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**Downwind of the Bus Lane:
Transit Pollution and Academic Performance**

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Abstract

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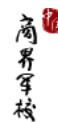
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DOWNWIND OF THE BUS LANE: TRANSIT POLLUTION AND ACADEMIC PERFORMANCE*

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ABSTRACT. We estimate the effect of air pollution from Bogotá’s Bus Rapid Transit system on high school test scores. Using wind direction interacted with bus route intensity as an instrument, we find that schools more frequently downwind of BRT corridors score significantly lower in math and global exams. The instrumental variable estimates imply that an additional $\mu\text{g}/\text{m}^3$ of PM2.5 reduces math scores by 0.10 standard deviations and global scores by 0.09 standard deviations, with no effect on language. NOx and PM10 show similar negative effects. Girls and students from higher-income households experience larger declines. A georeferenced household survey provides suggestive evidence that respiratory disease mediates the pollution-achievement relationship. These results reveal a human capital cost of diesel-powered transit and underscore the importance of cleaner fuel technologies in urban transportation policy.

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1. INTRODUCTION

Investments in public transportation reduce congestion, shorten commutes, and expand access to economic opportunities, particularly in developing countries where traffic congestion imposes large welfare costs (Tsekeris and Geroliminis, 2013; Barreca et al., 2021). When transit systems rely on fossil fuels, however, they become significant sources of air pollution, sometimes emitting more particulate matter per passenger-kilometer than private vehicles (Morales Betancourt, 2022). In such cases, infrastructure that improves urban mobility simultaneously degrades air quality, generating negative externalities for public health, worker productivity, and human capital accumulation (Kelly and Zhu, 2016; Hanna and Oliva, 2015; Deryugina et al., 2019; Aguilar-Gomez et al., 2022). This paper estimates the causal effect of pollution from a Bus Rapid Transit (BRT) system on the academic performance of high school students.

We study Bogotá, Colombia, where the BRT system TransMilenio operated a diesel fleet (Euro-II and Euro-III engines) throughout our study period (2014–2018). Diesel combustion produces a bundle of harmful pollutants: fine particulate matter (PM_{2.5}), coarse particulate matter (PM₁₀), and nitrogen oxides (NO_x), all of which are linked to respiratory disease and impaired cognitive function (Pope and Dockery, 2006; Dominici et al., 2014; EPA, 1999). Engineering estimates suggest that TransMilenio buses account for 30 to 50 percent of PM_{2.5} emissions in the city (Belalcazar-Cerón et al., 2021), and Bogotá’s average PM_{2.5} concentration during our study period was 20.4 $\mu\text{g}/\text{m}^3$, approximately four times the World Health Organization’s revised 2021 annual guideline of 5 $\mu\text{g}/\text{m}^3$.¹ We estimate the effect of each pollutant separately, treating PM_{2.5} as the primary measure and NO_x as a diesel-specific marker. We measure academic outcomes using the *Saber 11*, a mandatory national standardized exam taken by

¹As of 2024, Bogotá’s PM_{2.5} concentration has declined to approximately 1.4 times the WHO guideline value, partly reflecting the fleet transition that began in 2019. For comparison, Mexico City exceeds the guideline by a factor of 3.6, New York City by 2.4, and Los Angeles by 1.2 (IQAir, 2023).

all final-year secondary students (comparable to the SAT in the United States), covering approximately 95,000 students per year in Bogotá. We complement the education analysis with a georeferenced household health survey to examine respiratory disease as a mechanism.

Our identification strategy exploits exogenous variation in wind direction interacted with bus route intensity as an instrument for school-level pollution exposure. The instrument measures the share of daytime hours during which the wind blows from the nearest TransMilenio corridor toward a school, weighted by the number of buses operating on that corridor. Schools that are more frequently downwind of high-traffic BRT routes receive higher PM_{2.5} and NO_x concentrations. This approach builds on [Anderson \(2020\)](#), who uses wind patterns near Los Angeles highways to study pollution and adult mortality, and [Heissel et al. \(2022\)](#), who compare upwind and downwind schools in Florida. Our contribution is to apply this methodology to a public transit system in a major Latin American city, where diesel-powered BRT corridors serve as localized and measurable pollution sources.

The reduced-form estimates show that schools more frequently downwind of BRT corridors score lower in math and global exams, providing a direct, assumption-lean measure of the transit pollution externality. This relationship does not require scaling pollution units through the first stage and captures the policy-relevant margin: how much academic performance declines when a school is more exposed to BRT corridor emissions. The instrumental variable estimates, which scale the reduced-form effect per unit of pollution, indicate that an additional microgram per cubic meter ($\mu\text{g}/\text{m}^3$) of PM_{2.5} reduces math scores by 0.10 standard deviations and global scores by 0.09 standard deviations, with no significant effect on language scores. An additional unit of NO_x, the pollutant most directly linked to diesel combustion, reduces math scores by 0.015 standard deviations and global scores by 0.013 standard deviations. The effects are concentrated among schools within the 75th percentile of the school-to-corridor

distance distribution (1.86 km) and are robust to alternative distance cutoffs. They are driven by cumulative exposure throughout the academic year rather than short-term pollution fluctuations. Girls experience larger declines in math performance than boys, and students from higher-income households are more affected than those from lower-income households. This pattern is consistent with lower baseline pollution exposure among higher-SES families, making additional exposure more disruptive. Using the Multipurpose Survey, we find suggestive evidence that higher PM_{2.5} and NO_x exposure increases the likelihood of respiratory disease among school-age children, consistent with a health-mediated channel linking pollution to academic performance.

We put these results to an extensive set of robustness tests organized around three concerns: instrument validity, sample sensitivity, and specification choices. A central identification challenge is that BRT corridors are also major traffic arteries, so the estimated effects could partly reflect private vehicle emissions rather than bus pollution. Three tests address this concern directly: wind from comparable non-TransMilenio highways does not predict test scores, confirming that the effects are specific to BRT corridors; removing the bus intensity interaction from the instrument weakens its predictive power, confirming that the volume of bus traffic matters; and a local projections difference-in-differences specification shows that TransMilenio corridor openings directly increased PM_{2.5} and NO_x concentrations at nearby schools, providing causal evidence that BRT operations raised local pollution.

To further validate the instrument, we show that nighttime wind frequency (when fewer buses operate and students are not in school) does not predict test scores and the first stage loses strength; weekend pollution has no effect on academic performance; and the first-stage relationship between wind share and pollution strengthens with longer cumulative exposure windows, confirming that sustained annual exposure is the relevant margin. To assess sample sensitivity, we show that effects attenuate beyond

2.25 kilometers from BRT routes, consistent with localized pollution dispersion; transient wildfire pollution has no effect on scores; wind frequency does not predict student demographics, ruling out sorting; and older test-takers (ages 19–70), who spend less time in school buildings, show no pollution effects. For specification checks, we show that controlling for co-pollutants (O₃, SO₂, CO) and climate variables (temperature, precipitation, humidity) preserves the main estimates, and an alternative exposure measure based on extreme pollution hours confirms the results.

This paper makes three contributions. First, it provides the first causal estimate of the effect of BRT-related air pollution on educational outcomes in a major city outside the United States and Europe. Existing studies of pollution and academic performance focus predominantly on developed countries (Heissel et al., 2022; Marcotte, 2017; Ebenstein et al., 2016) or examine pollution from general sources without identifying a specific infrastructure origin (Merkus, 2024; Balakrishnan and Tsaneva, 2021; Zhang et al., 2018). We isolate the effect of a single, identifiable pollution source, the diesel BRT fleet, using within-city variation in wind exposure. Second, we demonstrate that sustained cumulative exposure throughout the academic year, rather than acute pollution episodes, drives the negative effects on test scores. This finding distinguishes our results from studies that exploit day-of-exam pollution variation (Marcotte, 2017) and has direct implications for policy: interventions that reduce average pollution levels (such as fleet electrification) may be more effective than those targeting peak episodes. Third, we provide evidence on the health mechanism linking pollution to academic performance. Using a georeferenced household survey, we show that PM_{2.5} and NO_x exposure increases respiratory disease among school-age children, while the effects on younger children who spend less unsupervised time near BRT corridors are absent, supporting a school-proximate exposure channel.

Our findings relate to several strands of the literature. A growing body of work documents the negative effects of air pollution on broader development outcomes, including worker productivity (Lichter et al., 2017; He et al., 2019; Fu et al., 2021), crime (Herrnstadt et al., 2021; Aguilar-Gomez et al., 2022), and long-term human capital accumulation (Chen, 2025). Within the education literature, studies in the United States (Lu et al., 2021; Persico and Venator, 2019; Heissel et al., 2022; Gilraine, 2023; Duque and Gilraine, 2022), Israel (Ebenstein et al., 2016), China (Zhang et al., 2018), India (Balakrishnan and Tsaneva, 2021), and Brazil (Bedi et al., 2021) have established that pollution reduces test scores. In Colombia, Merkus (2024) finds that the air quality index correlates with lower *Saber 11* scores across municipalities but does not identify the pollution source or estimate causal effects, and Villalobos and Blackman (2025) document a negative association between fine particulates and high-stakes test scores in Bogotá. We advance this literature by identifying a specific infrastructure source, estimating causal effects with a credible instrument, and documenting heterogeneous impacts by gender and socioeconomic status. On gender, our finding that girls are more affected than boys aligns with Balakrishnan and Tsaneva (2021) in India but contrasts with evidence from Israel and China, where boys experience larger declines (Ebenstein et al., 2016; Zhang et al., 2018). In contrast to Chen (2025), who study cross-regional pollution exposure and long-run outcomes, we exploit within-city variation and show that adverse effects extend beyond early childhood to later learning stages.

The rest of the paper proceeds as follows. Section 2 describes Bogotá’s TransMilenio system and school system. Section 3 presents the pollution, test score, and health survey data. Section 4 develops the empirical strategy. Section 5 reports the main results, and Section 6 presents the robustness tests. Section 7 concludes.

2. BACKGROUND

2.1. TransMilenio: Bogotá’s Bus Rapid Transit System. TransMilenio (TM) is Bogotá’s Bus Rapid Transit system, operating high-capacity bi-articulated buses on exclusive corridors (Echeverry et al., 2005). Construction began in 1998 and the first phase opened in 2000, replacing a fragmented network of competing private bus operators without dedicated lanes (Cracknell, 2003). Phase II (2003–2006) extended the network to additional corridors, and Phase III (2012) reached the city’s western and southern periphery. No new corridors have been added since 2013. Figure 1 displays the network as it was during our study period. Despite successive expansions, the system remains overcrowded and unable to meet demand (Hidalgo et al., 2013; Guzman and Oviedo, 2018; Tsivanidis, 2022).

TM buses are a major source of urban air pollution. The fleet accounts for 30 to 50 percent of PM_{2.5} emissions in Bogotá, producing between 0.8 and 3.7 $\mu\text{g}/\text{min}$ depending on the corridor (Belalcazar-Cerón et al., 2021). Diesel combustion also generates nitrogen oxides (NO_x) and coarse particulate matter (PM₁₀), both of which are associated with respiratory disease and are present at elevated concentrations along BRT corridors. Until 2019, the fleet ran on diesel engines (Euro-II and Euro-III standards), generating pollution exposure substantially higher than electric alternatives (Castillo-Camacho et al., 2020). In July 2019, the city began replacing diesel buses with Euro-VI compressed natural gas and filter-equipped Euro-V vehicles, reducing PM_{2.5} concentrations by 45 percent inside buses and 76 percent inside stations relative to 2017 levels (Morales Betancourt, 2022). Because this fleet transition coincides with the onset of the COVID-19 pandemic, which independently affected test scores and student health through school closures and economic disruption (Jack and Oster, 2023), our analysis covers the pre-transition period from 2014 through 2018.

2.2. School System in Bogotá. Colombia’s school system spans 11 years: five years of primary education followed by six years of secondary education, with children typically entering at age six and graduating at 17 (Barrera-Osorio et al., 2020). All final-year secondary students must take the *Saber 11* exam, a national standardized test administered by ICFES that serves as the primary criterion for university and technical institution admissions, comparable to the SAT in the United States (Posso et al., 2023). We focus on this exam as our outcome measure.

Bogotá is the fifth-largest metropolitan area in Latin America, with a population of approximately eight million, and ranks among the ten most congested cities in the world (Statista Research Department, 2024; TomTom, 2023). Secondary education coverage in the city is high: the net enrollment rate for children aged 5 to 17 is 86.5 percent, and the gross enrollment rate reaches 100 percent. These rates have remained stable over the past 13 years (Ministerio de Educación Nacional de Colombia, 2024). The combination of near-universal secondary enrollment and a mandatory, high-stakes exit exam means that our estimates capture pollution effects on a representative cross-section of Bogotá’s student population, approximately 95,000 exam-takers per year.

3. DATA

3.1. Air pollution. Bogotá’s Secretary of the Environment operates eleven air quality monitoring stations across the city (Figure 1). Five stations began recording in 2000, with the remaining six added between 2004 and 2010 (see Table A-1). Each station reports hourly concentrations of PM_{2.5}, PM₁₀, and nitrogen oxides (NO_x), among other pollutants, along with meteorological variables including wind direction, wind speed, temperature, relative humidity, and precipitation. We use data from 2014 through 2018 and compute, for each school, the average concentration from the last week of January through the date students sat for the *Saber 11* exam, which takes place in August of each year for Calendar A students, who represent approximately 95

percent of test-takers ([Secretaría de Educación del Distrito, 2025](#)). This cumulative measure captures students' exposure to pollution throughout the academic year.

