects of Air Pollution on Educational Outcomes:

Evidence from Chile

Sebastián J. Miller
Mauricio A. Vela

December 2013

Inter-American Development Bank
Department of Research and Chief Economist

The Effects of Air Pollution on Educational Outcomes:

Evidence from Chile

Sebastián J. Miller
Mauricio A. Vela

Inter-American Development Bank

Inter-American Development Bank
2013

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Miller, Sebastian J.
The effects of air pollution on educational outcomes : evidence from Chile / Sebastian J. Miller, Mauricio A. Vela.
p. cm. — (IDB Working Paper Series ; 468)
Includes bibliographic references.
1. Learning—Effect of air pollution on—Chile. I. Vela, Mauricio A. II. Inter-American Development Bank. Department of Research and Chief Economist. III. Title. IV. Series.
IDB-WP-468

http://www.iadb.org

Abstract

In addition to the morbidity and mortality concerns of outdoor air pollution, studies have shown that air pollution also generates problems for childrens cognitive performance and human capital formation. High concentrations of pollutants can affect children's learning process by exacerbating respiratory illnesses, fatigue, absenteeism and attention problems. The purpose of this work is to analyze the possible contemporary effects of PM_{10} and other different air pollutants on standardized test scores in Chile. It examines results for 3,880 schools in the Metropolitan, Valparaiso and O'Higgins regions for children in fourth, eight and tenth grades between 1997 and 2012. Data for particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), nitrogen oxide (NO_x) and ozone (O_3) were interpolated at school level using a kriging methodology. The results suggest that higher annual PM_{10} and O_3 levels are clearly associated with a reduction in test scores. Nonetheless, as of 2012 many municipalities in these Chilean regions are still exceeding the annual PM_{10} international standard quality norm (50 micrograms per cubic meter) by 15 micrograms per cubic meter on average. Efforts to reduce pollution below this norm in the most polluted municipalities would account for improvements in reading and math test scores of 3.5 percent and 3.1 percent of a standard deviation, respectively.

JEL classification: I250, H23, Q51, Q530.
Keywords: Education; Air Pollution; Environmental Policy.

1 Introduction

Ambient air pollution is a common cause of adverse health conditions, contributing to the occurrence and severity of respiratory diseases and infections. Children, being one of the most sensitive subgroups of the population, can be highly vulnerable, and high air pollution can end up affecting children's daily school performance. Several studies have identified the effects of ambient air pollution on hospital admissions, mortality rates, absenteeism and cognitive deficits in children. Therefore, numerous mechanisms can explain the association between ambient air pollution and school performance. For instance, absenteeism has been associated with negative effects on school attainment (Carroll, 2010). There is also a vast literature on the general importance of health for school achievement that views physical health as a necessary pre-condition for childrens daily school work. From early health problems to common illnesses, health deficiencies can limit children's cognitive ability. Conversely, favorable environmental conditions can play an important role in childrens learning processes.

With these considerations in mind, this paper seeks to quantify the negative consequences of ambient air pollutants. This is done by analyzing the correlation of concentrations of different air pollutants with standardized test scores of fourth, eighth and tenth graders. To this end a school panel set data is constructed for three regions in Chile (Metropolitan, Valparaiso and O'Higgins) covering a total of 3,880 schools. Using a kriging interpolation method we construct a daily air pollution concentration level for the location of each school. Five different air pollutants are examined; however, particular emphasis is placed on particulate matter with a diameter less than 10 microns (PM_{10}), which is one of the most common and harmful pollutants. Data coverage for this pollutant is also the most comprehensive, covering 15 years (1997-2012).

This study is thus the first to analyze, using a long panel dataset, the effects of air pollution on a comparable educational outcome in a developing country with high levels of pollution. Conditions in a developing country as compared to a developed country may be quite different. The marginal effect of pollution can be totally different at higher levels of pollution, and different contexts, such as limited health care access, can exacerbate the effect of pollution. Findings from Arceo-Gomez et al. (2012) suggest that in fact estimates from developed countries are not externally valid for a developing country given the non-linearity in the relationship of pollution with health. Despite reductions in recent years, Chile continues to be exposed to high levels of air pollution that are significantly above international health standards, in particular for PM_{10} levels. Thus, using data for Chile allows having great variability of exposure to air pollution within and between schools. This topic also merits study because many children exposed to high levels of ambient air pollution could, through policies aiming to reduce air pollution, not only benefit from better health conditions but also gain from indirect positive effects such as human capital formation.

1.1 Chile's Situation

Industrial activities, vehicles, residential emissions, copper smelters and fossil fuel power plants are the main sources of high pollutant concentrations in the central part of Chile (Metropolitan, Valparaiso and O'Higgins regions). Concentrations of pollutants such as particulate matter (PM), carbon monoxide (CO) and nitrogen oxide (NO_x) are mainly produced by direct emissions of these pollutants into the atmosphere. This zone, especially in the Metropolitan region, presents high levels of pollution throughout most of the year, especially high concentrations of PM during autumn and winter and high levels of ozone (O_3) during spring and summer (Gramsch et al., 2006).

Because of the potential health effects associated with air pollution, the Chilean government has over the years developed several plans and strategies to reduce emissions and hence pollution. This has helped to reduce pollution levels in the Metropolitan region, especially since 1993, by establishing management tools including emission standards, decontamination plans, prevention and quality standards (Gligo, 2010). The main mechanism for controlling pollution in Chile has been command and control measures in the transportation, industrial and residential sectors, although a market mechanism has also been tried. In 1998 a plan for prevention and atmospheric decontamination of the Metropolitan region aimed to reduce emissions of NO_x and PM_{10} by 50 percent by 2005.

However, despite environmental efforts and different tools used, there is still little compliance with the limits set in the current air quality standards. For that reason, in 2010 the Ministry of the Environment began implementing a new Clean Air Program. The current situation of pollution in the central zone of Chile is therefore not yet resolved. In the case of PM_{10}, municipalities are still exceeding the 120 micrograms per cubic meter standard established as the maximum 24 hour average limit in the current regulation. During the period between 2001 and 2008, almost all monitoring stations in the Metropolitan region reported annual averages of PM_{10} close to the 75 micrograms per cubic meter (Gligo, 2010). There were also 165 days with declaration of pre-emergency due to high levels of PM_{10} (above 300 micrograms per cubic meter) between 1998 and 2008. A similar situation occurred with ozone concentration, where all stations reported greater values above the eight-hour norm (61 ppb) during most days. In contrast, the concentration of CO in the Metropolitan region is below the norm as reported from all the monitoring stations.

Although most studies focus on the high pollution problems of the Santiago Metropolitan Region, increasing monitoring efforts have begun to show that air pollution is also a problem in several other Chilean cities.

1.2 Air Pollution Effects

The epidemiology literature has long established many effects of exposure to air pollution. Several studies have shown the link between concentration levels of pollutants and the incidence of premature deaths and cardiorespiratory diseases. Particulate matter (PM) is the pollutant most significantly associated with mortality and morbidity events. Furthermore, it is estimated that more than 4,000 people die prematurely each year due to cardiopulmonary diseases associated with chronic particulate matter exposure (Ponce, 2012). Exposure to PM can cause serious damage to human health for both adults and children. It may reduce pulmonary functions, increase susceptibility to respiratory infections and cause cancer, among other risks. Health effects depend on both the concentration of pollutants and the length of exposure. Long-term exposure has been associated with increased cardiovascular mortality, various blood markers of cardiovascular risk, histopathological markers of subclinical chronic inammatory lung injury, and subclinical atherosclerosis (Pope III and Dockery, 2006).

Air pollution also has acute and chronic health effects on children. High levels of particulate pollution are responsible for aggravation of asthma and increases in acute respiratory illness (Bates, 1995). Hospital admissions of children have been shown to be associated with high levels of PM_{10}. In a study for Santiago, Ostro et al. (1999) medical visits and their association with daily PM_{10} and O_3 exposures were analyzed. A statistically significant association between PM_{10} concentrations and medical visits for lower respiratory symptoms in children between 3 and 15 years of age was found. In a similar analysis, Burnett et al. (1994) showed that hospital admissions for children in the summer are associated with ambient ozone pollution.

Thus, many studies have provided evidence that pollution can increase childrens morbidity and even mortality. Schoolchildren are in fact highly exposed to ambient pollution because of their outdoor activity. With high pollution levels, this can lead to consequences ranging end up from raising the respiratory illness rates on children to the aggravation of serious chronic illness as for example problems with lung functions. Van der Zee et al. (1999) revealed that acute respiratory health effects in children are stronger for children with chronic respiratory symptoms.

1.3 Pollution effects on school performance

Many of the analyses in the economic and medical fields have focused on the negative effects of pollution on absenteeism, fatigue, brain development and cognitive functioning of children. These works suggest strong impacts of outdoor pollution on the academic performance of children. There are two main channels through which pollution can affect the children academic outcomes. The first one shows how pollution is associated with absenteeism, fatigue and attention problems. Higher pollution exacerbates respiratory problems and it generates negative effects on academic performance because of the fatigue related to the illness and repeated absenteeism. Environmental pollutants can at the same time lead to long-lasting health problems on children. A second channel denounces the negative impacts of pollutants on brain development and behavioral problems.

One of the clearest mechanisms whereby pollution is related to lower academic results is its direct effect on illness-related absenteeism. Higher exposure to pollution is accompanied by a higher probability of being sick and therefore higher chances that children fail to attend school. For example, Mohai et al. (2011) examine the relationship of air pollution levels with attendance rates in Michigan. Schools located in areas with higher pollution from industrial sources had the lowest attendance rates and highest proportion of students who failed to meet state educational testing standards. Another study in California by Gilliland et al. (2001) shows that a 20 ppb decrease in O_3 was associated with a 62.9 percent increase in absence rates, a 45.1 percent increase in upper respiratory illness and a 173.9 percent increase in lower respiratory illness. In another work, Currie et al. (2009) used a longitudinal data set in Texas to show the effect of air pollution, CO and PM_{10}, on elementary and middle school absences.[1].