We extract hourly concentrations of three pollutants: PM2.5 (particulate matter with diameter below 2.5 micrometers), PM10 (below 10 micrometers), and NOx (nitrogen oxides). PM2.5 is the most widely used measure of air quality and is linked to respiratory disease, cardiovascular conditions, and premature mortality ([Pope and Dockery, 2006](#); [Dominici et al., 2014](#)). NOx is a direct byproduct of diesel combustion ([EPA, 1999](#)), making it a marker for TransMilenio bus emissions during the pre-2019 period when the fleet ran on diesel engines. Exposure to NOx, particularly nitrogen dioxide (NO₂), irritates the respiratory tract, exacerbates asthma and bronchitis, and impairs lung function at sustained concentrations ([World Health Organization, 2021](#); [Peden, 2002](#)). These respiratory effects can reduce school attendance and impair concentration during school hours, providing a plausible pathway from NOx exposure to lower academic performance. The pairwise correlations among all measured pollutants (see [Table A-2](#)) confirm that PM2.5, PM10, and NOx are positively correlated, consistent with a common combustion source.

During our study period, average PM2.5 across all monitors in Bogotá was 20.4 $\mu\text{g}/\text{m}^3$, more than twice the 2005 WHO guideline of 10 $\mu\text{g}/\text{m}^3$ and four times the revised 2021 guideline of 5 $\mu\text{g}/\text{m}^3$ ([Panel A, Figure 2](#)). The mean in our estimation sample (schools within 1.86 km of a BRT corridor) is 16.7 $\mu\text{g}/\text{m}^3$ (see [Table 1](#)), reflecting the spatial distribution of monitors and the Kriging interpolation used to assign pollution to schools. NOx concentrations exceeded WHO standards by a factor of four. [Panel B of Figure 2](#) shows that the distribution of PM2.5 shifts toward higher concentrations during daytime hours (6:00 a.m. to 6:00 p.m.) relative to nighttime. This daytime pollution premium is central to our identification strategy: students attend school during the hours when pollution is highest, and we exploit this temporal pattern in our robustness tests by comparing daytime and nighttime wind exposure.

With eleven monitors covering a city of eight million residents, we cannot observe pollution at each school directly. We assign pollution levels to schools using Kriging interpolation, a spatial estimation technique that predicts concentrations at unobserved locations by exploiting the spatial covariance structure of observed readings across monitors (Shad et al., 2009; Jerrett et al., 2005; Beelen et al., 2009). Kriging produces a variance-minimizing weighted average of monitor readings for each school, where the weights depend on the distance and spatial correlation between the school and each monitor. As a robustness check, we also estimate our main specifications using the nearest-station assignment method, in which each school receives the pollution reading from its closest monitor weighted by inverse distance (Gilraine and Zheng, 2022; Duque and Gilraine, 2022; Diao et al., 2019). The IV estimates under nearest-station assignment (see Table A-5) are consistent with the Kriging-based results, confirming that the findings do not depend on the spatial interpolation method.

Pollution concentrations decline with distance from TransMilenio routes. Figure A-1 plots average PM_{2.5} (Panel A) and NO_x (Panel B) against distance to the nearest BRT corridor using binned regressions. The gradient is steepest within the first two kilometers and flattens beyond that range. We restrict the sample to schools within the 75th percentile of the school-to-corridor distance distribution (1.86 kilometers), where the pollution gradient from BRT corridors is strongest. Section 6 shows that the results are robust across alternative distance cutoffs from 1.25 to 3.0 kilometers.

3.2. Test scores. We measure academic performance using the *Saber 11* exam, a mandatory national standardized test administered to all final-year high school students in Colombia. The exam is a prerequisite for admission to higher education and is administered by the ICFES (*Instituto Colombiano para la Evaluación de la Educación*). We use three score outcomes: math, language, and a global composite. The

exam format was restructured in 2014, making scores comparable from that year onward; we use data through 2018, the last pre-pandemic year before the TransMilenio fleet transition.

The data include individual scores, demographic characteristics (gender, age, mother's education, socioeconomic stratum, household size), and school identifiers. We georeferenced each school using publicly available geocoding services to obtain latitude and longitude coordinates for matching with pollution data and calculating distance to BRT routes.

The estimation sample (see Table 1) contains approximately 276,000 students across five cohorts. The average math score is 54 out of 100 (0.11 standard deviations above the national mean) and the average language score is 55 (0.12 standard deviations above the national mean), with men scoring four points higher than women in math and one point higher in language (Figure A-2). The typical student is 17 years old, female (54 percent of the sample), enrolled in a public school (53 percent), and lives in a household of about five people. Half of students come from low-income families, 40 percent from middle-income families, and 9 percent from high-income families.² Thirty-seven percent of mothers have some postsecondary education without completing a degree, 30 percent hold a completed tertiary degree, and 30 percent have a high school education or less. We standardize all scores to have mean zero and unit standard deviation at the national level for the regression analysis.

3.3. Multipurpose Survey (EM). To examine health mechanisms, we use the Multipurpose Survey (Encuesta Multipropósito, EM), a representative household survey of Bogotá conducted by the National Statistics Department, DANE (*Departamento Administrativo Nacional de Estadística*) and the District Planning Secretary, SDP (*Secretaría Distrital de Planeación de Bogotá*). The EM is designed to be representative at

²We define low-income as strata 1–2, middle-income as strata 3–4, and high-income as strata 5–6 in Colombia's socioeconomic classification system.

the locality level (Bogotá is divided into 20 localities); our block-level analysis exploits within-locality variation in proximity to BRT corridors, so we interpret the health results as suggestive evidence of a mechanism rather than precise causal estimates. The EM collects health, economic, and demographic information at the individual and household levels. We use the 2011, 2014, and 2017 waves, excluding 2021 because COVID-19 school closures confound health and education outcomes (Jack and Oster, 2023). We georeferenced each household at the neighborhood (block) level and assigned pollution exposure from the nearest air quality monitor. The sample for the health analysis consists of children under 18 living within 1.86 km of a TransMilenio route, matching the distance restriction in the education analysis.

4. EMPIRICAL STRATEGY

We estimate the effect of air pollution on academic performance in two steps. We begin with an Ordinary Least Squares (OLS) regression that relates test scores to pollutant exposure, controlling for student, household, and school characteristics. We then implement an Instrumental Variables (IV) strategy that exploits exogenous variation in wind direction from TransMilenio corridors to isolate pollution exposure driven by meteorological conditions rather than unobserved neighborhood or school characteristics.

The baseline OLS specification is:

$$(4.1) \quad y_{ist} = \alpha + \beta \text{Pollutant}_{st} + \mathbf{X}'_{it} \delta + \gamma_s + \gamma_t + \varepsilon_{ist}$$

where y_{ist} is the standardized test score (math, language, or global) for student i in school s in year t , and $\text{Pollutant}_{st} \in \{PM2.5, NOx\}$ is the average pollutant concentration at school s from late January through the *Saber 11* exam date in year t . This cumulative measure captures exposure throughout the academic year rather

than short-term fluctuations.³ The vector X_{it} includes student age, sex, mother’s education, socioeconomic stratum, household size, computer access, and an indicator for public school enrollment.⁴ We include school fixed effects (γ_s) to absorb time-invariant differences across institutions and year fixed effects (γ_t) to control for common shocks. Standard errors are clustered at the school \times year level.

4.1. IV Strategy. The OLS estimates from equation 4.1 face two identification concerns. First, pollution exposure is not randomly assigned: neighborhoods with higher PM2.5 and NOx concentrations may differ systematically from cleaner areas in ways that also affect student achievement (e.g., industrial activity, income sorting). Second, pollution is measured with error given the sparse distribution of monitors across the city, which biases OLS estimates toward zero through classical attenuation (Gilraine and Zheng, 2022; Deryugina et al., 2019).

We address both concerns with an instrumental variable strategy that exploits the interaction between downwind frequency from TransMilenio corridors and bus route intensity. The approach builds on Anderson (2020) and Heissel et al. (2022), who use wind patterns near highways to study the effects of pollution on mortality and academic performance, respectively. Our contribution is to apply this methodology to a public transit system as the pollution source. The first and second stages are:

$$(4.2) \quad \text{Pollutant}_{st} = \alpha + \eta \text{Wind Share}_{st} + \mathbf{X}'_{it} \delta + \gamma_s + \gamma_t + \epsilon_{ist}$$

$$(4.3) \quad y_{ist} = \alpha + \beta \widehat{\text{Pollutant}}_{st} + \mathbf{X}'_{it} \delta + \gamma_s + \gamma_t + \epsilon_{ist}$$

The instrument, WindShare_{st} , measures the percentage of daytime hours (6:00 a.m. to 5:00 p.m.) during which wind blows from the nearest TransMilenio route toward

³Not all students take the exam at their own school. Some are assigned to nearby testing centers, which can introduce variation in their immediate exposure to pollution on the test day.

⁴Public schools account for 55 percent of the sample.

school s at speeds of one mile per hour or less, within a 45-degree cone extending from the nearest point on the bus corridor to the school. We interact this downwind frequency with bus route intensity, defined as the average number of TransMilenio buses per hour operating on the nearest corridor segment during our study period, to capture heterogeneity in pollution emissions across corridors with different traffic volumes.⁵ Low wind speeds allow pollutants to accumulate in nearby neighborhoods, generating higher exposure for downwind schools, while higher wind speeds disperse pollution over greater distances, diluting its local concentration.

We construct the instrument in three steps. First, we compute the angle and distance from each school to the nearest point on a TransMilenio highway segment, which determines whether the school faces the corridor. Second, we calculate the downwind frequency at each air quality monitor and assign schools to monitors using inverse-distance weights, so that schools closer to a monitor receive greater weight from that station’s readings (Hanna and Oliva, 2015; Currie and Neidell, 2005). Third, we interact the downwind frequency with bus intensity to form the excluded instrument.

The identifying assumption is that, conditional on school and year fixed effects and student covariates, the direction and speed of wind from BRT corridors affect test scores only through their effect on pollution exposure. Because BRT corridors are also major traffic arteries, we cannot fully separate bus emissions from private vehicle emissions on the same roads. Our estimates therefore capture the effect of pollution on high-traffic BRT corridors, which bundles bus and car emissions. This is the policy-relevant externality of the infrastructure as built: the decision to route a BRT system along a corridor changes the total pollution burden on nearby schools, and the reduced-form estimates measure this total effect. Three pieces of evidence nonetheless support the interpretation that TransMilenio buses are the primary driver within this bundle: (i) wind from comparable non-BRT highways does not predict test scores (Section 6), (ii)

⁵Bus intensity data come from [TransMilenio S.A. \(2018\)](#). Intensity varies across corridors but is stable within corridors over our study period (2014–2018), since no new routes were added after 2013.

removing the bus intensity interaction weakens the instrument’s predictive power, and (iii) a difference-in-differences specification shows that TransMilenio corridor openings increased local pollution concentrations. Figure 3 illustrates the intuition: schools on opposite sides of a BRT corridor face different pollution levels depending on prevailing wind direction. Figure 4 provides graphical evidence of the first stage, showing that higher downwind frequency is positively associated with PM2.5 (Panel A) and NOx (Panel B) concentrations in a binned regression.

Wind direction varies across monitoring stations, which generates the cross-sectional variation underlying our instrument. Figures A-3 and A-4 plot the relationship between PM2.5 and NOx with wind direction for Bogotá as a whole (Panel A) and for each individual monitoring station. Figure A-3 displays all eleven stations for PM2.5 (Panels B–L), while Figure A-4 displays the nine stations that report NOx (Panels B–I), since two stations do not measure nitrogen oxides.⁶ PM2.5 increases with wind from the southwest, west, and northwest, while eastern winds carry little pollution, consistent with the Andes mountain range forming a natural barrier to the east. For NOx, the variation at each station follows a similar pattern, where pollution increases as winds from the south and southwest intensify. This station-level heterogeneity in wind-pollution relationships provides the variation that identifies the causal effect of pollution on test scores. In the BRT sample (Panel A of Table A-3), the wind share instrument predicts PM2.5, PM10, and NOx concentrations but does not predict O3 or CO, consistent with diesel combustion as the relevant pollution source.

5. RESULTS

Table 2 reports the OLS, reduced-form, and IV estimates of the effect of pollution on test scores. Panel B presents the OLS results from equation 4.1. An additional microgram per cubic meter ($\mu g/m^3$) of PM2.5 exposure throughout the academic year

⁶These are daily-level regressions of PM2.5 and NOx on indicators for wind direction divided into eight bins, with North as the reference category, controlling for day and hour fixed effects.

reduces math scores by 0.0027 standard deviations (column 2) and global scores by 0.0039 standard deviations (column 4), though neither estimate is statistically significant at conventional levels. The effect on language scores is negative (0.0016 standard deviations, column 3) and also insignificant. All specifications include student and household covariates, school fixed effects, and year fixed effects.

Panel A of Table 2 presents the reduced-form and first-stage estimates. Columns 1 and 5 confirm a positive and significant relationship between the wind share instrument and both PM2.5 and NOx concentrations, validating the relevance of the instrument. Columns 2 and 4 show that the wind share has a direct negative and significant association with math and global scores, while column 3 shows no effect on language scores. A similar result is drawn from columns 6-8 for NOx. These reduced-form estimates are the most policy-relevant parameters: they capture the total effect of being downwind of a BRT corridor on academic performance, without requiring assumptions about the scaling from wind share to pollution units. Appendix Figure A-5 displays the same negative relationship between downwind frequency and test scores separately by gender. Panel C reports the IV estimates: an additional $\mu\text{g}/\text{m}^3$ of PM2.5 reduces math scores by 0.1015 standard deviations and global scores by 0.0928 standard deviations, with no significant effect on language. For NOx, an additional part per billion significantly decreases math and global scores by 0.0145 and 0.0132 standard deviations, respectively. The Kleibergen-Paap F-statistic exceeds 15, confirming instrument relevance (Borusyak and Hull, 2023).

The IV estimates are substantially larger than OLS. For PM2.5, the IV-to-OLS ratio is approximately 24 to 38 depending on the outcome; for NOx, the OLS estimates are near zero or positive, so the ratio is not well defined. Three factors likely contribute to this gap. First, pollution is measured with considerable error: eleven monitors serve a city of eight million, and Kriging interpolation smooths over local variation, producing classical attenuation bias that shrinks OLS estimates toward zero (Gilraine

and Zheng, 2022; Deryugina et al., 2019). Second, the IV identifies a local average treatment effect on complier schools, those whose pollution exposure shifts most with wind patterns from BRT corridors, and this subpopulation may experience larger effects than the average school. Third, schools near BRT corridors serve a somewhat more advantaged student population (see Table 1), suggesting that unobserved school quality may be positively correlated with pollution exposure, biasing OLS toward zero. Large IV-to-OLS ratios are common in the pollution literature when instruments rely on meteorological variation and sparse monitor networks, where measurement error is severe (Gilraine and Zheng, 2022; Deryugina et al., 2019).

5.1. Other pollutants. PM_{2.5} is the primary pollutant in our analysis, but diesel combustion also produces PM₁₀. We additionally examine O₃, a secondary pollutant formed through atmospheric reactions involving diesel-emitted precursors. Because the TransMilenio fleet ran on diesel before 2019, these pollutants provide additional tests of the relationship between bus emissions and academic performance. Table A-4 reports the second-stage IV estimates using PM₁₀ and O₃ as the endogenous variable. An additional $\mu\text{g}/\text{m}^3$ of PM₁₀ significantly reduces math scores by 0.0345 standard deviations, while the O₃ estimate is large but unreliable given a weak first stage (Kleibergen-Paap F-statistic of 1.49).

5.2. Heterogeneous effects. Table 3 reports the differential effect of PM_{2.5} and NO_x by gender. Girls aged 15 to 18 experience the largest negative effects: the interaction between pollution and a male indicator is positive and significant, indicating that boys score 0.022 and 0.015 standard deviations higher than girls in math and global scores, respectively, for the same level of PM_{2.5} exposure, while for NO_x, those coefficients amount to 0.015 and 0.011, respectively. The Kleibergen-Paap F-statistic for the PM_{2.5} specification is 7.98, below the conventional threshold of 10, so the PM_{2.5} gender estimates should be interpreted with caution; the NO_x specification has

adequate instrument strength ($F = 31.37$) and confirms the same pattern. This finding aligns with Balakrishnan and Tsaneva (2021) in India but contrasts with evidence from Israel and China, where boys experience larger declines (Ebenstein et al., 2016; Zhang et al., 2018). Several mechanisms could explain the gender gap: differences in lung development and respiratory sensitivity during adolescence (Aguilera et al., 2013; Ebenstein et al., 2017), higher rates of pollution-related respiratory conditions among girls (Zhang et al., 2018), or behavioral differences in outdoor exposure near school buildings. We cannot isolate the specific channel with the available data.

Table 4 examines heterogeneity by household income.⁷ Students from higher-income households (strata 5–6) experience larger declines in performance than those from middle- or low-income families. The PM_{2.5} estimates in this specification have a Kleibergen-Paap F-statistic of 3.90, indicating a weak instrument problem when the first stage is split across three stratum interactions; the NO_x estimates ($F = 14.59$) are more reliable. Two interpretations are consistent with this pattern. First, disadvantaged students may face higher baseline pollution exposure from other sources (cooking fuels, industrial activity, unpaved roads), making the marginal effect of additional PM_{2.5} and NO_x from BRT corridors comparatively smaller (Heissel et al., 2022). Second, higher-income families in Bogotá may be more likely to live near TransMilenio corridors, which provide valued transit access, resulting in greater effective exposure for their children. We cannot fully distinguish between these explanations with the available data, but the sorting test in Section 6 shows that wind share does not predict student socioeconomic characteristics, suggesting that differential exposure through residential choice is unlikely to drive the heterogeneity.

5.3. Health outcomes. If pollution reduces test scores, a natural channel is respiratory health. In Bogotá, buses and cars account for 80 percent of total emissions

⁷Colombian households are classified into six strata, where higher values indicate greater socioeconomic status. In our estimation sample, 50 percent fall in strata 1–2, 40 percent in strata 3–4, and 9 percent in strata 5–6.

contributing to poor air quality (CONPES, 2018), and prior research has established that traffic-related pollution exacerbates respiratory conditions including asthma, bronchitis, and pneumonia (Peden, 2002; Beatty and Shimshack, 2011; Simeonova et al., 2019; Currie and Walker, 2011; Knittel et al., 2016).

We present two types of evidence. First, Figure 5 shows binned regressions of health outcomes on PM2.5 concentrations for children under 14 in Bogotá, using locality-level data from the city’s Department of Health.⁸ Panel A shows a positive association between PM2.5 and school absences due to respiratory illness for both boys and girls. Panels B and C show that coughing and wheezing rates increase with PM2.5 concentrations, with stronger gradients for girls. These correlations are suggestive but consistent with pollution-induced respiratory impairment as a mechanism linking air quality to academic performance. Figure 6 shows attenuated patterns using NOx concentrations.

Second, we estimate the IV specification on health outcomes using the georeferenced Multipurpose Survey. Table A-6 reports the results for PM2.5 and NOx: children under 18 exposed to higher PM2.5 levels are more likely to develop respiratory diseases (column 2, significant at the 10 percent level), while effects on allergies, emergency visits, and routine medical check-ups are not statistically significant. The NOx results (columns 7–12) show a similar pattern. Table A-7 shows that the respiratory effects of PM2.5 and NOx do not differ significantly by gender or socioeconomic stratum. When we restrict the sample to elementary school children (under 11 years of age), Table A-8 shows no significant health effects for either pollutant, even though the first stage remains strong. This suggests that younger children, who spend less unsupervised time near BRT corridors, face lower effective exposure than secondary school students. We note two limitations of the health analysis. First, we cannot construct time-weighted

⁸The health variables were collected by surveying a sample of parents, with responses aggregated at the locality-year level, yielding approximately 100 observations. We match each locality centroid to the nearest pollution station and control for year and locality fixed effects. Bogotá is divided into 20 localities.

home-plus-school exposure because student home addresses are not available in the *Saber 11* data. Second, while the descriptive evidence in Figure 5 shows a positive association between pollution and school absenteeism, we cannot test whether absenteeism mediates the test score effect because individual-level attendance records are not available for our sample.

6. ROBUSTNESS TESTS

We evaluate the robustness of the main results through three categories of tests.⁹ First, we assess instrument validity by testing whether the pollution-achievement relationship operates specifically through daytime BRT exposure rather than through correlated channels such as general road traffic, weather conditions, or contemporaneous shocks. Second, we examine sample and measurement sensitivity to determine whether the results depend on particular distance thresholds, pollution sources, or student composition. Third, we conduct specification checks to confirm that the estimates are not driven by omitted co-pollutants, climate confounders, or the functional form of the exposure measure.

6.1. Instrument validity.

Wind frequency at night. If daytime BRT traffic drives the pollution-achievement relationship, nighttime wind patterns, when fewer buses circulate and students are not in school, should not predict test scores. We re-estimate equation 4.3 using nighttime downwind frequency as the instrument. Columns 1-6 of Table A-9 use wind frequency between 6:00 p.m. and 11:00 p.m., when TransMilenio still operates but students are not in school, and between 12:00 a.m. and 5:00 a.m., when the system is shut down. The second-stage estimates for both PM_{2.5} and NO_x are weak (F-statistic below 3.0) and statistically insignificant. Pollution instrumented with nighttime wind direction

⁹Our falsification tests follow the negative control framework formalized by [Danieli et al. \(2026\)](#). The nighttime wind, weekend pollution, and non-TransMilenio route tests are negative control instruments, while the sorting and older test-taker tests are negative control outcomes.

has no effect on test scores, confirming that the daytime exposure channel drives the results.

Pollution on weekends. Students attend school Monday through Friday, so weekend pollution near schools should not affect their performance. We estimate equation 4.3 using PM2.5, NOx, and wind direction measured separately on Saturdays and Sundays. Panel A of Tables A-10 and A-11 confirms that wind frequency predicts pollution levels on weekends. However, the IV estimates in Panel C show no effect of weekend pollution on test scores.

Non-TransMilenio routes. A central identification concern is that BRT corridors are also major traffic arteries, so the estimated effects could reflect pollution from private vehicles rather than from TransMilenio buses. We test this directly by re-estimating the IV specification using wind frequency from the nearest non-TransMilenio route as the instrument, restricting the sample to schools within 1.86 kilometers of a non-BRT highway but more than 1.16 kilometers from a TransMilenio corridor.¹⁰ If general road traffic drives the results, wind from these comparable highways should also predict lower test scores. Table A-12 shows that it does not: the first stage is weak for PM2.5 (Panel A), and the second-stage estimates for both pollutants are insignificant (Panel C). This result indicates that the negative effects on test scores are specific to BRT corridor pollution rather than general highway emissions.

Wind share by month. Tables A-13 and A-14 regress PM2.5 and NOx measured over progressively shorter windows before the exam on the yearly wind share instrument. For the former, the first-stage coefficient is largest in magnitude and most significant for the full-year measure and declines as the exposure window shortens, confirming that cumulative annual exposure, rather than short-term fluctuations, is the relevant margin. For the latter, the coefficients decline slightly but remain statistically

¹⁰The 1.16-kilometer threshold equals the median distance between schools and TransMilenio routes.

significant across all windows, consistent with NO_x as a persistent byproduct of daily diesel combustion on BRT corridors.

6.2. Sample and measurement sensitivity.

Distance to pollution sources. The main estimates restrict the sample to schools within 1.86 kilometers (the 75th percentile of school-BRT distance) of the nearest BRT route. To demonstrate that this threshold is not driving the results, we report estimates across a range of cutoffs. Table A-15 reports estimates across eight distance cutoffs from 1.25 to 3.0 kilometers. The negative effects on math and global scores are significant and stable between 1.5 and 2.25 kilometers, then attenuate and lose significance at greater distances. This gradient is consistent with the physics of near-road pollution dispersion and confirms that the results are not an artifact of a particular distance threshold.

Wildfires. Bogotá experiences occasional wildfires during dry periods.¹¹ Unlike in the United States, where large-scale wildfires generate sustained pollution exposure with documented effects on labor productivity and health (Borgschulte et al., 2022), wildfires in Bogotá are small and sporadic. We construct an analogous wind share instrument for wildfire locations and estimate the IV specification using pollution from wildfire events during our study period. Panel B of Table A-3 confirms that the wildfire wind share predicts pollution levels at schools, so the first stage is strong. However, Table 5 shows no significant effects of wildfire-related pollution on test scores for schools beyond 6.5 kilometers from burn sites, despite large F-statistics across all four pollutants. The contrast between the two samples is informative: the wind-based approach predicts pollution from both BRT corridors and wildfires, but only sustained BRT exposure affects academic performance, consistent with cumulative school-year exposure rather than transient pollution episodes driving the results.

¹¹Between 2020 and 2022, the city recorded 47 fires affecting approximately 130 hectares, concentrated in the dry months of January through March (Secretaría de Ambiente de Bogotá, 2020, 2022).

Sorting. If families sort into schools based on pollution exposure, our estimates could reflect differences in student composition rather than causal pollution effects. We test this by regressing student and household characteristics (age, gender, parental education, socioeconomic stratum, household size, computer access) on the wind share instrument. Table A-16 shows that neither daytime (Panel A) nor nighttime (Panel B) wind frequency predicts any demographic characteristic, ruling out sorting as a confound.

Older test-takers. The *Saber 11* can be taken by adults seeking higher education access. These individuals spend less time in school buildings and should be less affected by school-proximate pollution. Table A-17 confirms that test-takers aged 19 to 70 show no significant effects of PM_{2.5} or NO_x exposure, whether instrumented with daytime (Panel A) or nighttime (Panel B) wind frequency.

Randomized pollution. We randomly reassign PM_{2.5} and NO_x levels across stations 1000 times and re-estimate the OLS specification. Figure A-7 shows that the placebo estimates cluster around zero, while the actual OLS coefficients fall in the tails of the distribution, confirming that the estimated relationship is not spurious. Appendix Figure A-6 shows the same exercise for the reduced-form (Panel A) and first-stage (Panel B) estimates, with analogous results.

6.3. Specification checks.

Pollution without bus intensity. The main instrument interacts wind frequency with bus route intensity, a route-level measure of TransMilenio traffic volume. If the effects were driven by general road traffic rather than BRT buses, the bus intensity interaction should not matter. Table A-18 estimates the specification without this interaction. Removing the bus intensity interaction weakens the PM_{2.5} estimates from the 5 percent to the 10 percent significance level and reduces the Kleibergen-Paap F-statistic from 15.86 to 10.66, while the NO_x estimates remain significant at the 5 percent level. This confirms that corridor-level bus traffic volume contributes to

instrument strength and that the volume of BRT traffic on each corridor, not merely proximity to a major road, determines the magnitude of pollution exposure.