Asthma represents an additional risk factor for emotional and behavioral problems. Results from a logistic regression show that children with asthma problems had higher scores in the Behavior Problem Index (BPI) than children without asthma (Bussing et al., 1995). Behavioral problems are also found in the literature to be negatively associated with academic performance. Segal (2008) evaluate how behavioral problems in eight graders are associated with lower probabilities of college graduation and higher probabilities of dropping out of high school.

Air pollution has similar effects on productivity, fatigue and memory (Kampa and Castanas, 2008). Graff Zivin and Neidell (2012) found that a 10ppb change in average ozone exposure results in a significant 5.5 percent decrease in productivity. Wang et al. (2009) presented a study showing that children in schools in polluted areas had lower cognitive scores than children in schools in a clear area. They found significant associations between traffic-related air pollution exposures and poor performance on several neurobehavioral tests. This result is similar to what is concluded in a work by Suglia et al. (2008) on the relationship between cognition and air pollution. These findings suggest that air pollution has a neurodegenerative effect that can lead to lower memory and learning capacity.

One strand of the literature has emphasized the effects of earlier exposure to pollution, linking air pollution concentrations with deficits in brain development. This means that pollution affects children even before birth and can have long-lasting results on cognitive ability in later years. Calderón-Garcidueñas et al. (2008) conclude that exposure to air pollution can cause neuroinflammation in healthy children. They concluded that children residing in polluted urban en-

[1]Children with respiratory symptoms and asthma are likely to have greater school absenteeism, lower attention capacity, behavioral problems and therefore worse school achievement (Silverstein et al., 2001, Spee-Van Der Wekke et al., 1998, Ehrenberg et al., 1991, Halterman et al., 2001).

vironment have deficits in cognitive tasks. Low-level lead exposure can also affect neurocognitive functioning in children (Banks et al., 1997). Rau et al. (2013) analyzed the effect of environmental negligence that led some families to be exposed to lead in Arica, Chile. They found a strong relationship between blood lead levels and distance from home to the source of contamination and a strong relationship between student performance and distance from home to the source.

Finally, and in a similar vein to this paper, some studies have analyzed the association of air pollution with standardized tests scores of students. In a cross-sectional study in California, Pastor et al. (2006) examined the correlation of respiratory risks associated with air pollution and academic performance. After controlling for student-socio economic status, teacher quality, parent education and other measures, their results suggest that there may be negative impacts of pollution on the Academic Performance Index (API). Zweig et al. (2012) also found that higher levels of PM_{10}, $PM_{2.5}$ and NO_2 are associated with lower achievement on standardized tests in California. The results indicate that a 10 percent increase in PM_{10}, $PM_{2.5}$ or NO_2 would decrease math test scores by 0.15 percent, 0.34 percent or 0.18 percent, respectively.

Lavy et al. (2012) obtained similar results after evaluating air pollution on the day of the Bagrut exams, Israeli high-stakes high school exit tests, on student performance. They conclude that an additional deviation of $PM_{2.5}$ relative to mean air quality is associated with a 2.1 percentage point decline in the probability of not receiving the Bagrut certificate. An additional standard deviation of exposure to $PM_{2.5}$ and CO is associated with standard deviation declines of 2.8 percent and 2.4 percent, respectively, in test scores. Therefore, the results suggest that taking the exam on highly polluted days could have a negative effect on test scores.

In summary, air pollution can have three main contemporary effects on children: illness-related absenteeism, fatigue and attention problems. These conditions can affect childrens test performance (see Figure 1); therefore children are likely to be affected by short-term pollution. Early exposure to pollution has other consequences, as many pollutants have adverse effects on neurobehavioral functions, asthma and brain development. This work, however, will emphasize the contemporary effects of several pollutants.

2 Data and Research Design

School-level pollution variables were constructed from daily data reported by the SINCA (*Sistema de Información Nacional de Calidad del Aire*) of the Ministry of Environment. Air pollution data are included from 57 monitoring stations (11 in the Metropolitan Region, 14 in Region VI and 32 in Region V). Figure 2 shows the map with the exact location of each monitoring station. Daily data on pollution with some gaps for some stations were available for years between 1997 and 2012. With the exact coordinate location of schools and monitoring stations, data were interpolated using a kriging methodology.[2] Kriging interpolates using the spatial variation of air pollution based on the empirical semi-variogram:

$$\gamma(h) = \frac{1}{2M(h)} \sum_{j=1}^{M)(h)} \{z(x_i) - z(x_i + h)\}^2 \quad (1)$$

where h is the distance, $z(x_i)$ the observed value at x_i and $M(h)$ are the number of pairs. The kriging procedure utilizes the semi-variogram to determine the nature of variance and localized variability of data to generate values on a surface taking into account localized spatial trends. Kriging involves estimating values for any location using weights, which are optimized according to the semi-variogram model, the location of the samples and all the relevant inter-relationship between known and unknown values. With ordinary kriging, the variable *Z* at a given location x_0 is written as a weighted linear function of the *N* neighboring values:

$$\hat{Z}(x_0) = \sum_{i=1}^{N} w_i z(x_i) \quad (2)$$

The interpolation was done day by day but conditioning days with at least five reports from different monitoring stations in each region.[3] The parameters for the variogram model were estimated using a likelihood-based method with an exponential correlation function and, finally, data were interpolated with an ordinary kriging. Using a kriging interpolation avoids the assumption that pollution was the same for all schools close to the same monitoring station.

The final result was daily data on all pollution variables for each school during the same period between 1997 and 2012. Data for PM_{10}, $PM_{2.5}$, CO, NO_x and O_3 were interpolated. The PM_{10} data from the monitoring stations was the most complete, while data for $PM_{2.5}$ had the fewest observations. Table 1 shows the average number of stations by year and the number of interpolated days for PM_{10}.

Figure 3 shows the kernel density for the daily PM_{10} interpolation at school level. As mentioned in the literature review, the average level for most schools is above 50 micrograms per cubic meter. Nonetheless, on some days the pollution exposure for certain schools can reach 500 micrograms per cubic meter. However, these are extreme cases, and the average PM_{10} level for a school in a day is around 63 micrograms per cubic meter. The maps in Figure 4 average the

[2]We used geoR package in R software, which makes it possible to handle spatial data and undertake several geostatistical procedures.

[3]Some 1,167 schools out of 3,880 in the whole sample in the Metropolitan, Fifth or Sixth Regions were located more than 5 km from a monitoring station. Estimations without these 1,167 schools are included in the Appendix.

PM10 estimations by municipality. The figure displays the classification of each municipality-year in eight quantiles according to the average PM_10 level (darker red indicates higher pollution levels), reflecting how air pollution levels of PM_10 have decreased for most municipalities in the Metropolitan Region from 1997 to the present.

School performance is measured by the SIMCE (*Sistema de Medición de la Calidad de la Educación*) test undertaken by the Education Ministry, which is the learning outcomes assessment system providing data for all schools in Chile. Information for 3,880 schools in the Metropolitan, Fifth and Sixth Regions was available for years between 1997 and 2012. While the SIMCE includes results for mathematics, reading, natural science and social comprehension, in this work we focus primarily on math and reading scores. The tests are taken by children in fourth, eighth and tenth grades.

Since 2005 the test has been taken every year by children in fourth grade and every two years (on alternating basis) for children in eighth and tenth grade. Before 2005, the test was taken by only one grade each year. Thus, as shown in Table 2, before 2005 each grade alternated in taking the test. The table also shows the average and standard deviation (in parenthesis) of SIMCE results by grade and year. Those results include an important improvement in the reading test results for fourth graders since 1999, but not in math. For eighth and tenth graders, however, there is no clear trend in either math or reading test scores.[4]

School-level data from the SIMCE also include information on schools including socio-economic status and classification according to public, private or charter type. Socio-economic status is classified in five categories from low to high.

Our estimation strategy will consider the following model to examine the contemporary correlation between air pollution variables and test scores outcomes:[5]

$$Test_{gsct}^{m} = \alpha + \beta_1^m POLL_{sct} + \gamma' X_s + \nu_{gs} + \lambda_t + \varepsilon_{gst} \quad (3)$$

where $Test_{gsct}$ is the test score for grade g, school s, municipality c and year t, m indicates math, reading, natural science or social comprehension scores, $POLL_{sct}$ is the measure of pollution for school s in year t, ν_{gs} denotes school-grade fixed effect, λ_t captures year fixed effect, and X_s[6]

[4]Table 2 shows the score summary for social and natural science tests, which are taken only by children in fourth and eighth grades

[5]Although SIMCE scores may be affected by more long-run impacts of pollution, the data unfortunately do not include children's place of residence or any other data that would allow us to infer if children changed from one school to another. Therefore, it is not possible to use cumulative air pollution as a dependent variable to capture the long-run effects of air pollution on children. In this way, we cannot be sure that these regressions reflect only contemporary effects.

[6]We included as robustness checks regressions including climatological variables, precipitation and temperature, and our main results were unchanged. However, we decided not to report these results, as we consider that the interpolation of these variables at school level was not very reliable.

denotes school controls including number of children, categorical variables for socio-economic status and for private, charter or public school.[7] Finally, ε_{gst} is the error term capturing all other observed and unobserved determinants.