Controlling for other pollutants. Our main specification does not control for co-pollutants that may correlate with PM_{2.5}. Table A-19 adds ozone (O₃), sulfur dioxide (SO₂), and carbon monoxide (CO) as controls, one at a time. The PM_{2.5} and NO_x IV estimates remain negative and significant across all specifications, while the PM₁₀ estimates are sensitive to the inclusion of CO. This confirms that the main results are not driven by omitted co-pollutants.

Controlling for climate variables. A threat to the exclusion restriction is that wind direction may correlate with temperature, precipitation, or humidity, which could independently affect both pollution levels and cognitive performance. Table A-20 adds each climate variable separately. The PM_{2.5} and NO_x IV estimates remain negative and significant when controlling for precipitation and humidity. The estimates are attenuated when controlling for temperature, consistent with temperature correlating with both pollution and cognitive performance, though the direction of the effect is preserved.

Pollution abnormalities. Rather than using average pollution levels, we measure the share of hours during which pollution exceeds the 90th percentile of the citywide distribution during school hours. Table A-21 shows that higher frequencies of extreme pollution episodes reduce math and global scores, reinforcing the main results with an alternative measure of exposure intensity.

TransMilenio expansion and pollution. The preceding tests establish that the pollution-achievement relationship is specific to BRT corridors, but they do not directly show that BRT operations caused the pollution. To provide this evidence, we estimate a local projections difference-in-differences specification following Dube et al. (2025), identifying treated schools as those whose distance to the TransMilenio network decreased after a corridor expansion. Because TransMilenio was rolled out in phases

(2000, 2003–2006, 2012), we can test whether corridor openings increased pollution at nearby schools relative to schools farther away. Table A-22 shows that new corridor openings increased PM_{2.5} and NO_x concentrations during daytime hours at one month, one quarter, and one year after opening (Panels A–C). The NO_x effects are consistently significant across all three daytime horizons; the PM_{2.5} effects are significant at the month and quarter horizons but imprecise at the year horizon, reflecting the smaller sample available for this specification (3,350 school-week observations). Panels D–F show that nighttime PM_{2.5} also increased, consistent with residual pollution accumulation, though the NO_x effects are less precise at night when fewer buses operate. Together with the non-TransMilenio highway placebo and the bus intensity interaction test, these results support the causal chain from BRT operations to local pollution to lower test scores.

7. CONCLUSIONS

This paper estimates the causal effect of air pollution from Bogotá’s Bus Rapid Transit system on high school academic performance. Using wind direction interacted with bus route intensity as an instrument, we find that schools more frequently downwind of BRT corridors score significantly lower in math and global exams. The instrumental variable estimates imply that an additional $\mu\text{g}/\text{m}^3$ of PM_{2.5} reduces math scores by 0.10 standard deviations and global scores by 0.09 standard deviations, with no significant effect on language scores. An additional part per billion of NO_x decreases math and global scores by 0.015 and 0.013 standard deviations, respectively. The effects are concentrated among schools closer to BRT corridors, are driven by daytime exposure during school hours, and reflect cumulative pollution throughout the academic year rather than short-term fluctuations. Girls and students from higher-income households experience larger declines in performance. A georeferenced household health

survey provides suggestive evidence that respiratory disease mediates the pollution-achievement relationship.

Three features of the evidence support a causal interpretation centered on BRT emissions. Wind from comparable non-TransMilenio highways does not predict test scores, confirming that the effects are specific to BRT corridors rather than general road traffic. Removing the bus intensity interaction from the instrument weakens its predictive power, indicating that the volume of bus traffic on each corridor matters. A local projections difference-in-differences specification shows that TransMilenio corridor openings directly increased PM_{2.5} and NO_x concentrations at nearby schools. Additional falsification tests reinforce these findings: nighttime wind frequency does not predict test scores, weekend pollution has no effect on academic performance, wind share does not predict student demographics, and older test-takers who spend less time in school buildings show no pollution effects.

These results carry direct policy implications. Bogotá’s decision to replace its diesel fleet with compressed natural gas and electric buses beginning in 2019 reduced PM_{2.5} concentrations by 45 percent inside buses and 76 percent inside stations ([Morales Betancourt, 2022](#)). Our estimates suggest that this fleet transition may yield measurable improvements in academic outcomes for students near BRT corridors. To illustrate the magnitudes: a one-standard-deviation increase in PM_{2.5} exposure (approximately $3 \mu\text{g}/\text{m}^3$) corresponds to a 0.30 standard deviation decline in math scores. Given that approximately 95,000 students take the *Saber 11* exam each year, the aggregate human capital cost of diesel-powered transit is potentially substantial. More broadly, the results demonstrate that the design of public transit systems, not only their existence, determines whether they generate net welfare gains. Cities expanding BRT networks with diesel fleets face a trade-off between mobility benefits and human capital costs that policymakers can mitigate through cleaner fuel technologies or air filters (see [Kremer et al., 2025](#)).

REFERENCES

- Aguilar-Gomez, S., H. Dwyer, J. Graff Zivin, and M. Neidell (2022). This is air: The “nonhealth” effects of air pollution. *Annual Review of Resource Economics* 14, 403–425.
- Aguilera, I., M. Pedersen, R. Garcia-Esteban, F. Ballester, M. Basterrechea, A. Esplugues, A. Fernández-Somoano, A. Lertxundi, A. Tardón, and J. Sunyer (2013). Early-life exposure to outdoor air pollution and respiratory health, ear infections, and eczema in infants from the inma study. *Environmental health perspectives* 121(3), 387–392.
- Anderson, M. L. (2020). As the Wind Blows: The Effects of Long-Term Exposure to Air Pollution on Mortality. *Journal of the European Economic Association* 18(4), 1886–1927.
- Balakrishnan, U. and M. Tsaneva (2021). Air pollution and academic performance: Evidence from India. *World Development* 146, 105553.
- Barreca, A. I., M. Neidell, and N. J. Sanders (2021). Long-run pollution exposure and mortality: Evidence from the acid rain program. *Journal of Public Economics* 200, 104440.
- Barrera-Osorio, F., A. De Barros, S. Dryden-Peterson, B. Mulimbi, N. Nakajima, and P. Uccelli (2020). Levers for learning: Relationships between school-level factors and literacy outcomes in low-income schools in Colombia. *Comparative Education Review* 64(2), 269–298.
- Beatty, T. K. and J. P. Shimshack (2011). School buses, diesel emissions, and respiratory health. *Journal of Health Economics* 30(5), 987–999.
- Bedi, A. S., M. Y. Nakaguma, B. J. Restrepo, and G. Riella (2021). Particle pollution and cognition: Evidence from sensitive cognitive tests in brazil. *Journal of the Association of Environmental and Resource Economists* 8(3), 443–474.

- Beelen, R., G. Hoek, E. Pebesma, D. Vienneau, K. de Hoogh, and D. J. Briggs (2009). Mapping of background air pollution at a fine spatial scale across the european union. *Science of The Total Environment* 407(6), 1852–1867.
- Belalcazar-Cerón, L. C., P. Dávila, A. Rojas, M. A. Guevara-Luna, H. Acevedo, and N. Rojas (2021). Effects of fuel change to electricity on pm_{2.5} local levels in the Bus Rapid Transit System of Bogota. *Environmental Science and Pollution Research* 28(48), 68642–68656.
- Borgschulte, M., D. Molitor, and E. Y. Zou (2022). Air pollution and the labor market: Evidence from wildfire smoke. *Review of Economics and Statistics*, 1–46.
- Borusyak, K. and P. Hull (2023). Nonrandom exposure to exogenous shocks. *Econometrica* 91(6), 2155–2185.
- Castillo-Camacho, M. P., I. C. Tunarrosa-Grisales, L. M. Chacón-Rivera, M. A. Guevara-Luna, and L. C. Belalcázar-Cerón (2020). Personal exposure to pm_{2.5} in the massive transport system of bogotá and medellín, colombia. *Asian Journal of Atmospheric Environment* 14(3), 210–224.
- Chen, P. (2025). Industrialization and pollution: The long-term impact of early-life exposure on human capital formation. *Journal of Public Economics* 241, 105270.
- CONPES (2018). Política para el mejoramiento de la calidad del aire. Technical report, Consejo Nacional de Política Económica y Social.
- Cracknell, J. (2003). Transmilenio busway-based mass transit, Bogotá, Colombia. *World Bank Working Paper*.
- Currie, J. and M. Neidell (2005). Air pollution and infant health: What can we learn from california’s recent experience?. *The Quarterly Journal of Economics* 120(3), 1003 – 1030.
- Currie, J. and R. Walker (2011). Traffic congestion and infant health: Evidence from e-zpass. *American Economic Journal: Applied Economics* 3(1), 65–90.

- Danieli, O., D. Nevo, I. Walk, B. Weinstein, and D. Zeltzer (2026). Negative control falsification tests for instrumental variable designs. *American Economic Review*.
- Deryugina, T., G. Heutel, N. H. Miller, D. Molitor, and J. Reif (2019, December). The mortality and medical costs of air pollution: Evidence from changes in wind direction. *American Economic Review* 109(12), 4178–4219.
- Diao, M., T. Holloway, S. Choi, S. M. O’Neill, M. Z. Al-Hamdan, A. Van Donkelaar, R. V. Martin, X. Jin, A. M. Fiore, D. K. Henze, et al. (2019). Methods, availability, and applications of pm_{2.5} exposure estimates derived from ground measurements, satellite, and atmospheric models. *Journal of the Air & Waste Management Association* 69(12), 1391–1414.
- Dominici, F., R. D. Peng, M. L. Bell, L. Pham, A. McDermott, S. L. Zeger, and J. M. Samet (2014). Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA* 295(10), 1127–1134.
- Dube, A., D. Girardi, O. Jordà, and A. M. Taylor (2025). A local projections approach to difference-in-differences. *Journal of Applied Econometrics* 40(7), 741–758.
- Duque, V. and M. Gilraine (2022). Coal use, air pollution, and student performance. *Journal of Public Economics* 213, 104712.
- Ebenstein, A., M. Fan, M. Greenstone, G. He, and M. Zhou (2017). New evidence on the impact of sustained exposure to air pollution on life expectancy from china’s huai river policy. *Proceedings of the National Academy of Sciences* 114(39), 10384–10389.
- Ebenstein, A., V. Lavy, and S. Roth (2016). The long-run economic consequences of high-stakes examinations: Evidence from transitory variation in pollution. *American Economic Journal: Applied Economics* 8(4), 36–65.
- Echeverry, J. C., A. M. Ibanez, A. Moya, L. C. Hillon, M. Cárdenas, and A. Gómez-Lobo (2005). The economics of transmilenio, a mass transit system for bogotá [with comments]. *Economía* 5(2), 151–196.

- EPA (1999). Nitrogen oxides (nox), why and how they are controlled. Technical report, Environmental Protection Agency.
- Fu, S., V. B. Viard, and P. Zhang (2021). Air pollution and manufacturing firm productivity: Nationwide estimates for China. *The Economic Journal* 131(640), 3241–3273.
- Gilraine, M. (2023). Air filters, pollution, and student achievement. *Journal of Human Resources*, 0421–11642R2.
- Gilraine, M. and A. Zheng (2022). Air pollution and student performance in the U.S. Working Paper 30061, National Bureau of Economic Research.
- Guzman, L. A. and D. Oviedo (2018). Accessibility, affordability and equity: Assessing ‘pro-poor’ public transport subsidies in Bogotá. *Transport Policy* 68, 37–51.
- Hanna, R. and P. Oliva (2015). The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City. *Journal of Public Economics* 122, 68–79.
- He, J., H. Liu, and A. Salvo (2019). Severe air pollution and labor productivity: Evidence from industrial towns in China. *American Economic Journal: Applied Economics* 11(1), 173–201.
- Heissel, J. A., C. Persico, and D. Simon (2022). Does pollution drive achievement? the effect of traffic pollution on academic performance. *Journal of Human Resources* 57(3), 747–776.
- Herrnstadt, E., A. Heyes, E. Muehlegger, and S. Saberian (2021). Air pollution and criminal activity: Microgeographic evidence from Chicago. *American Economic Journal: Applied Economics* 13(4), 70–100.
- Hidalgo, D., L. Pereira, N. Estupiñán, and P. L. Jiménez (2013). TransMilenio BRT system in Bogota, high performance and positive impact—main results of an ex-post evaluation. *Research in Transportation Economics* 39(1), 133–138.
- IQAir (2023). World air quality report 2023. Technical report, IQAir.

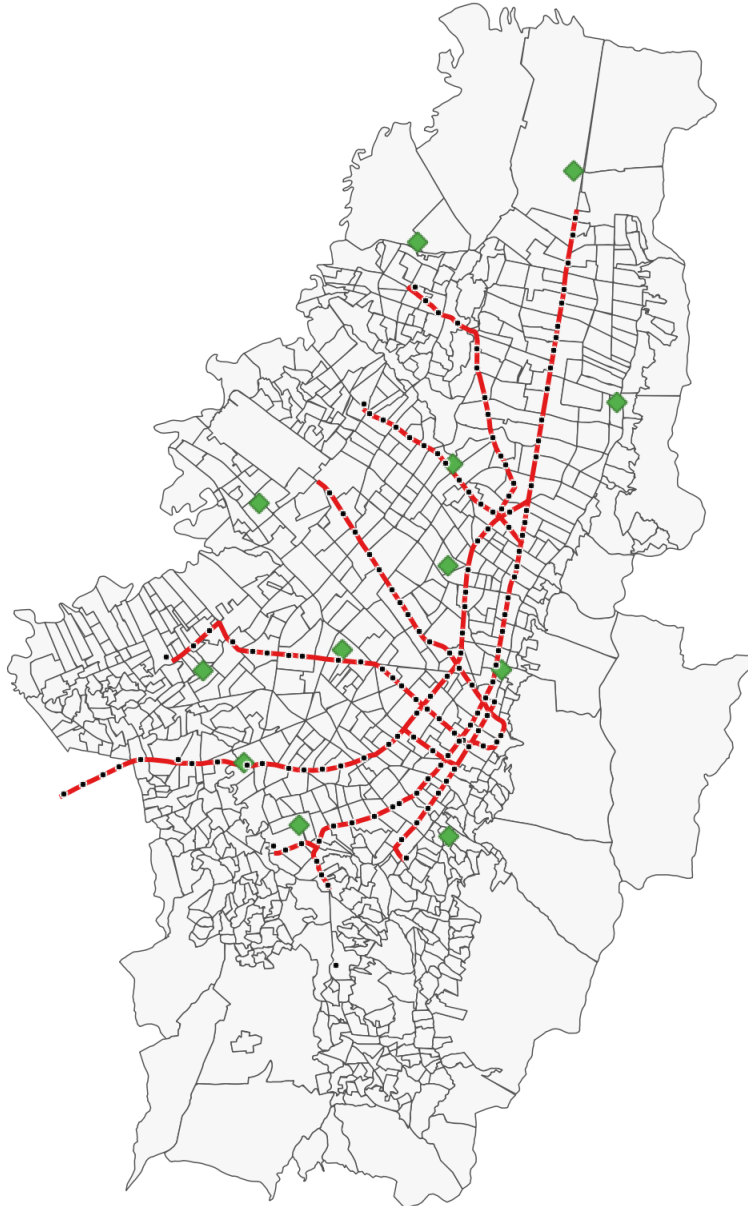
- Jack, R. and E. Oster (2023, November). Covid-19, school closures, and outcomes. *Journal of Economic Perspectives* 37(4), 51–70.
- Jerrett, M., M. Buzzelli, R. T. Burnett, and P. F. DeLuca (2005). Particulate air pollution, social confounders, and mortality in small areas of an industrial city. *Social Science Medicine* 60(12), 2845–2863. Burning Issues - Selected papers from the 10th International Symposium in Medical Geography, Manchester 2003.
- Kelly, F. J. and T. Zhu (2016). Transport solutions for cleaner air. *Science* 352(6288), 934–936.
- Knittel, C. R., D. L. Miller, and N. J. Sanders (2016). Caution, drivers! children present: Traffic, pollution, and infant health. *The Review of Economics and Statistics* 98(2), 350–366.
- Kremer, M., M. Romero, and S. Saavedra (2025). Do air filters improve student learning? experimental evidence from colombia. Technical report, Working Paper.
- Lichter, A., N. Pestel, and E. Sommer (2017). Productivity effects of air pollution: Evidence from professional soccer. *Labour Economics* 48, 54–66.
- Lu, W., D. A. Hackman, and J. Schwartz (2021). Ambient air pollution associated with lower academic achievement among us children: a nationwide panel study of school districts. *Environmental Epidemiology* 5(6), e174.
- Marcotte, D. E. (2017). Something in the air? air quality and children’s educational outcomes. *Economics of Education Review* 56, 141–151.
- Merkus, E. (2024). Hold your breath! air pollution and cognitive performance in Colombia. *World Development Sustainability* 4, 100123.
- Ministerio de Educación Nacional de Colombia (2024). Estadísticas en Educación en Preescolar, Básica, y Media. Accessed: November 4, 2024.
- Morales Betancourt, Ricardo, e. a. (2022). Toward cleaner transport alternatives: Reduction in exposure to air pollutants in a mass public transport. *Environmental Science & Technology* 56, 7096–7106.

- Peden, D. B. (2002). Pollutants and asthma: role of air toxics. *Environmental Health Perspectives* 110(suppl 4), 565–568.
- Persico, C. L. and J. Venator (2019). The effects of local industrial pollution on students and schools. *Journal of Human Resources*.
- Pope, C. A. and D. W. Dockery (2006). Health effects of fine particulate air pollution: Lines that connect. *Journal of the Air & Waste Management Association* 56(6), 709–742.
- Posso, C., E. Saravia, and P. Uribe (2023). Acing the test: Educational effects of the saber test preparation program in Colombia. *Economics of Education Review* 97, 102459.
- Secretaría de Educación del Distrito (2025). Calendario escolar 2025 para colegios públicos en bogotá. <https://www.educacionbogota.edu.co/boletin-prensa/conozca-calendario-escolar-2025-para-colegios-publicos-en-bogota> (accessed April 3, 2026).
- Secretaría de Ambiente de Bogotá (2020). Informe de eventos forestales 2020. Technical report, Secretaría de Ambiente de Bogotá. Accessed: 2024-03-11.
- Secretaría de Ambiente de Bogotá (2022). Análisis de los eventos forestales 2023. Technical report, Secretaría de Ambiente de Bogotá. Accessed: 2024-03-11.
- Shad, R., M. S. Mesgari, A. abkar, and A. Shad (2009). Predicting air pollution using fuzzy genetic linear membership kriging in gis. *Computers, Environment and Urban Systems* 33(6), 472–481. Spatial Data Mining–Methods and Applications.
- Simeonova, E., J. Currie, P. Nilsson, and R. Walker (2019). Congestion pricing, air pollution, and children’s health. *Journal of Human Resources*.
- Statista Research Department (2024). Population of Bogotá, Colombia (2018-2024). Accessed: November 4, 2024.
- TomTom (2023). TomTom Traffic Index 2023. Accessed: 2024-11-04.

- TransMilenio S.A. (2018). Estadísticas de oferta y demanda del Sistema TransMilenio. Technical report, TransMilenio S.A., Bogotá, Colombia.
- Tsekeris, T. and N. Geroliminis (2013). City size, network structure and traffic congestion. *Journal of Urban Economics* 76, 1–14.
- Tsivanidis, N. (2022). Evaluating the impact of urban transit infrastructure: Evidence from Bogotá’s transmilenio.
- Villalobos, M. and A. Blackman (2025). Air pollution and high-stakes test scores: Evidence from Bogota, Colombia. *Applied Economics Letters*.
- World Health Organization (2021). WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Technical report, World Health Organization.
- Zhang, X., X. Chen, and X. Zhang (2018). The impact of exposure to air pollution on cognitive performance. *Proceedings of the National Academy of Sciences* 115(37), 9193–9197.

TABLES AND FIGURES

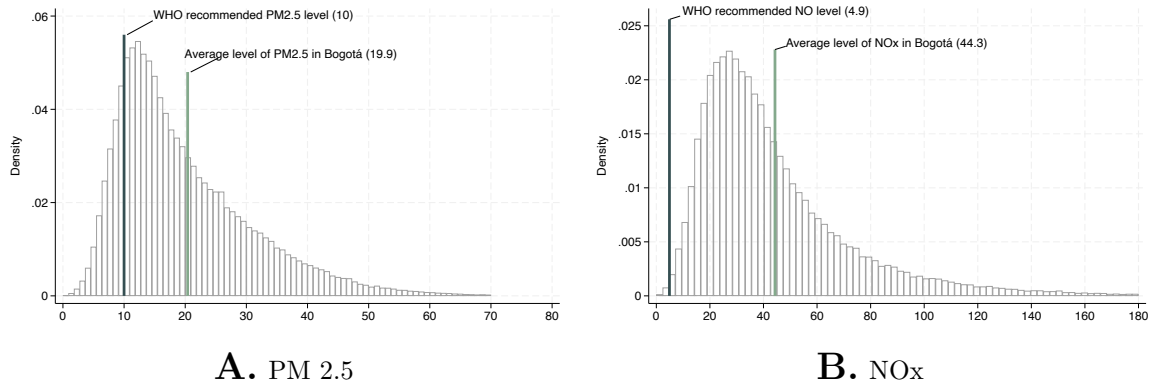
FIGURE 1. TransMilenio and Air Quality Monitors



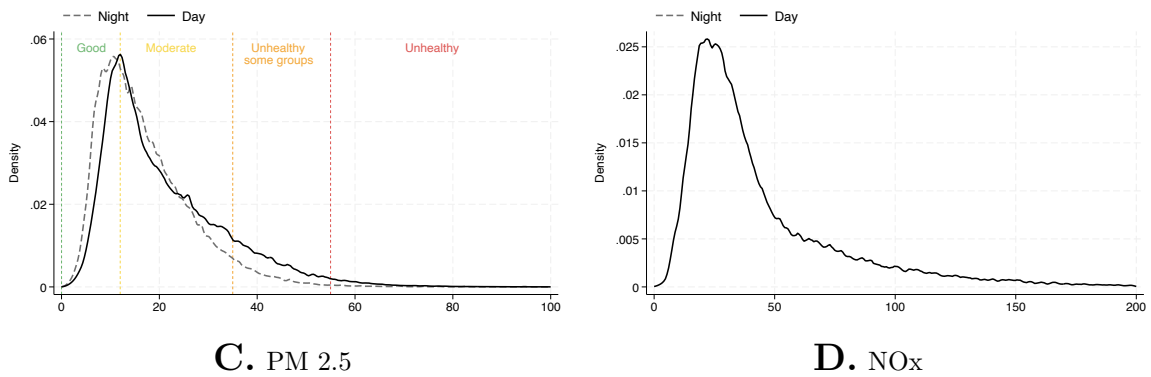
Notes: The figure shows the transport and air quality monitoring network in Bogotá. The lines represent the TransMilenio network. The dots over the lines indicate TransMilenio stations where buses stop. The diamond markers represent stations in the Bogotá Air Quality Monitoring Network.

FIGURE 2. Pollution Density in Bogotá’s Schools

Panel A: Pollution Distribution



Panel B: Pollution Distribution by time of Day



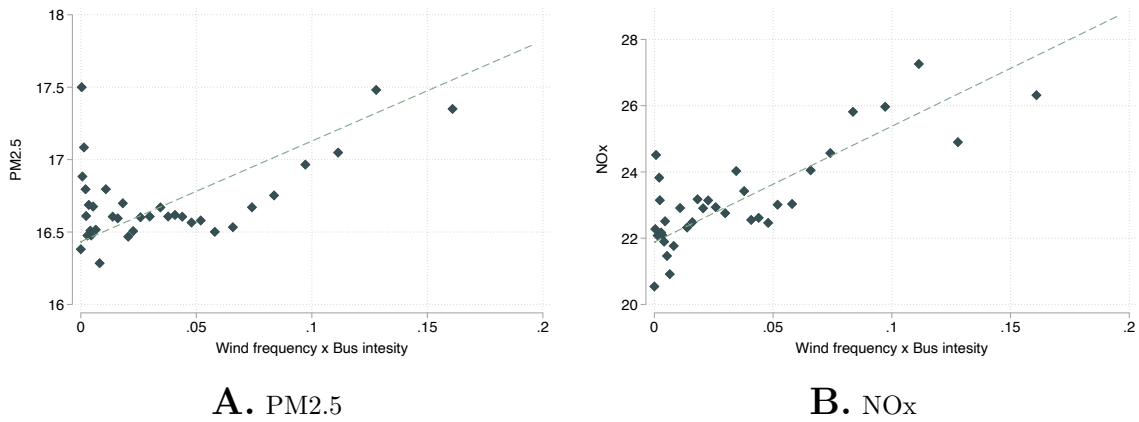
Notes: The figures show the distribution of PM2.5 and NOx levels in Bogotá’s schools from 2014 to 2018. Panel A shows the distribution of all values during all hours. Panel B shows the distribution separately for daylight hours (6 AM to 6 PM) and night hours (midnight to 6 AM).

FIGURE 3. Schools and Wind Direction



Notes: The figure shows a group of schools (black markers) near a segment of the Caracas trunk route (bright pink line). The arrows depict the frequency of downwind conditions from west to east.

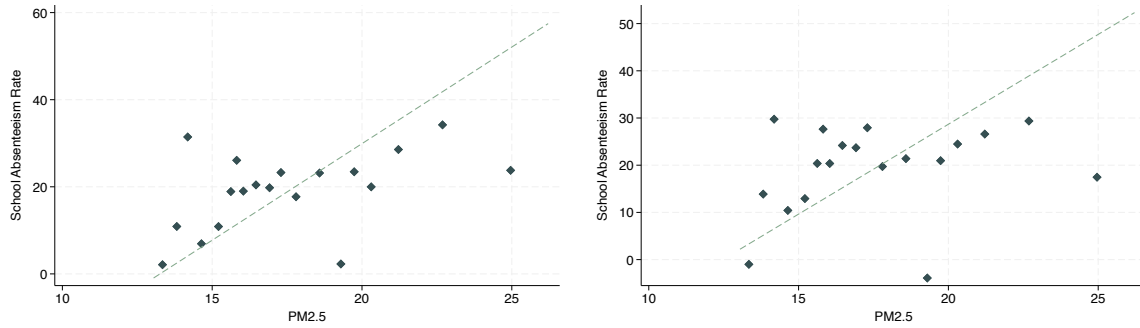
FIGURE 4. Pollutants and Downwind Frequency



Notes: The figures illustrate the relationship between PM2.5 and NOx levels with wind frequency during daylight hours, with wind blowing from the TransMilenio route to the school. This relationship is derived from a binned regression of daily pollutant levels on the percentage of time that pollution stations are downwind.