We used a fixed effect estimation to identify the effect of air pollution on test scores. The school-grade fixed effect will help control for unobservable time-constant factors and the time fixed effect will help capture sample-wide effects for each year. One key assumption for a correct estimation by equation 3 is that unobserved time-varying variables will not affect both pollution and test scores. With the fixed effect we are controlling for many possible confounding factors, such as the location of schools with certain characteristics in high-pollution areas. Measurement errors in the interpolation of pollution to schools could also lead to misleading results.[8]

Since 1998, the SIMCE scale has been revised to allow comparisons of scores over time, and procedures have been changed to increase the tests' validity. Therefore, SIMCE results are highly comparable between years and even comparable in an international context (Meckes and Carrasco, 2010). The day of the SIMCE tests was always between the first and third week of November, with the exception of the last three years, when the test was administered in the middle of October. Approximately 14 percent of schools in the sample are private schools, while 37 percent are public schools and 48 percent are charter schools.[9] In socio-economic terms, 7 percent of schools are in the the lowest status group, 32 percent in the middle low category, 31 percent in the middle category, 17 percent in the middle high category, and 11 percent in the highest socio-economic status.[10]

For our pollution variable we use several outdoor air pollution contaminants. The pollutants used in our estimations include PM_{10}, $PM_{2.5}$, CO, NO_x and O_3. All pollutants are measured in micrograms per cubic meter. Appendix Tables A.2, A.3 and A.4 show the daily average and standard deviations of these variables by municipality in each region. PM_{10} refers to particulate matter with a diameter less than 10 microns and is often considered a marker of coarse particles. $PM_{2.5}$, on the other hand, is considered a marker for fine particles. It measures particulate matter but with a diameter of less than 2.5 microns. The most important problem with atmospheric contamination in the Metropolitan, Valparaiso (Fifth) and O'Higgins (Sixth) Regions is associated with these pollutants. For our sample period, 1997 to 2012, these two pollutants have exceeded the standard quality norm of 50 and 20 micrograms per cubic meter for PM_{10} and $PM_{2.5}$, respectively. However, data for $PM_{2.5}$ were not available for many of the years in our sample. Particulate matter is

[7]For many schools these variables are almost time-invariant, but specially with the socio-economic variable there is some within-school variation over time, especially for the socio-economic variable.

[8]In robustness checks we omit from the regressions schools farther than 5 kilometers from a monitoring station to avoid possible overestimation or underestimation of pollution in those relatively remote locations.

[9]Table A.1 shows the summary statistics

[10]Some schools changed their socio-economic status and their private, public or charter type over time.

highly associated in all the literature with health problems, as these particulates are small enough to penetrate through airways until they reach the lungs.

PM_{10} is composed of pollutants of both natural and anthropogenic origin. The latter include both primary pollutants such as natural dust, soot and metals and secondary pollutants composed of organic compounds, heavy metals, and nitrogenous compounds. Pollutants such as nitrogen oxide, NO_x, are the main sources of those compounds, which is why particulate matter is highly correlated with such pollutants. Emissions from the industrial and transport sector are the main sources of nitrogen oxide. Ozone, O_3, is also a secondary pollutant highly correlated with NO_x. Levels of ozone in the three regions are very high and exceed quality standard norms. Unlike PM_{10}, ozone levels are higher during summer because of higher photochemical activity. The reason for lower values of PM_{10} during summer is higher dispersion and ventilation in warm temperatures. Carbon monoxide, CO, is a pollutant mainly released by motor vehicles; the annual one-hour norm is normally not exceeded in the three regions of study. As shown in Table 4, all pollutants are positively correlated. The main annual measure for each of the pollutants will be the annual mean. Nevertheless, the robustness of the estimations will be checked by using other annual measures: the annual 98^{th} percentile, the percentage of days, weeks and months above certain values related to the standard quality norm, the week moving average and the average 98^{th} percentiles by months and weeks.

3 Results

3.1 PM_{10} *Effects*

Table 5 reports the baseline results of this work, i.e., the relationship of PM_{10} levels with test scores. The dependent variable is average grade test scores for reading, math, social comprehension and natural science as dependent variables. This includes both time and school-grade fixed effects and the standard errors are clustered by school to allow for heteroskedasticity and dependence across schools. Coefficients for the PM_{10} variable in columns (1) and (2) indicate that a decrease of 10 micrograms per cubic meter is associated with an increase of 0.7 units in reading and math scores. This represents a decrease in 2.3 percent, 2.6 percent, 2.7 percent and 4.9 percent of a standard deviation for reading, math, social science and natural science, respectively.[11] Calculating the elasticities, this means that a 10 percent decrease in the PM_{10} levels would increase math and reading scores by 0.16 percent and 0.14 percent, respectively. The magnitude of the coefficients in columns (2) and (3) is slightly similar, but the magnitude increases when using natural science scores as dependent variable.[12] All the coefficients estimated are statistically significant at

[11] The coefficients are higher when doing the estimations just for the Metropolitan Region (see Table A.5).

[12] Significant results were also found in the estimations in Appendix Table A.6 weighting by the number of students in each school. The number of observations is smaller, as the data on number of students are missing for two years

the 1 percent level and suggest a strong correlation between PM_{10} air pollution levels and SIMCE results.[13]

In the municipality of Rancagua, one of the most polluted municipalities in Chile, the average PM_{10} level in 2012 was around 76 micrograms per cubic meters. This means that if Rancagua would reduce the PM_{10} pollution below the standard quality norm (50 micrograms per cubic meter), that reduction would be associated with an increase in reading test scores of 1.12 units (3.75 percent of a standard deviation) for an average school in this municipality. This magnitude is almost half as large as the effect of one year more of education of a children's mother and a third of the effects of productivity bonuses for teachers (Contreras et al., 2003).

Compared with other studies, these results show very similar effects of air pollution. In the work by Zweig et al. (2012), the authors found that a 10 percent decrease in PM_{10} would increase math test scores by 0.36 percent. Lavy et al. (2012) analyzed $PM_{2.5}$ and affirmed that a 10-unit increase in this pollution variable reduces Bagrut test scores by 1.9 percent of a standard deviation. Similarly to those studies, we found that a 10-unit increase in PM_{10} is associated with a decrease in 2.3 percent, 2.6 percent, 2.7 percent and 4.9 percent of a standard deviation for reading, math, social science and natural science, respectively.

In Table 6, we report whether pollution affects all school grades in the same way. As the table shows, the effect of PM_{10} air pollution is higher with eighth graders. The coefficients using only SIMCE results for eighth graders are statistically significant at the 1 percent level. These results indicate that a 10-unit decrease in PM_{10} is related to an increase in 1.3, 1.4, 1.3 and 1.8 points in reading, math, social science and natural science SIMCE scores, respectively. The effect is also negative when doing the estimations for only fourth graders, but the coefficients reflect less than half of the effect of air pollution as compared with the results for eighth graders.[14] The results are not significant when using social science and natural science as dependent variables. Results for tenth graders do not show any statistically significant effect of air pollution, although the sample is reduced. The coefficient for math scores even has an unexpected positive sign. Table A.7 in the Appendix reports the results by disaggregating schools according to their socio-economic status and by the type of schools, i.e., public, private or charter. Results show higher magnitude for the coefficients with only the sample of schools of low socio-economic status. However, coefficients are still significant and negative for schools of middle-high socio-economic status. The results for the sample of private and public schools are quite similar.

We also construct several annual indicators for PM_{10} air pollution to check the robustness of our results. Each row of Table 7 is a different estimation with a different measure for PM_{10}

[13]Regressions in Appendix Table A.6 show the robustness check for our estimations including and excluding some fixed effects, including a variable to control for trends in tests score and estimations using quantile regression.

[14]The F-test indicated that the coefficients were statistically different from each other at the 1 percent level

levels. It includes the 98^{th} annual percentile, the percentage of months and weeks with the average and 98^{th} percentile of PM_{10} above the 2012 quality standard norm (120 micrograms per cubic meter) and the previous quality standard norm (150 micrograms per cubic meter), and several measures for the percentage of days, weekdays and winter weekdays above both thresholds. All the coefficients results are negative and almost all are statistically significant. These results confirm our previous suggestions about the negative association between PM_{10} levels and standardized tests scores.

In the estimations of Appendix Table A.8 all schools farther than 5 km from a monitoring station are omitted in order to avoid any coefficient bias because of errors in the interpolation of pollution variables. These schools could be far enough to generate some errors in the kriging interpolation.[15] The results from this exercise show results similar to those of previous estimations but with coefficients of slightly higher magnitude. Nevertheless, the coefficients when using social and natural science as dependent variables are no longer significant.

3.2 Non-Linear Effects of PM_{10}

Table 8 examines the possible non-linear effects of PM_{10}. Results from these estimations including the squared PM_{10} variable suggest that the negative marginal effects become higher when pollution increases. The coefficient of the non-squared variable is positive, but the turning points, i.e., the point when SIMCE results start to decline with PM_{10} levels, are at low values of PM_{10}. The turning points of reading, math, social comprehension and natural science test scores are 41.09, 24.37, 43.18 and 50.1 micrograms per cubic meter, respectively. These turning points are relatively low compared with the annual PM_{10} averages for many of the municipalities in the three regions of study between 1997-2012. Even in the recent and less polluted years, most municipalities in these regions have PM_{10} annual averages above 50 micrograms per cubic meter(Ponce, 2012).

The results are interesting as they suggest that PM_{10} levels have greater marginal effects on test scores when pollution concentrations are higher. Likewise, the negative effects seem to occur only when PM_{10} levels surpass 50 micrograms per cubic meter, which is the international quality standard norm for annual PM_{10}. Annual exposure to PM_{10} levels above this threshold is considered to have serious impacts on health. Nonetheless, in 2012 schools in certain municipalities continued to be exposed to annual PM_{10} levels close to 75 micrograms per cubic meters, while other schools were exposed to levels around the 40 micrograms per cubic meter. This means that the negative effect on reading test scores of a 10 micrograms per cubic meter of PM_{10} increment for a school in the most polluted municipalities is close to 0.8 units, while for a school in the least polluted municipalities the effect is close to zero.

[15]Kriging interpolation was, however, checked with cross-validation to avoid errors in estimation

3.3 Other Pollutants

We continue to examine the effects of other pollution variables on test scores. Tables 9 and 10 show the estimation results for reading and math scores using annual averages for different pollutants. Reporting days for these other pollutants were fewer than those in the data for PM_{10}. Therefore, we were not able to take advantage of the time variability within schools as with PM_{10}. Many of the coefficients do not show significant results, and some of them are even positive. Results for ozone (O_3) are as expected: negatively correlated with test scores and statistically significant when using reading test scores. This pollutant is extremely harmful for human health even at low concentration levels. Scientific evidence indicates that ozone pollution induces respiratory inflammation in healthy people. Ozone is also responsible for many of the medical visits related to lower and upper respiratory symptoms in Santiago (Ostro et al., 1999). Estimation of column (5) in Table 9 suggests that an increase in 10 micrograms per cubic meter is associated with a decline in reading tests of 0.6 units.