FIGURE 5. PM2.5, School Absenteeism, and Respiratory Health

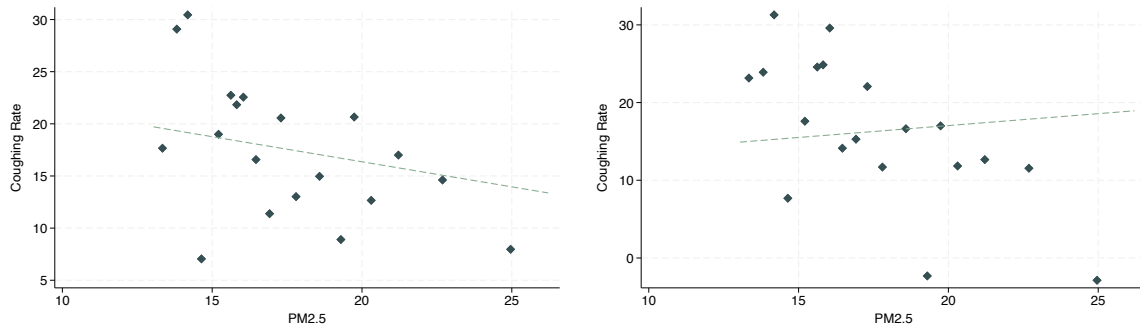
Panel A: School absenteeism rate



A. Men

B. Women

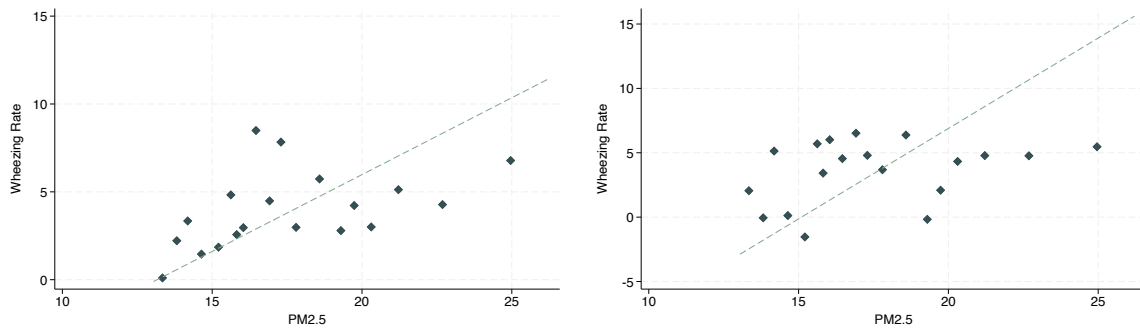
Panel B: Coughing Rate



C. Men

D. Women

Panel C: Wheezing Rate



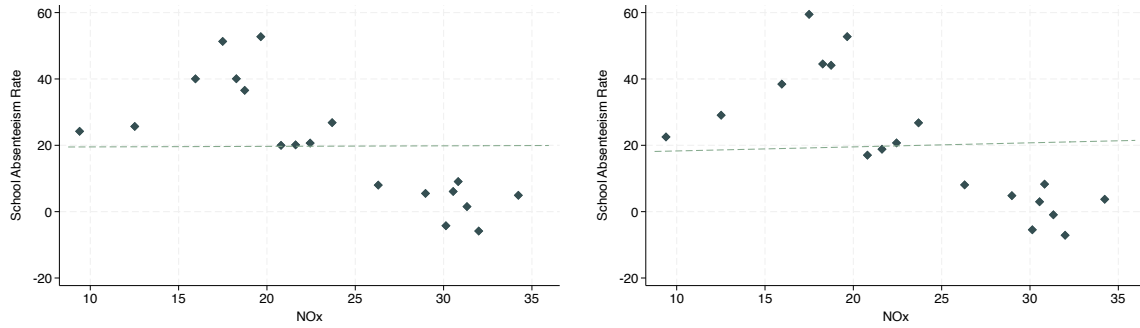
E. Men

F. Women

Notes: The figures show the relationship between PM2.5 levels and various health outcomes for children under 14 for boys and girls. Panel A shows the absenteeism rate, Panel B shows the coughing rate, and Panel C shows the wheezing rate. These relationships are derived from a binned regression of the rates on average PM2.5 levels of students at the locality level based on the school location. The rates are based on surveys conducted by Bogotá's Department of Health, which collected information about the health status of their children from a sample of parents. Binned regression controls for year and locality fixed effects and malnutrition rates.

FIGURE 6. NO_x, School Absenteeism, and Respiratory Health

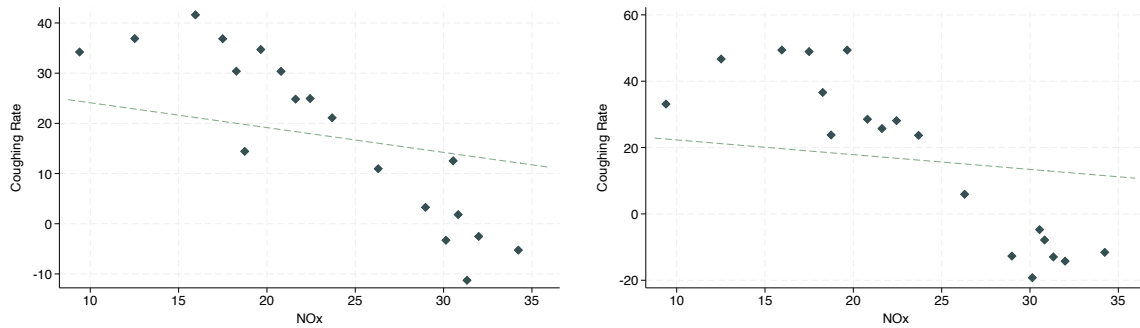
Panel A: School absenteeism rate



A. Men

B. Women

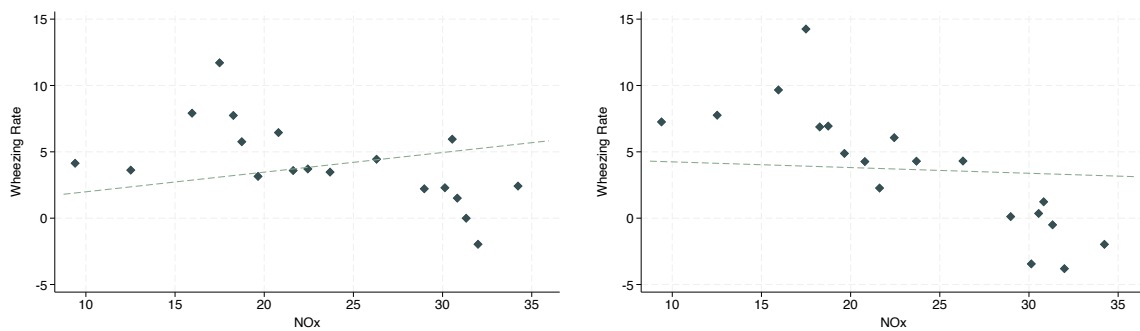
Panel B: Coughing Rate



C. Men

D. Women

Panel C: Wheezing Rate



E. Men

F. Women

Notes: The figures show the relationship between NO_x levels and various health outcomes for children under 14 for boys and girls. Panel A shows the absenteeism rate, Panel B shows the coughing rate, and Panel C shows the wheezing rate. These relationships are derived from a binned regression of the rates on average NO_x levels of students at the locality level based on the school location. The rates are based on surveys conducted by Bogotá's Department of Health, which collected information about the health status of their children from a sample of parents. Binned regression controls for year and locality fixed effects and malnutrition rates.

TABLE 1. Descriptive Statistics

| | Within BRT pollution gradient | | Beyond BRT pollution gradient | |
|--|-------------------------------|-------|-------------------------------|-------|
| | Mean | Stdv. | Mean | Stdv. |
| <i>Panel A: Academic achievements outcomes</i> | | | | |
| Math score | 0.11 | 0.92 | 0.01 | 0.96 |
| Language score | 0.12 | 0.94 | -0.01 | 0.97 |
| Global score | 0.12 | 0.92 | -0.01 | 0.96 |
| <i>Panel B: Pollution</i> | | | | |
| PM2.5 ($\mu\text{g}/\text{m}^3$) | 16.73 | 2.99 | 16.19 | 2.96 |
| PM10 ($\mu\text{g}/\text{m}^3$) | 39.14 | 6.20 | 37.97 | 4.38 |
| NOx (Parts per billion) | 23.12 | 7.32 | 22.30 | 6.72 |
| O3 (Parts per billion) | 5.27 | 1.14 | 5.73 | 0.97 |
| CO (Parts per million) | 0.66 | 0.06 | 0.66 | 0.05 |
| SO2 (Parts per billion) | 1.22 | 0.49 | 1.23 | 0.48 |
| <i>Panel C: Controls</i> | | | | |
| Age | 16.96 | 0.71 | 16.99 | 0.70 |
| Female | 0.54 | 0.50 | 0.55 | 0.50 |
| Gender (No info) | 0.00 | 0.03 | 0.00 | 0.02 |
| Mother education | | | | |
| Lower completed primary school | 0.07 | 0.26 | 0.12 | 0.32 |
| Lower completed high school | 0.23 | 0.42 | 0.29 | 0.45 |
| Lower completed tertiary education | 0.37 | 0.48 | 0.34 | 0.47 |
| Completed tertiary education | 0.30 | 0.46 | 0.23 | 0.42 |
| No info | 0.03 | 0.17 | 0.02 | 0.15 |
| Family stratum | | | | |
| Lower | 0.50 | 0.50 | 0.70 | 0.46 |
| Medium | 0.40 | 0.49 | 0.18 | 0.39 |
| High | 0.09 | 0.28 | 0.10 | 0.30 |
| No info | 0.01 | 0.12 | 0.02 | 0.12 |
| Household Size | 4.56 | 1.66 | 4.67 | 1.68 |
| Household Size (No info) | 0.01 | 0.09 | 0.01 | 0.08 |
| Household has computer | 0.87 | 0.33 | 0.83 | 0.38 |
| Household has computer (No info) | 0.01 | 0.08 | 0.01 | 0.07 |
| <i>Panel D: School characteristics</i> | | | | |
| Public school | 0.53 | 0.50 | 0.62 | 0.48 |
| School type | | | | |
| Academic | 0.83 | 0.37 | 0.92 | 0.28 |
| Academic-Technical | 0.13 | 0.34 | 0.06 | 0.24 |
| Technical | 0.02 | 0.15 | 0.01 | 0.12 |
| Other | 0.00 | 0.06 | 0.00 | 0.05 |
| No info | 0.01 | 0.11 | 0.00 | 0.07 |
| Observations | 275,987 | | 95,984 | |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year. We define “Within BRT pollution gradient” as schools located within 1.86 km of the nearest TransMilenio corridor, and “Beyond BRT pollution gradient” as those located beyond this distance. This 1.86 km threshold corresponds to the 75th percentile of the distribution of distances between schools and their nearest BRT corridor. This threshold is data-driven rather than based on pollution dispersion physics, so we test sensitivity to this choice in Table A-15, which reports estimates across eight distance cutoffs from 1.25 to 3.0 km. The results are stable between 1.5 and 2.25 km and attenuate at greater distances, consistent with localized pollution dispersion.

TABLE 2. Effects of Air Pollution on Exam Scores

| | PM 2.5 | | | | | NOx | | | |
|--|-----------------------|------------------------|---------------------|------------------------|--|------------------------|------------------------|---------------------|------------------------|
| | PM2.5 (1) | Math (2) | Lang. (3) | Global (4) | | NOx (5) | Math (6) | Lang. (7) | Global (8) |
| <i>Panel A: First-stage and reduced-form estimates</i> | | | | | | | | | |
| Wind share blowing to the school \times bus intensity | 2.5321*** (0.6358) | -0.2570*** (0.0876) | -0.1056 (0.0771) | -0.2349*** (0.0770) | | 17.7377*** (2.2444) | -0.2570*** (0.0876) | -0.1056 (0.0771) | -0.2349*** (0.0770) |
| R2 | 0.9670 | 0.3153 | 0.2314 | 0.3550 | | 0.9081 | 0.3153 | 0.2314 | 0.3550 |
| Observations | 275987 | 275987 | 275987 | 275987 | | 275987 | 275987 | 275987 | 275987 |
| <i>Panel B: OLS estimates</i> | | | | | | | | | |
| Pollution | -- | -0.0027 (0.0033) | -0.0016 (0.0032) | -0.0039 (0.0032) | | -- | 0.0003 (0.0008) | 0.0015* (0.0008) | 0.0006 (0.0008) |
| R2 | | 0.3152 | 0.2314 | 0.3550 | | | 0.3152 | 0.2314 | 0.3550 |
| Observations | | 275987 | 275987 | 275987 | | | 275987 | 275987 | 275987 |
| <i>Panel C: IV estimates</i> | | | | | | | | | |
| Pollution | -- | -0.1015** (0.0430) | -0.0417 (0.0330) | -0.0928** (0.0383) | | -- | -0.0145*** (0.0052) | -0.0060 (0.0045) | -0.0132*** (0.0046) |
| Observations | | 275987 | 275987 | 275987 | | | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | | 15.86 | 15.86 | 15.86 | | | 62.46 | 62.46 | 62.46 |
| Controls | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). Table A-15 shows that the results are robust across alternative distance cutoffs from 1.25 to 3.0 km. The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of daytime hours (6:00 a.m. to 5:00 p.m.) during which wind blows from the nearest TransMilenio corridor toward the school at speeds of one mile per hour or less, within a 45-degree cone. Bus intensity is the average number of TransMilenio buses per hour operating on the nearest corridor segment (source: [TransMilenio S.A., 2018](#)). In Panel A, the instrument is the wind share interacted with bus intensity. In Panel C, this instrument is used for a student's yearly average pollution exposure. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE 3. Effects of Air Pollution on Exam Scores by Gender

| | Math (1) | PM2.5 Lang. (2) | Global (3) | Math (4) | NOx Lang. (5) | Global (6) |
|---------------------|------------------------|-----------------------|------------------------|------------------------|-----------------------|------------------------|
| <i>IV estimates</i> | | | | | | |
| Pollution | -0.1155*** (0.0437) | -0.0462 (0.0333) | -0.1014*** (0.0386) | -0.0219*** (0.0052) | -0.0079* (0.0044) | -0.0183*** (0.0045) |
| Pollution x Male | 0.0217*** (0.0004) | 0.0053*** (0.0004) | 0.0154*** (0.0004) | 0.0150*** (0.0003) | 0.0037*** (0.0003) | 0.0106*** (0.0003) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 7.98 | 7.98 | 7.98 | 31.37 | 31.37 | 31.37 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). Table A-15 shows that the results are robust across alternative distance cutoffs from 1.25 to 3.0 km. The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. We estimate the differential effect according to students' gender. The instruments are the wind share and its interaction with a male indicator, where the wind share is defined as in Table 2. The yearly average exposure to each pollutant is instrumented with this wind share and the interaction. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE 4. Effects of Air Pollution on Exam Scores by Income

| | PM2.5 | | | NOx | | |
|---------------------|-----------------------|----------------------|-----------------------|------------------------|----------------------|------------------------|
| | Math (1) | Lang. (2) | Global (3) | Math (4) | Lang. (5) | Global (6) |
| <i>IV estimates</i> | | | | | | |
| Pollution | -0.1164** (0.0467) | -0.0492 (0.0350) | -0.1039** (0.0416) | -0.0202*** (0.0065) | -0.0062 (0.0053) | -0.0164*** (0.0057) |
| Pollution x Medium | 0.0045*** (0.0014) | 0.0022** (0.0010) | 0.0039*** (0.0012) | 0.0035*** (0.0010) | 0.0016** (0.0008) | 0.0030*** (0.0009) |
| Pollution x Poor | 0.0035** (0.0017) | -0.0015 (0.0012) | 0.0012 (0.0015) | 0.0031** (0.0012) | -0.0009 (0.0010) | 0.0013 (0.0011) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 3.90 | 3.90 | 3.90 | 14.59 | 14.59 | 14.59 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). Table A-15 shows that the results are robust across alternative distance cutoffs from 1.25 to 3.0 km. The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. We estimate the differential effect according to the students' family stratum, with high stratum (strata 5-6) as the omitted category. The instruments are the wind share and its interactions with stratum indicators, where the wind share is defined as in Table 2. The yearly average exposure to each pollutant is instrumented with this wind share and the interactions. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE 5. Effects of Wildfire Pollution on Exam Scores

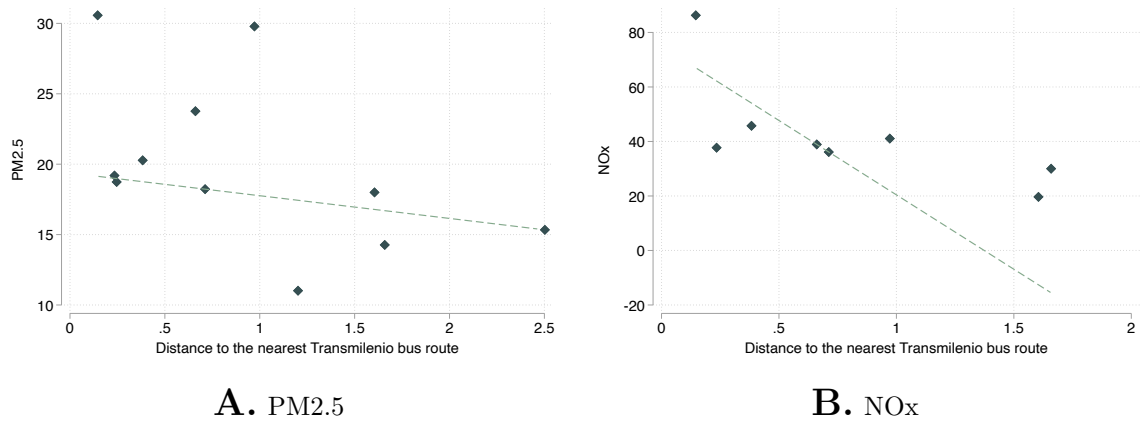
| | PM2.5 | | PM10 | | NOx | | SO2 | | | | | |
|-------------------|--------------------|--------------------|---------------------|--------------------|--------------------|---------------------|--------------------|--------------------|---------------------|--------------------|--------------------|---------------------|
| | Math (1) | Lang. (2) | Global (3) | Math (4) | Lang. (5) | Global (6) | Math (7) | Lang. (8) | Global (9) | Math (10) | Lang. (11) | Global (12) |
| Pollution | 0.0004 (0.0047) | 0.0037 (0.0042) | -0.0015 (0.0042) | 0.0002 (0.0023) | 0.0019 (0.0021) | -0.0007 (0.0021) | 0.0003 (0.0045) | 0.0035 (0.0040) | -0.0014 (0.0040) | 0.0049 (0.0651) | 0.0515 (0.0576) | -0.0202 (0.0583) |
| Observations | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 |
| Kleiberger-Paap F | 319.84 | 319.84 | 319.84 | 118.80 | 118.80 | 118.80 | 73.45 | 73.45 | 73.45 | 30.46 | 30.46 | 30.46 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

IV estimates

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are on average more than 6.5 km from the burn sites. The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The yearly average exposure to each pollutant is instrumented with the percentage of time during the year when wind speeds are above 6 mph, blowing from the burn locations to the school during sunlight hours. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

Appendix

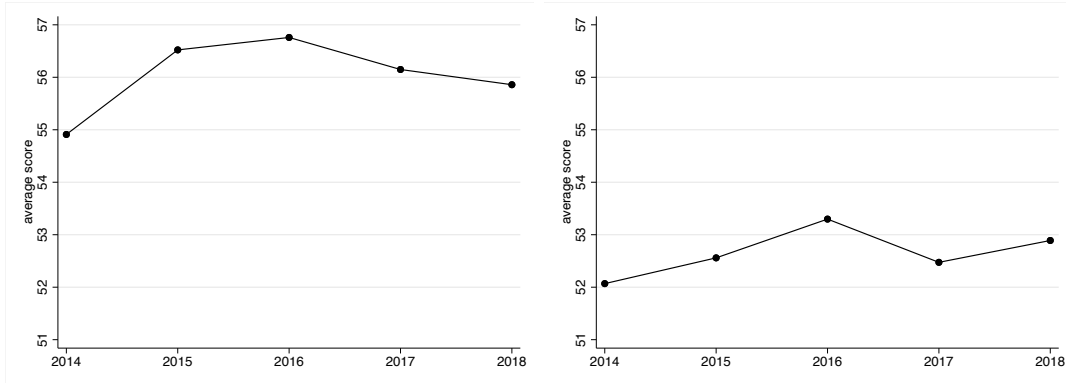
FIGURE A-1. Pollutants and Distance to Bus Stations

**A.** PM2.5**B.** NO_x

Notes: The figure illustrates the relationship between PM2.5 (Panel A) and NO_x (Panel B) levels and the distance to the nearest TransMilenio bus route. This relationship is derived from a binned regression of daily pollution levels on the distance to the routes.