As mentioned before, particulate matter has been implicated as one of the major contributor to the increase in morbidity and mortality. Particulate matter of very small diameter is considered more toxic than PM_{10}. Notwithstanding, both PM_{10} and $PM_{2.5}$ can generate serious respiratory illnesses. Ilabaca et al. (1999) find huge impacts of particulate matter, in particular $PM_{2.5}$, on the number of respiratory-related emergency visits. However, in our estimations for this pollutant the coefficients for this variable are not statistically different from zero.

We now turn to analyze the effect of pollution in the week of the exams. The idea is to look for the immediate effects of air pollution on academic performance. This examination will capture the very short-term effects of pollution, especially fatigue and acute respiratory health problems. We are assuming that air pollution would affect both the more healthy children and children with chronic respiratory illnesses. Short-term air pollution would end up affecting SIMCE tests scores because of fatigue and weakness associated with illnesses.

Tables 11 and 12 show the estimations for reading and math scores, respectively. The effects of air pollution on test results are substantial, especially for PM_{10}, PM_{25} and NO_x. Exposure to particulate matter is extremely harmful for human health because of the effects on breathing and respiratory systems. Children with chronic diseases such as asthma tend to be very sensitive to exposure to these pollutants. Nitrogen oxide is related to high levels of particulate matter as well as with ozone. Exposure to this pollutant can generate airway inflammation to healthy people as well as respiratory problems for children with asthma. It has been proved by different studies that short-term concentrations can increase the number of visits to emergency and hospital admissions for respiratory issues.

These results suggest a negative relationship between the different air pollution measures and test scores. Calculating the elasticities, the coefficients tell us that a 10 percent decrease in the levels of PM_{10}, $PM_{2.5}$ and NO_x is associated with an increase of 0.29 percent, 0.17 percent and 0.1 percent, respectively, in reading scores. The same 10 percent decline in air pollutants is related to an increase of 0.24 percent, 0.06 percent and 0.1 percent, respectively, in math scores. We found higher effects for $PM_{2.5}$ than in the work by Lavy et al. (2012). Our specification indicates that a 10-unit increase in $PM_{2.5}$ is associated with a decline of 2.68 percent and 2.35 percent of a standard deviation in reading and math scores, respectively.

4 Conclusions

We have found a clear relationship of different air pollutants with schools performance in the SIMCE exams. Using a large panel sample of schools in the Metropolitan, Valparaiso and O'Higgins regions, we estimated some fixed effects regressions that showed a robust negative association of pollution with school performance. This work provides another reason to promote environmental policies in order to reduce outdoor air pollution. Several studies have shown the effects of particulate matter and other pollutants on morbidity and mortality, and other studies studies have likewise affirmed the effects of air pollution on cognition and brain development, as well as secondary effects on school performance by worsening behavioral problems, absenteeism and fatigue in children. The results from this work suggest that air pollution does in fact affect school performance, in particular standardized test scores.

The main effect is from PM_{10} pollution, which consists of solid or liquid particles in the air originating from mobile and stationary sources such as diesel trucks and power plants. Particulate matter pollution is one of the major atmospheric pollution problems in these regions of Chile, and several efforts have been made to reduce it. The results indicate that a 10 micrograms per cubic meter increase in this variable is associated with a decline of 0.7 units in test scores. The magnitudes of the coefficients are increased only when considering the Metropolitan Region and eighth grade exams. Effects of other pollutants on test scores were only found when using ozone concentrations.

Short-term air pollution can also generate temporary symptoms that can affect childrens school performance. The effect of average pollution in the week of the exam was examined, and the results were significant, showing that high levels of different pollutants, in particular PM_{10}, $PM_{2.5}$ and NO_x, in the week of exam can affect results in reading and math.

The results from this work are similar to the findings of previous studies. This work found slightly higher magnitude effects for some pollutants and considers the effects in a developing country where pollution levels are much higher than in most developed countries. Therefore the conclusions from this analysis suggest that reducing ambient pollution could also have positive effects on children's education and on their future human capital formation and earnings. However, with this work it is not possible to affirm the exact pathway through which pollution may be affecting schools performance, nor have we have controlled for all factors associated with both pollution and test scores. Likewise, future work is needed to identify the exact timing through which pollution exposure can affect children. In particular, the effects of long-term exposure to pollution on school performance should be mentioned. As mentioned, pollution exposure can have long-lasting effects on brain development, with an impact on cognitive ability.

Figure 1. Effect of Air Pollution on Test Scores

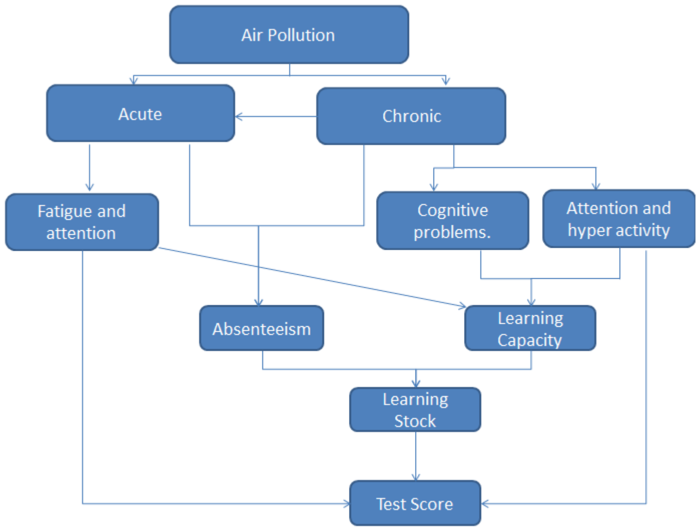


Figure 2. Monitoring Stations Location

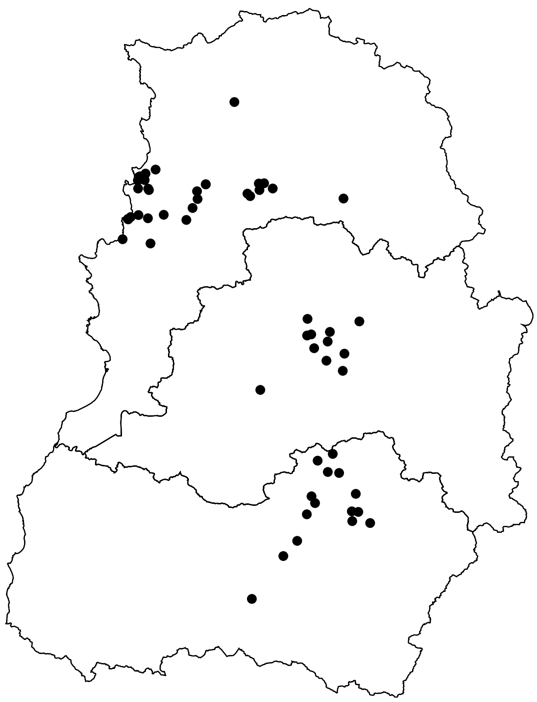
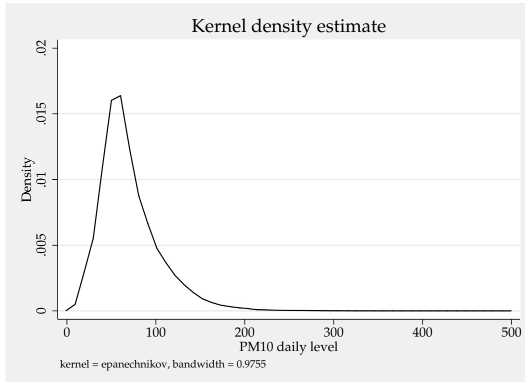


Figure 3. Kernel for Daily PM10



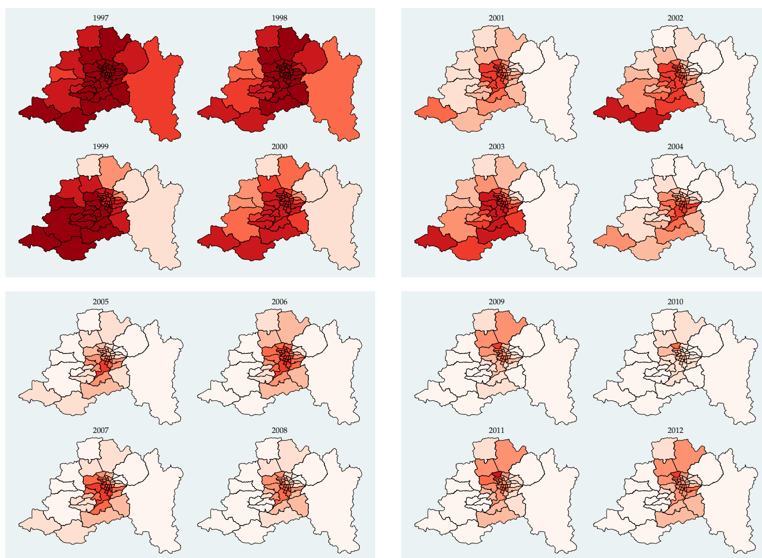


Figure 4. PM10 Municipality Annual Mean (8 quantiles)

Table 1. Average PM10 Daily Information Available

Year	Average number of stations in region Metro.	Average number of stations in region V	Average number of stations in region VI	Days with PM10 interpolated
1997	4.9	1.6	0.0	114
1998	6.8	1.7	0.0	171
1999	6.9	2.8	0.0	287
2000	6.9	3.6	0.0	154
2001	7.4	3.6	0.2	163
2002	7.7	4.4	0.3	227
2003	6.9	4.8	0.5	271
2004	6.9	6.3	2.4	339
2005	7.9	7.6	3.1	364
2006	6.9	7.7	3.7	365
2007	7.0	8.6	5.1	365
2008	7.9	11.4	5.5	366
2009	10.8	7.7	4.3	364
2010	10.7	8.8	3.5	364
2011	10.8	3.6	3.4	363
2012	8.3	3.2	3.3	281

Table 2. Reading and Math Scores Summary Table

	4th Read.	8th Read.	10th. Read.	4th Math	8th Math	10th Math
1997		251.7			247.6	
		(33.39)			(34.87)	
1998			263.4			262.0
			(34.94)			(36.52)
1999	250.0			250.4		
	(29.73)			(28.18)		
2000		249.2			249.2	
		(28.39)			(29.67)	
2001			262.5			259.6
			(32.02)			(39.76)
2002	250.8			246.6		
	(31.32)			(30.83)		
2003			263.8			259.4
			(31.87)			(45.34)
2004		250.8			252.6	
		(29.10)			(30.00)	
2005	254.4			246.7		
	(28.38)			(29.84)		
2006	250.8		261.8	245.7		261.2
	(27.95)		(33.37)	(30.73)		(47.51)
2007	252.0	251.1		243.9	254.1	
	(28.18)	(28.13)		(31.73)	(29.98)	
2008	257.2		261.1	244.3		257.7
	(28.02)		(33.09)	(31.95)		(46.62)
2009	257.3	248.6		248.4	256.6	
	(27.96)	(28.13)		(31.99)	(31.20)	
2010	266.8		264.6	248.1		263.0
	(24.82)		(33.48)	(30.25)		(45.49)
2011	261.8	249.3		252.5	254.7	
	(25.17)	(28.26)		(28.81)	(29.20)	
2012	261.1		261.3	253.5		269.3
	(27.06)		(34.90)	(29.54)		(46.17)

Standard deviation in parenthesis

Table 3. Social and Natural Science Scores Summary Table

	4th Bsc Soc.	8th Bsc Soc.	4th Bsc Nat.	8th Bsc Nat.
1997		243.9		238.9
		(32.93)		(34.68)
1998				
1999				
2000		250.5		250.0
		(26.85)		(28.13)
2001				
2002				
2003				
2004		250.4		256.0
		(27.22)		(29.60)
2005				
2006				
2007		249.4	248.3	256.3
		(27.92)	(28.89)	(29.63)
2008	248.2			
	(27.79)			
2009		248.4	251.9	255.9
		(28.43)	(28.98)	(30.60)
2010	251.3			
	(26.70)			
2011		256.5	253.8	257.8
		(27.16)	(26.73)	(30.83)
2012	251.9			
	(27.54)			

Table 4. Correlations of pollutant variables

Variables	PM10	PM25	CO	NOx	O3
PM10 mean	1.00				
PM25 mean	0.57	1.00			
	(0.00)				
CO mean	0.20	0.44	1.00		
	(0.00)	(0.00)			
NOx mean	0.73	0.40	0.54	1.00	
	(0.00)	(0.00)	(0.00)		
O3 mean	0.10	0.10	0.30	0.34	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	

Table 5. Contemporary Effect of PM10 on Test Scores in Metropolitan, V and VI Regions

	(1)	(2)	(3)	(4)
	read	math	soc	nat
VARIABLES	FE	FE	FE	FE
Annual PM10 mean	-0.0715***	-0.0785***	-0.0775***	-0.150***
	(0.0195)	(0.0204)	(0.0213)	(0.0300)
Observations	50,431	50,419	33,246	23,014
Number of School-level	8,282	8,284	6,543	6,148
School FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table 6. Contemporary Effect of PM10 on Test Scores in Metropolitan V and VI Regions by Grades

	(1)	(2)	(3)	(4)
	read	math	soc	nat
VARIABLES	FE	FE	FE	FE
4th Graders				
Annual PM10 mean	-0.0664**	-0.0479*	-0.0356	0.0233
	(0.0263)	(0.0277)	(0.0277)	(0.0578)
Observations	26,983	26,977	18,585	8,346
8th Graders				
Annual PM10 mean	-0.129***	-0.138***	-0.126***	-0.181***
	(0.0323)	(0.0331)	(0.0320)	(0.0340)
Observations	14,669	14,664	14,661	14,668
10th Graders				
Annual PM10 mean	0.0651	-0.0432		
	(0.0575)	(0.0444)		
Observations	8,779	8,778		
School FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table 7. Effect for different PM10 measures using Metropolitan, V and VI regions

	Math Score		Reading Score	
PM10 Variable	Coefficient	Std. Error	Coefficient	Std. Error
Annual 98th percentile	-0.01	(0.01)**	-0.03	(0.01)***
Perc. months with 98th percentile PM10 above 120 ug/m3	-1.06	(0.24)***	-1.25	(0.22)***
Perc. months with 98th percentile PM10 above 150 ug/m3	-0.32	(0.37)	-1.43	(0.34)***
Perc. weeks with 98th percentile PM10 above 120 ug/m3	-4.39	(1.23)***	-4.84	(1.12)***
Perc. weeks with 98th percentile PM10 above 150 ug/m3	-7.35	(1.87)***	-10.17	(1.75)***
Perc. of days with PM10 above 120 ug/m3	-0.13	(0.03)***	-0.13	(0.03)***
Perc. of days with PM10 above 150 ug/m3	-0.17	(0.05)***	-0.25	(0.04)***
Perc.of days with PM10 above 150 ug/m3 (week moving average)	-0.16	(0.04)***	-0.27	(0.04)***
Perc. months with PM10 above 120 ug/m3	-0.10	(0.02)***	-0.12	(0.02)***
Perc. months with PM10 above 150 ug/m3	-0.03	(0.04)	-0.16	(0.04)***
Perc. of weekdays with PM10 above 120 ug/m3	-0.14	(0.03)***	-0.12	(0.03)***
Perc. of weekdays with PM10 above 150 ug/m3	-0.17	(0.04)***	-0.20	(0.04)***
Perc. weeks with PM10 above 120 ug/m3	-0.09	(0.03)***	-0.11	(0.03)***
Perc. weeks with PM10 above 150 ug/m3	-0.17	(0.04)***	-0.25	(0.04)***
P. winter weekdays>120	-0.07	(0.02)***	-0.05	(0.02)***
P. winter weekdays>150	-0.09	(0.03)***	-0.11	(0.02)***

Entries in each row are point estimates from a separate regression.

Standard errors in parentheses clustered by school.

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table 8. Non-Linear Effect of PM10 on Test Scores in Metropolitan, V and VI Regions

VARIABLES	(1) read FE	(2) math FE	(3) soc FE	(4) nat FE
$Annual\ PM_{10}\ mean$	0.0983	0.0393	0.114	0.268***
	(0.0679)	(0.0725)	(0.0766)	(0.100)
$Annual\ PM_{10}\ mean^2$	-0.00120**	-0.000831	-0.00132**	-0.00267***
	(0.000469)	(0.000509)	(0.000543)	(0.000681)
Observations	50,431	50,419	33,246	23,014
Number of School-Level	8,282	8,284	6,543	6,148
School-Level FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table 9. Contemporary Effect of Pollution on Reading Scores in Metropolitan, V and VI Regions

VARIABLES	(1) read FE	(2) read FE	(3) read FE	(4) read FE
PM25 mean	0.0218			
	(0.0350)			
CO mean		0.647		
		(0.562)		
NOx mean			-0.0226	
			(0.0233)	
O3 mean				-0.0628**
				(0.0258)
Observations	18,762	26,413	23,060	31,763
Number of School-Level	5,636	6,229	6,036	6,491
School-Level FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table 10. Contemporary Effect of Pollution on Math Scores in Metropolitan, V and VI Regions

VARIABLES	(1) math FE	(2) math FE	(3) math FE	(4) math FE
PM25 mean	0.0284			
	(0.0380)			
CO mean		0.00558		
		(0.605)		
NOx mean			-0.0195	
			(0.0251)	
O3 mean				-0.0351
				(0.0278)
Observations	18,773	26,427	23,068	31,773
Number of School-Level	5,637	6,231	6,039	6,492
School-Level FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table 11. Effect in the Week of the Exam on Reading Scores in Metropolitan, V and VI Regions

VARIABLES	(1) read FE	(2) read FE	(3) read FE	(4) read FE	(5) read FE
PM10week	-0.140***				
	(0.0144)				
PM25week		-0.238***			
		(0.0424)			
COweek			0.984		
			(0.911)		
NOxweek				-0.180***	
				(0.0358)	
O3week					0.0652
					(0.0407)
Observations	38,929	18,433	23,061	19,219	25,991
Number of School-Level	6,820	5,475	5,863	5,689	6,136
School-Level FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 12. Effect in the Week of the Exam on Math Scores in Metropolitan, V and VI Regions

	(1)	(2)	(3)	(4)	(5)
	math	math	math	math	math
VARIABLES	FE	FE	FE	FE	FE
PM10week	-0.115***				
	(0.0143)				
PM25week		-0.0822*			
		(0.0448)			
COweek			-1.314		
			(0.999)		
NOxweek				-0.155***	
				(0.0356)	
O3week					0.0566
					(0.0436)
Observations	38,929	18,444	23,073	19,224	26,001
Number of School-Level	6,821	5,476	5,863	5,687	6,137
School-Level FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

References

Arceo-Gomez, E. O., Hanna, R., and Oliva, P. 2012. "Does the Effect of Pollution on Infant Mortality Differ Between Developing and Developed Countries? Evidence from Mexico City". Technical report, National Bureau of Economic Research.

Banks, E. C., Ferretti, L. E., and Shucard, D. 1997. "Effects of low level lead exposure on cognitive function in children: a review of behavioral, neuropsychological and biological evidence.". *Neurotoxicology*, 18(1):237.

Bates, D. V. 1995. "The effects of air pollution on children.". *Environmental health perspectives*, 103(6):49.

Burnett, R. T., Dales, R. E., Raizenne, M. E., Krewski, D., Summers, P. W., Roberts, G. R., Raad-Young, M., Dann, T., and Brook, J. 1994. "Effects of low ambient levels of ozone and sulfates on the frequency of respiratory admissions to Ontario hospitals.". *Environmental research*, 65(2):172.

Bussing, R., Halfon, N., Benjamin, B., and Wells, K. B. 1995. "Prevalence of behavior problems in US children with asthma". *Archives of pediatrics & adolescent medicine*, 149(5):565.

Calderón-Garcidueñas, L., Mora-Tiscareño, A., Ontiveros, E., Gómez-Garza, G., Barragán-Mejía, G., Broadway, J., Chapman, S., Valencia-Salazar, G., Jewells, V., Maronpot, R. R., et al. 2008. "Air pollution, cognitive deficits and brain abnormalities: a pilot study with children and dogs". *Brain and cognition*, 68(2):117–127.

Carroll, H. T. 2010. "The effect of pupil absenteeism on literacy and numeracy in the primary school". *School Psychology International*, 31(2):115–130.

Contreras, D., Flores, L., Lobato, F., and Macías, V. 2003. "Monetary incentives for teachers and school performance: Evidence for Chile". *Department of Economics, University of Chile*.

Currie, J., Hanushek, E. A., Kahn, E. M., Neidell, M., and Rivkin, S. G. 2009. "Does pollution increase school absences?". *The Review of Economics and Statistics*, 91(4):682–694.

Ehrenberg, R. G., Ehrenberg, R. A., Rees, D. I., and Ehrenberg, E. L. 1991. "School district leave policies, teacher absenteeism, and student achievement". *The Journal of Human Resources*, 26:72–105.

Gilliland, F. D., Berhane, K., Rappaport, E. B., Thomas, D. C., Avol, E., Gauderman, W. J., London, S. J., Margolis, H. G., McConnell, R., Islam, K. T., et al. 2001. "The effects of ambient air pollution on school absenteeism due to respiratory illnesses". *Epidemiology*, 12(1):43.

Gligo, N. V. 2010. Estado del Medio Ambiente en Chile 2008, chapter Aire, pages 34–71. Centro de Análisis de Políticas Públicas Instituto de Asuntos Públicos. Universidad de Chile.

Graff Zivin, J. and Neidell, M. 2012. "The impact of pollution on worker productivity". *American Economic Review*, 102:3652–3673.

Gramsch, E., Cereceda-Balic, F., Oyola, P., and Von Baer, D. 2006. "Examination of pollution trends in Santiago de Chile with cluster analysis of PM10 and Ozone data". *Atmospheric environment*, 40(28):5464–5475.

Halterman, J. S., Montes, G., Aligne, C. A., Kaczorowski, J. M., Hightower, A. D., and Szilagyi, P. G. 2001. "School readiness among urban children with asthma". *Ambulatory Pediatrics*, 1(4):201–205.

Ilabaca, M., Olaeta, I., Campos, E., Villaire, J., Tellez-Rojo, M. M., and Romieu, I. 1999. "Association between levels of fine particulate and emergency visits for pneumonia and other respiratory illnesses among children in Santiago, Chile". *Journal of the Air & Waste Management Association*, 49(9):154–163.

Kampa, M. and Castanas, E. 2008. "Human health effects of air pollution". *Environmental Pollution*, 151(2):362–367.

Lavy, V., Ebenstein, A., and Roth, S. 2012. "The Impact of Air Pollution on Cognitive Performance and Human Capital Formation". *Unpublished*. `http://www2.warwick.ac.uk/fac/soc/economics/staff/academic/lavy/text_and_tables_air_pollution_draft_20_09_12.pdf`.

Meckes, L. and Carrasco, R. 2010. "Two decades of SIMCE: an overview of the National Assessment System in Chile". *Assessment in Education: Principles, Policy & Practice*, 17(2):233–248.

Mohai, P., Kweon, B.-S., Lee, S., and Ard, K. 2011. "Air pollution around schools is linked to poorer student health and academic performance". *Health Affairs*, 30(5):852–862.

Ostro, B. D., Eskeland, G. S., Sanchez, J. M., and Feyzioglu, T. 1999. "Air pollution and health effects: a study of medical visits among children in Santiago, Chile.". *Environmental Health Perspectives*, 107(1):69.

Pastor, M., Morello-Frosch, R., and Sadd, J. L. 2006. "Breathless: schools, air toxics, and environmental justice in California". *Policy Studies Journal*, 34(3):337–362.

Ponce, M. 2012. Official Environment Status Report 2011. Ministerio del Medio Ambiente. Gobierno de Chile.

Pope III, C. A. and Dockery, D. W. 2006. "Health effects of fine particulate air pollution: lines that connect". *Journal of the Air & Waste Management Association*, 56(6):709–742.

Rau, T., Reyes, L., and Urzúa, S. S. 2013. "The Long-term Effects of Early Lead Exposure: Evidence from a case of Environmental Negligence". *NBER Working Paper*, 18915.

Segal, C. 2008. "Classroom behavior". *Journal of Human Resources*, 43(4):783–814.

Silverstein, M. D., Mair, J. E., Katusic, S. K., Wollan, P. C., OConnell, E. J., and Yunginger, J. W. 2001. "School attendance and school performance: a population-based study of children with asthma". *The Journal of pediatrics*, 139(2):278–283.

Spee-Van Der Wekke, J., Meulmeester, J., Radder, J., and Verloove-Vanhorick, S. 1998. "School absence and treatment in school children with respiratory symptoms in The Netherlands: data from the Child Health Monitoring System.". *Journal of epidemiology and community health*, 52(6):359–363.

Suglia, S. F., Gryparis, A., Wright, R., Schwartz, J., and Wright, R. 2008. "Association of black carbon with cognition among children in a prospective birth cohort study". *American Journal of Epidemiology*, 167(3):280–286.

Van der Zee, S., Hoek, G., Boezen, H. M., Schouten, J. P., van Wijnen, J. H., and Brunekreef, B. 1999. "Acute effects of urban air pollution on respiratory health of children with and without chronic respiratory symptoms.". *Occupational and Environmental Medicine*, 56(12):802–812.

Wang, S., Zhang, J., Zeng, X., Zeng, Y., Wang, S., and Chen, S. 2009. "Association of traffic-related air pollution with childrens neurobehavioral functions in Quanzhou, China". *Environmental health perspectives*, 117(10):1612.

Zweig, J., Ham, J., and Avol, E. 2012. "Air Pollution and Academic Performance: Evidence from California Schools". *Unpublished*. `http://econweb.umd.edu/~ham/test%20scores%20submit.pdf`.

.

A Appendix Tables

Table A.1. Summary statistics

Variable	Mean	(Std. Dev.)
Reading Score	255.852	(29.847)
Math Score	251.997	(34.018)
Social Comprehension Score	251.448	(28.877)
Natural Science Score	252.512	(30.243)
PM10 daily annual mean	63.354	(14.212)
PM2.5 daily annual mean	23.925	(6.707)
CO daily annual mean	0.703	(0.418)
NOx daily annual mean	46.671	(23.347)
O3 daily annual mean	18.207	(12.619)
Private School	0.137	
Public School	0.377	
Charter School	0.486	
Low Socio-economic status	0.078	
Middel Low Socio-economic status	0.326	
Middel Socio-economic status	0.307	
Middel high Socio-economic status	0.172	
High Socio-economic status	0.116	

Table A.2. Pollutants Variables by Municipality in the Metropolitan Region

comuna	Mean Daily PM10	Sd Daily PM10	Mean Daily PM25	Sd Daily PM25	Mean Daily CO	Sd Daily CO	Mean Daily SO2	Sd Daily SO2	Mean Daily O3	Sd Daily O3	Mean Daily NOx	Sd Daily NOx
ALHUE	60.6	14.0	40.40	7.62	1.19	0.84	7.2	1.1	13.4	10.6	32.7	10.0
BUIN	70.3	11.3	29.79	2.62	0.78	0.43	0.2	0.6	15.0	2.9	39.6	7.1
CALERA DE TANGO	69.9	9.9	27.45	4.44	0.81	0.27	0.2	0.5	15.9	2.1	51.8	7.8
CERRILLOS	74.1	10.2	27.68	5.66	0.70	0.24	4.4	1.2	18.1	2.9	66.7	6.9
CERRO NAVIA	75.1	9.8	29.11	6.73	0.77	0.25	3.4	0.9	16.8	2.7	70.1	5.8
COLINA	65.0	6.8	23.74	5.03	0.60	0.26	0.0	0.0	20.7	2.5	50.6	6.0
CONCHALI	71.2	8.7	27.04	5.85	0.70	0.22	3.4	0.9	16.0	2.8	73.4	4.0
CURACAVI	56.4	8.0	25.65	5.97	0.61	0.26	6.6	1.9	13.9	2.9	18.3	4.2
EL BOSQUE	76.0	9.2	28.56	5.10	0.84	0.19	3.4	1.3	16.2	2.3	69.3	6.6
EL MONTE	58.1	13.0	26.15	4.29	0.75	0.49	3.3	1.0	13.9	2.7	23.0	5.9
ESTACION CENTRAL	74.5	9.9	27.74	6.06	0.72	0.26	4.5	1.2	17.3	3.0	72.1	6.0
HUECHURABA	68.3	8.0	25.52	5.47	0.67	0.23	2.6	0.8	15.5	3.2	71.2	3.7
INDEPENDENCIA	71.6	9.4	26.71	5.80	0.72	0.23	4.2	1.4	15.6	3.2	76.9	4.2
ISLA DE MAIPO	61.3	12.7	27.90	3.18	0.87	0.58	1.1	1.4	13.6	3.0	29.3	7.6
LA CISTERNA	76.3	8.8	27.51	5.30	0.85	0.22	4.2	1.5	16.4	2.7	72.7	5.8
LA FLORIDA	71.4	8.9	26.97	2.95	0.81	0.21	3.8	2.4	20.6	3.3	50.8	6.9
LA GRANJA	74.7	8.9	27.97	4.15	0.83	0.22	2.6	1.0	18.3	2.7	63.5	5.7
LA PINTANA	72.7	9.2	28.27	3.20	0.81	0.17	1.3	0.8	19.8	2.7	55.6	8.1
LA REINA	64.3	8.7	24.57	3.51	0.71	0.19	4.1	1.8	19.4	4.5	52.2	6.2
LAMPA	66.6	6.5	24.74	5.95	0.58	0.19	0.0	0.1	23.4	2.1	37.2	5.3
LAS CONDES	61.5	9.7	23.22	3.55	0.66	0.19	3.4	2.0	20.0	5.4	51.8	9.3
LO BARNECHEA	55.4	7.8	22.00	3.00	0.58	0.20	3.2	1.7	22.4	5.4	41.9	6.5
LO ESPEJO	75.6	9.5	28.61	5.61	0.77	0.22	4.5	1.5	17.0	2.7	71.0	6.4
LO PRADO	74.4	9.6	28.51	6.53	0.75	0.25	4.1	1.0	16.3	2.9	72.5	5.9
MACUL	72.2	9.2	26.52	4.03	0.80	0.22	3.5	1.4	16.8	3.4	62.9	4.7
MAIPU	71.8	9.0	27.02	5.73	0.74	0.20	3.0	1.0	17.5	2.6	61.5	7.1
MARIA PINTO	56.8	10.4	28.16	6.10	0.66	0.35	9.7	3.3	12.2	3.8	19.1	4.7
MELIPILLA	57.0	12.5	30.26	5.92	0.86	0.52	9.8	3.2	12.5	6.2	22.5	6.5
NUNOA	70.0	9.6	25.47	4.18	0.76	0.22	3.6	1.6	16.6	3.9	65.3	6.2
PADRE HURTADO	69.1	10.0	27.15	5.10	0.76	0.23	1.2	0.3	16.7	2.1	51.3	8.2
PAINE	68.2	10.9	32.69	3.14	0.73	0.57	1.1	2.9	14.8	4.4	27.5	8.2
PEDRO AGUIRRE CERDA	75.0	9.3	28.15	5.66	0.75	0.24	4.4	1.5	17.3	2.9	72.6	5.8
PENAFLOR	63.5	11.1	25.91	4.81	0.75	0.34	0.7	0.2	15.9	1.9	37.0	6.7
PENALOLEN	66.6	8.3	25.59	3.27	0.75	0.20	4.6	2.0	19.6	4.1	51.2	6.0
PIRQUE	66.4	9.2	28.34	1.60	0.69	0.16	13.0	8.6	27.6	2.7	23.4	7.4
PROVIDENCIA	69.8	9.9	25.56	4.66	0.73	0.22	3.5	1.4	15.8	3.8	70.5	4.9
PUDAHUEL	72.7	9.0	27.81	6.56	0.74	0.22	3.0	1.0	17.9	2.8	64.9	8.3
PUENTE ALTO	68.1	8.9	27.61	1.66	0.75	0.15	4.5	3.9	24.9	2.7	37.0	6.5
QUILICURA	73.0	6.1	26.60	6.42	0.70	0.22	1.6	0.5	20.3	2.3	61.1	5.1
QUINTA NORMAL	74.2	9.4	27.97	6.39	0.74	0.25	4.1	1.0	16.7	2.9	74.3	4.9
RECOLETA	70.0	9.6	26.01	5.30	0.71	0.22	3.9	1.3	14.9	3.4	75.6	4.1
RENCA	74.2	9.0	27.75	6.61	0.74	0.24	3.3	0.9	17.1	2.6	71.1	5.0
SAN BERNARDO	74.5	9.8	28.28	4.30	0.81	0.17	1.6	0.9	16.5	2.3	62.3	7.2
SAN JOAQUIN	74.6	9.3	27.52	4.77	0.80	0.23	3.5	1.4	16.8	3.1	69.6	4.7
SAN JOSE DE MAIPO	54.0	6.1	27.49	1.56	0.52	0.16	56.0	29.1	35.2	5.4	2.0	4.1
SAN MIGUEL	75.1	9.0	27.57	5.26	0.80	0.24	3.9	1.5	17.2	3.0	72.7	5.1
SAN PEDRO	62.7	18.6	41.14	8.77	1.30	0.69	4.4	2.2	14.6	14.2	43.0	16.0
SAN RAMON	75.7	9.1	28.24	4.73	0.85	0.22	3.2	1.2	17.3	2.6	68.2	5.7
SANTIAGO	73.3	9.5	26.95	5.54	0.74	0.25	4.1	1.5	16.9	3.3	75.2	4.7
TALAGANTE	60.8	12.5	25.42	4.13	0.77	0.43	1.0	0.4	14.6	2.0	29.7	7.0
TIL-TIL	59.3	6.9	21.79	5.11	0.45	0.21	0.3	0.9	21.2	3.1	24.8	5.9
VITACURA	62.5	9.7	23.26	3.87	0.67	0.19	2.0	0.9	18.1	5.0	58.0	6.8
Total	70.0	10.8	27.03	5.22	0.75	0.27	3.7	4.8	18.1	4.6	57.5	16.9

Table A.3. Pollutants Variables by Municipality in Valparaiso (Fifth) Region

comuna	Mean Daily PM10	Sd Daily PM10	Mean Daily PM25	Sd Daily PM25	Mean Daily CO	Sd Daily CO	Mean Daily SO2	Sd Daily SO2	Mean Daily O3	Sd Daily O3	Mean Daily NOx	Sd Daily NOx
ALGARROBO	54.4	9.7	18.84	2.60	0.91	0.45	1.8	3.0	14.0	4.3	40.9	10.2
CABILDO	29.3	4.3	9.56	4.88	0.15	0.11	23.1	10.7	11.2	2.8	18.5	2.0
CALERA	49.6	3.5	15.26	1.62	0.31	0.17	4.3	1.5	10.2	1.5	13.6	1.7
CALLE LARGA	50.1	7.4	21.35	3.70	0.40	0.26	3.9	1.9	20.6	4.0	24.8	4.4
CARTAGENA	56.5	11.4	20.92	4.26	0.99	0.57	6.8	3.8	17.2	5.2	39.1	11.2
CASABLANCA	51.2	8.4	18.91	1.76	0.70	0.32	13.8	5.2	12.7	2.4	22.8	7.9
CATEMU	46.5	6.0	15.90	1.32	0.25	0.16	14.1	10.2	16.1	3.1	15.6	3.3
CONCON	43.2	4.8	15.50	2.23	0.44	0.09	9.7	6.2	10.7	0.7	21.7	3.1
EL QUISCO	56.9	11.9	19.66	3.11	0.95	0.49	1.0	1.5	15.7	4.4	45.7	11.7
EL TABO	57.9	12.7	19.96	3.73	0.96	0.53	2.0	2.0	16.0	4.9	44.5	12.1
HIJUELAS	51.4	4.4	16.29	2.00	0.29	0.16	6.2	1.8	11.9	2.1	13.0	2.4
LA CRUZ	49.8	4.5	15.79	2.11	0.36	0.19	3.5	1.7	10.7	1.2	14.3	1.8
LA LIGUA	29.6	4.4	8.18	4.09	0.16	0.09	12.1	5.6	9.5	2.3	26.5	3.8
LIMACHE	49.1	5.5	17.88	2.81	0.35	0.10	5.2	1.5	12.1	1.3	9.2	1.5
LLAILLAY	50.3	5.7	17.50	2.28	0.27	0.17	7.4	2.5	17.0	2.7	16.0	4.1
LOS ANDES	48.3	7.5	21.21	3.26	0.40	0.26	7.8	9.9	20.9	4.7	22.3	5.0
NOGALES	45.5	4.0	13.77	0.96	0.26	0.14	7.6	2.8	10.3	1.9	16.2	2.1
OLMUE	55.0	5.1	18.49	3.23	0.37	0.13	4.9	1.5	13.9	1.9	12.7	2.6
PANQUEHUE	46.2	6.2	17.20	1.40	0.31	0.21	8.5	3.0	18.7	3.1	19.1	4.1
PAPUDO	30.4	3.8	7.85	2.89	0.22	0.10	5.2	4.6	9.6	1.8	29.7	2.6
PETORCA	23.5	4.0	9.91	6.89	0.13	0.10	32.5	19.0	10.6	2.1	18.6	4.4
PUCHUNCAVI	36.9	4.5	12.89	1.27	0.37	0.10	8.1	5.1	10.2	1.9	19.1	3.5
PUTAENDO	40.8	6.3	14.55	2.33	0.28	0.21	18.2	7.2	18.0	3.3	16.7	2.2
QUILLOTA	49.8	4.6	16.52	2.43	0.39	0.20	4.0	1.2	11.1	1.2	16.1	2.1
QUILPUE	45.4	6.5	17.29	2.50	0.47	0.12	11.8	3.1	11.1	1.3	17.4	3.5
QUINTERO	40.2	4.6	13.82	1.67	0.44	0.09	0.7	2.1	9.1	0.9	20.4	3.5
RINCONADA	50.3	7.2	20.22	3.33	0.39	0.26	2.2	1.2	20.5	3.6	24.7	5.0
SAN ANTONIO	58.9	13.3	21.45	5.72	1.04	0.62	3.7	2.3	19.7	6.1	41.9	12.7
SAN ESTEBAN	46.0	7.1	20.06	2.63	0.38	0.26	9.9	4.7	20.4	4.3	19.6	3.1
SAN FELIPE	46.5	6.8	17.65	1.39	0.33	0.22	8.5	3.8	19.5	3.6	20.5	3.8
SANTA MARIA	45.7	7.0	17.99	1.40	0.36	0.24	9.6	3.7	19.9	3.8	19.9	3.3
SANTO DOMINGO	60.7	15.9	24.43	10.61	1.19	0.85	2.1	1.6	23.8	9.0	45.3	15.6
VALPARAISO	49.0	7.0	16.32	2.33	0.65	0.19	1.3	2.6	9.7	1.9	35.5	6.0
VILLA ALEMANA	45.1	5.7	17.66	2.58	0.42	0.11	9.4	2.5	10.3	1.1	11.8	2.3
VINA DEL MAR	46.7	6.3	16.35	2.40	0.55	0.15	8.6	4.1	10.7	1.4	27.1	4.7
ZAPALLAR	33.5	3.7	9.57	1.13	0.27	0.10	3.9	3.8	9.9	1.7	27.3	3.0
Total	47.2	9.3	16.82	4.12	0.50	0.33	7.4	6.8	12.8	4.8	24.2	10.8

Table A.4. Pollutants Variables by Municipality in O'Higgins (Sixth) Region

comuna	Mean Daily PM10	Sd Daily PM10	Mean Daily PM25	Sd Daily PM25	Mean Daily CO	Sd Daily CO	Mean Daily SO2	Sd Daily SO2	Mean Daily O3	Sd Daily O3	Mean Daily NOx	Sd Daily NOx
CHEPICA	58.6	10.9	22.78	0.92	1.57	1.03	1.6	1.0	73.4	51.0	74.1	26.8
CHIMBARONGO	55.8	9.1	20.93	0.86	1.18	0.66	0.7	0.5	50.1	38.8	53.2	18.7
CODEGUA	65.7	6.2	17.26	0.44	0.28	0.06	10.9	10.6	15.8	2.3	10.4	3.1
COINCO	56.9	5.8	15.81	0.08	0.90	0.39	7.1	1.2	12.5	3.5	47.6	13.7
COLTAUCO	56.6	6.6	15.26	0.15	1.00	0.48	5.8	1.6	19.0	8.4	55.9	16.4
DONIHUE	59.3	4.7	15.62	0.20	0.78	0.30	7.7	0.9	11.5	1.8	43.8	11.1
GRANEROS	68.0	4.8	16.43	0.18	0.37	0.07	2.3	1.0	11.3	1.3	20.6	4.1
LA ESTRELLA	59.2	10.5	17.09	0.76	1.72	1.13	1.4	0.9	50.8	18.9	97.8	33.9
LAS CABRAS	57.5	8.4	14.80	0.70	1.34	0.75	1.2	1.2	33.5	14.1	76.3	24.5
LITUECHE	58.1	10.1	15.50	1.09	1.60	1.00	1.0	1.0	42.4	15.2	87.7	30.6
LOLOL	63.5	14.8	26.03	1.02	2.03	1.45	5.4	2.8	92.5	41.3	108.9	44.7
MACHALI	65.1	7.4	18.54	1.24	0.38	0.08	13.8	8.8	19.8	8.4	14.6	6.7
MALLOA	53.6	6.6	17.55	0.50	0.93	0.43	0.7	0.9	18.0	6.2	44.5	14.6
MARCHIHUE	60.6	12.0	19.03	0.90	1.84	1.28	2.6	1.7	63.1	23.3	100.3	38.1
MOSTAZAL	64.5	6.0	16.66	0.47	0.26	0.07	2.8	3.4	13.5	2.9	13.7	5.3
NANCAGUA	57.2	10.5	20.58	0.32	1.47	0.90	1.0	0.6	56.0	39.5	70.5	26.6
NAVIDAD	56.4	9.6	14.76	0.42	1.83	1.09	1.7	1.3	43.1	11.4	95.4	32.3
OLIVAR	63.6	4.8	16.61	0.32	0.61	0.19	5.9	1.4	17.1	2.4	32.5	9.2
PALMILLA	59.9	11.0	19.35	0.71	1.54	0.99	1.0	0.7	56.5	30.0	82.9	28.3
PAREDONES	67.4	16.8	26.27	2.99	2.46	1.83	8.8	5.5	98.2	36.7	137.2	53.6
PERALILLO	59.6	11.3	19.49	1.04	1.75	1.18	1.5	0.9	60.0	28.7	89.0	34.0
PEUMO	57.0	8.9	16.30	0.32	1.25	0.68	0.3	0.1	33.5	17.2	67.8	22.6
PICHIDEGUA	57.1	8.9	16.80	0.54	1.40	0.85	0.4	0.3	41.4	20.5	75.1	26.4
PICHILEMU	63.8	15.6	21.96	1.79	2.44	1.77	7.9	4.6	83.2	25.0	128.7	49.6
PLACILLA	56.2	9.1	19.69	0.35	1.23	0.69	0.5	0.3	47.2	37.6	61.1	19.9
PUMANQUE	63.3	14.6	23.15	1.33	2.04	1.51	4.9	2.8	83.6	32.8	113.7	45.0
QUINTA DE TILCOCO	55.0	6.5	16.37	0.12	0.96	0.47	4.3	1.0	16.7	6.1	48.6	15.2
RANCAGUA	69.1	4.8	17.10	0.39	0.47	0.09	4.4	1.2	14.4	1.6	24.2	5.3
RENGO	53.7	5.5	17.62	0.33	0.80	0.33	3.0	2.0	16.8	5.5	36.4	10.5
REQUINOA	58.9	4.5	17.26	0.50	0.69	0.24	6.4	2.0	22.4	4.5	33.3	9.0
SAN FERNANDO	54.1	8.4	18.97	0.33	1.09	0.57	0.2	0.1	38.6	32.7	47.6	16.8
SAN VICENTE	55.6	8.3	17.14	0.44	1.11	0.58	0.2	0.4	32.8	20.5	57.7	19.5
SANTA CRUZ	60.7	12.3	21.41	0.61	1.64	1.06	1.7	1.0	64.0	36.6	84.7	30.9
Total	60.9	10.0	18.29	2.51	0.98	0.85	3.5	4.3	32.4	30.5	49.7	34.9

Table A.5. Contemporary Effect of PM10 on Test Scores in Metropolitan Region

	(1)	(2)	(3)	(4)
	read	math	soc	nat
VARIABLES	FE	FE	FE	FE
Annual PM10 mean	-0.152***	-0.0883**	-0.0876**	-0.0417
	(0.0379)	(0.0399)	(0.0366)	(0.0560)
Observations	32,793	32,787	21,551	14,833
Number of colegio_grado	5,275	5,275	2,211	2,118
School-Level FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table A.6. Robustness Check: Contemporary Effect of PM10 on Test Scores in Metropolitan, V and VI Regions

	(1)	(2)	(3)	(4)	(5)	(6)
Reading Scores						
Annual PM10 mean	-0.0956***	-0.0718***	-0.0553**	-0.0702*	-0.0778***	-0.127***
	(0.0117)	(0.0191)	(0.0231)	(0.0415)	(0.0196)	(0.0177)
Math Scores						
Annual PM10 mean	-0.0945***	-0.0721***	-0.0486*	-0.0771**	-0.0506**	-0.0933***
	(0.0123)	(0.0203)	(0.0265)	(0.0302)	(0.0203)	(0.0195)
Social Comprehension Scores						
Annual PM10 mean	-0.115***	-0.0799***	-0.0290	-0.0761***	-0.0588***	-0.125***
	(0.0129)	(0.0213)	(0.0272)	(0.0263)	(0.0213)	(0.0170)
Natural Science Scores						
Annual PM10 mean	-0.488***	-0.165***	-0.0353	-0.148***	-0.118***	-0.138***
	(0.0180)	(0.0297)	(0.0347)	(0.0363)	(0.0308)	(0.0193)
School-Level FE	Yes	No	Yes	Yes	Yes	Yes
Time FE	No	Yes	Yes	Yes	Yes	Yes
Municipality FE	No	Yes	No	No	No	No
Student Weighted	No	No	Yes	No	No	No
s.e. clustered by station	No	No	No	Yes	No	No
pvalue adjusted for small sample	No	No	No	Yes	No	No
School-Trend	No	No	No	No	Yes	No
Quantile reg.	No	No	No	No	No	Yes

Standard errors in parentheses clustered by school

Controlling for for total children per class, school socio-economic status

and public, private or charter type

Table A.7. Contemporary Effect of PM10 on Test Scores in Metropolitan, V and VI Regions by Socio-Economic Status and School Type

	(1)	(2)	(3)	(4)
	read	math	soc	nat
VARIABLES	FE	FE	FE	FE
Low				
Annual PM10 mean	-0.116**	-0.116*	-0.104*	-0.107
	(0.0539)	(0.0610)	(0.0608)	(0.0869)
Observations	3,940	3,937	2,401	1,740
Middle Low				
Annual PM10 mean	-0.0706**	-0.125***	-0.0865**	-0.211***
	(0.0306)	(0.0335)	(0.0349)	(0.0489)
Observations	16,444	16,444	11,037	7,789
Middle				
Annual PM10 mean	-0.0522	-0.0416	-0.0252	-0.151**
	(0.0329)	(0.0367)	(0.0376)	(0.0597)
Observations	15,479	15,475	10,479	7,247
Middle High				
Annual PM10 mean	-0.0930**	-0.0981*	-0.0527	-0.254**
	(0.0462)	(0.0539)	(0.0542)	(0.1000)
Observations	8,651	8,652	5,699	3,840
High				
Annual PM10 mean	-0.0794	-0.0432	-0.0918	0.109
	(0.0691)	(0.0715)	(0.0843)	(0.119)
Observations	5,836	5,830	3,562	2,398
Public				
Annual PM10 mean	-0.102***	-0.0984***	-0.0895***	-0.172***
	(0.0264)	(0.0283)	(0.0291)	(0.0386)
Observations	18,997	18,993	13,824	9,514
Charter				
Annual PM10 mean	-0.000566	-0.0241	-0.0367	-0.0817*
	(0.0292)	(0.0315)	(0.0336)	(0.0495)
Observations	24,530	24,528	15,502	10,828
Private				
Annual PM10 mean	-0.123*	-0.124*	-0.112	-0.115
	(0.0653)	(0.0678)	(0.0736)	(0.126)
Observations	6,904	6,898	3,920	2,672
School-Level FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** p<0.01, ** p<0.05, * p<0.1

Controlling for for total children per class, school socio-economic status and public, private or charter type

Table A.8. Robustness Check: Contemporary Effect of PM10 on Test Scores in Metropolitan, V and VI Regions without Schools Farther than 5km from a Monitoring Station

	(1)	(2)	(3)	(4)
	read	math	soc	nat
VARIABLES	FE	FE	FE	FE
Annual PM10 mean	-0.131***	-0.0934*	-0.0563	-0.0287
	(0.0495)	(0.0522)	(0.0519)	(0.0674)
Observations	26,874	26,876	17,589	12,100
Number of School-Level	4,261	4,261	3,299	3,097
School FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Standard errors in parentheses clustered by school

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Controlling for for total children per class, school socio-economic status and public, private or charter type