FIGURE A-2. Average Scores in Bogotá

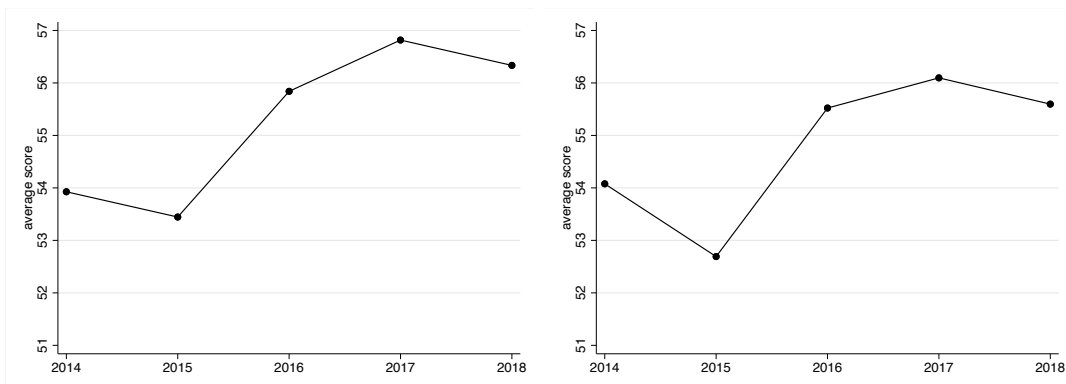
Panel A: Math scores



A. Men

B. Women

Panel B: Languages scores

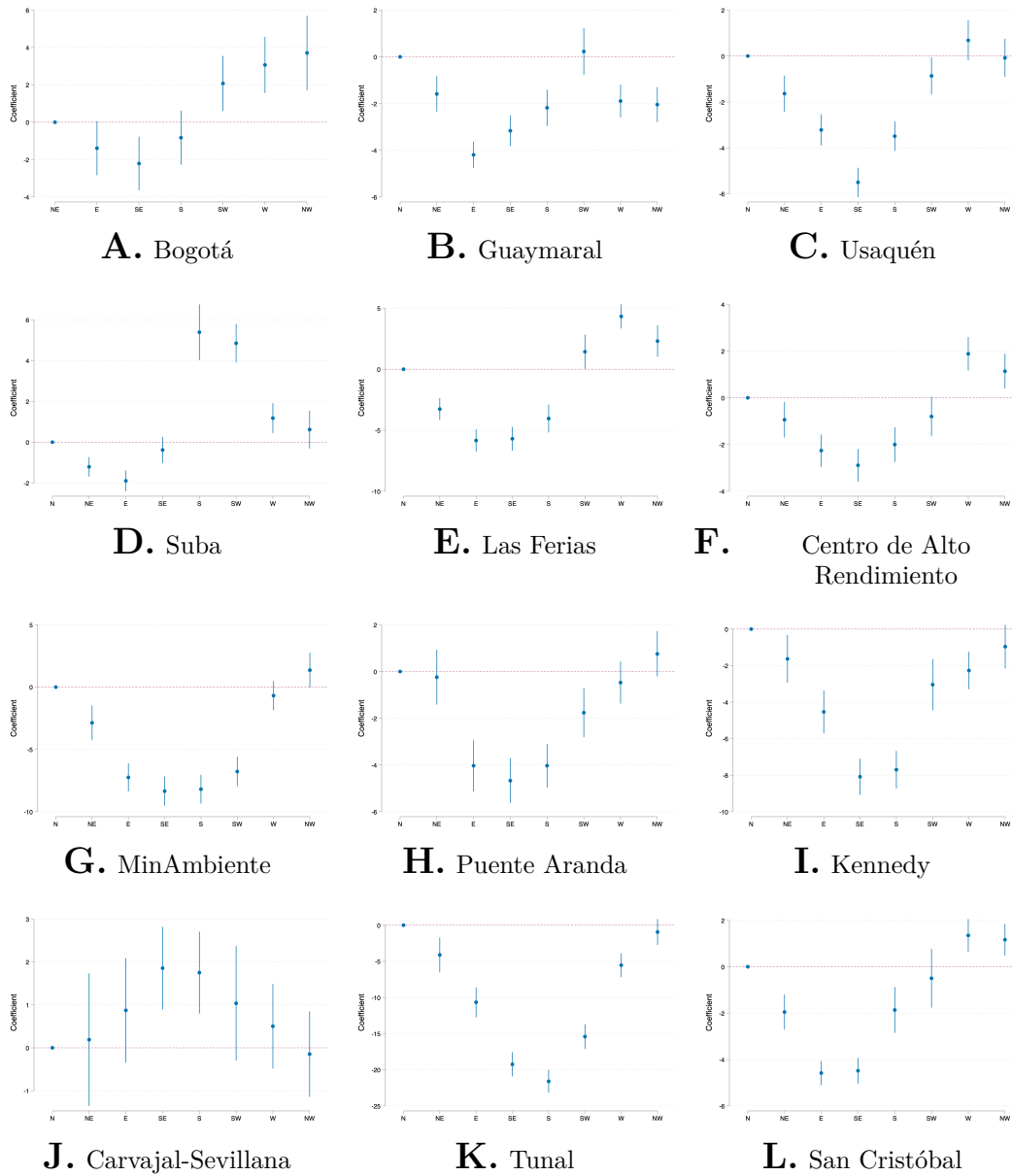


C. Men

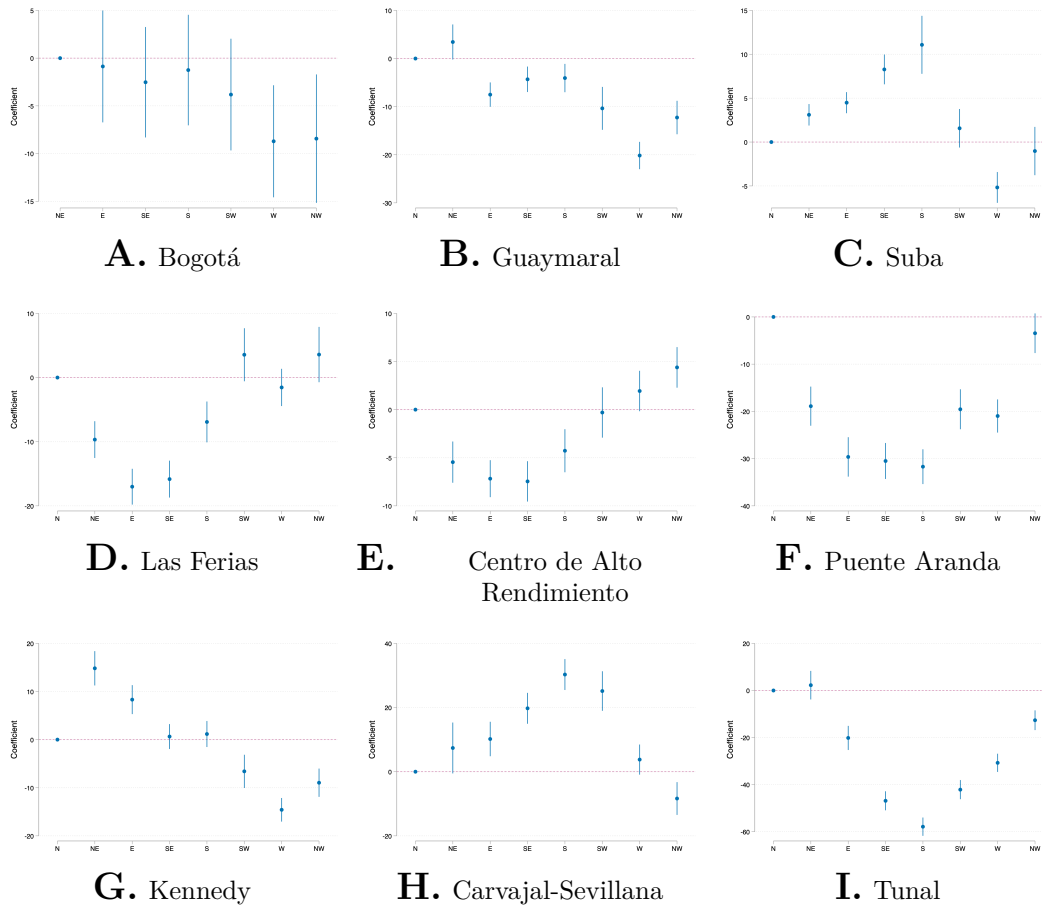
D. Women

Notes: The figures show the average math and language scores for men and women in Bogotá from 2014 to 2018. Panel A shows math scores and Panel B shows language scores.

FIGURE A-3. PM2.5 and Wind Direction



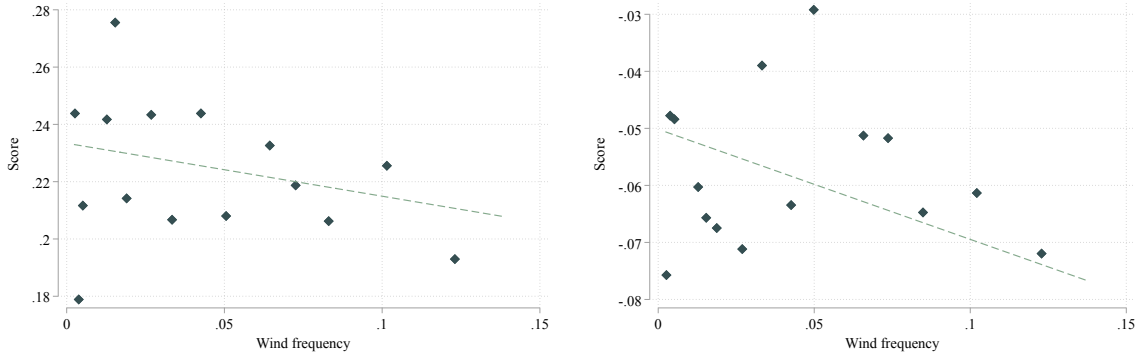
Notes: The figures plot the coefficients (aggregated for Bogotá and by air monitor station) of a regression in which the dependent variable is PM2.5 by hour and day and the regressors of interest are indicators for the daily wind direction divided into 8 bins, where North is the reference category. Controls include day and hour fixed effects. The 95 percent confidence intervals come from robust standard errors.

FIGURE A-4. NO_x and Wind Direction

Notes: The figures plot the coefficients (aggregated for Bogotá and by air monitor station) of a regression in which the dependent variable is NO_x by hour and day and the regressors of interest are indicators for the daily wind direction divided into 8 bins, where North is the reference category. Controls include day and hour fixed effects. The 95 percent confidence intervals come from robust standard errors.

FIGURE A-5. Wind Frequency and Test Scores

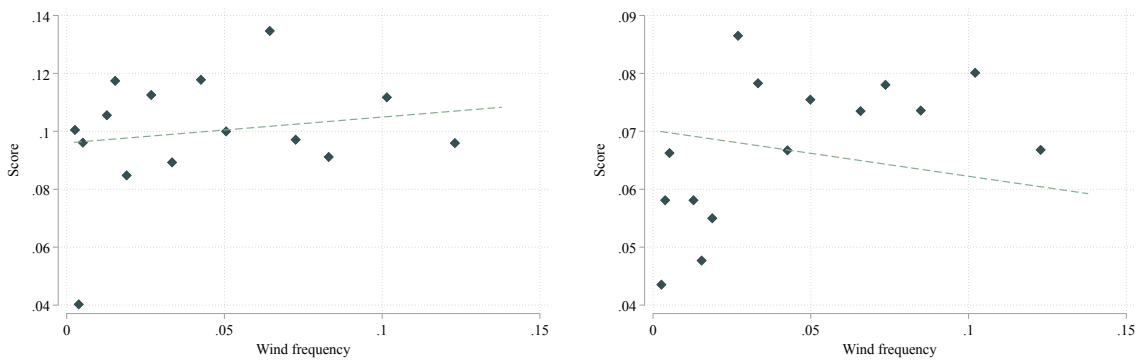
Panel A: Math scores



A. Men

B. Women

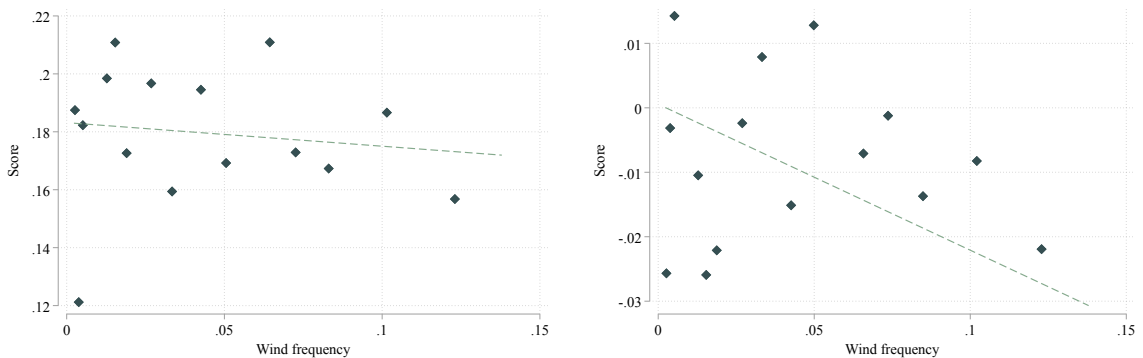
Panel B: Languages scores



C. Men

D. Women

Panel C: Global scores



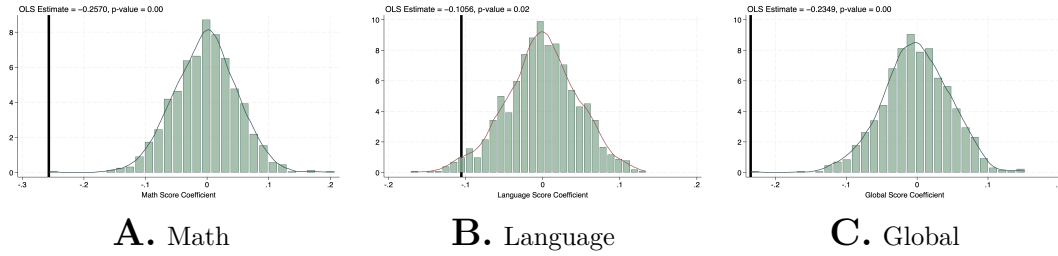
E. Men

F. Women

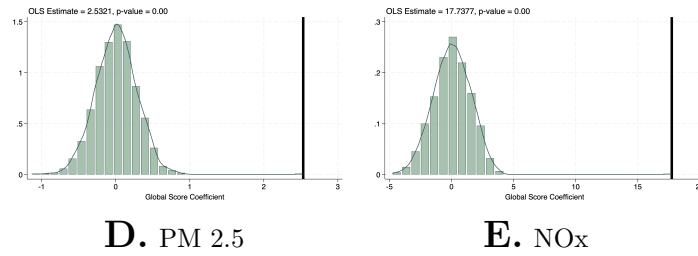
Notes: The figures show the relationship between wind frequency blowing from TransMilenio routes to the school and test scores. Panel A shows math scores, Panel B shows language scores, and Panel C shows global scores. These relationships are derived from a binned regression of test scores on the downwind frequency.

FIGURE A-6. Randomized Instrument by School

Panel A: Reduced-form estimation

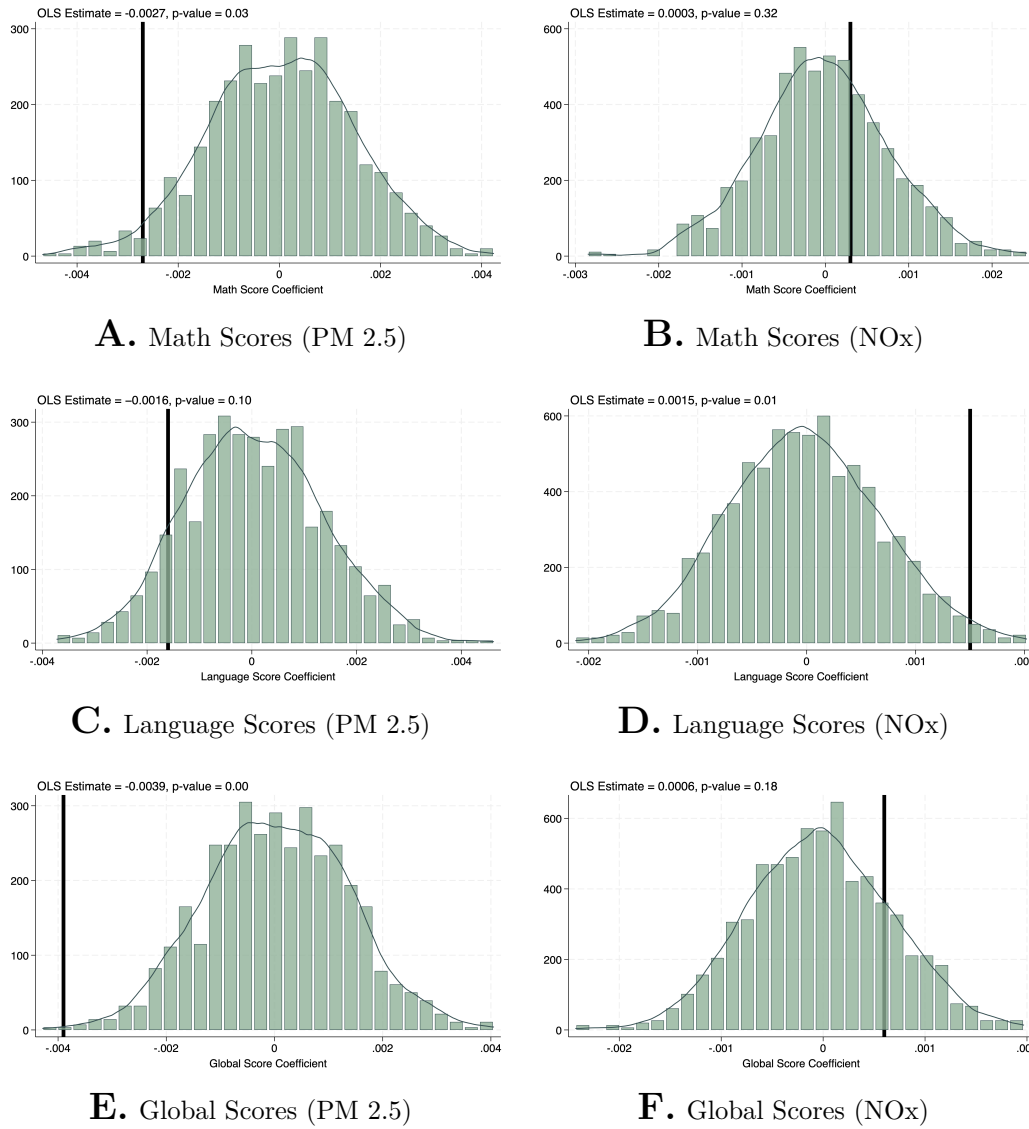


Panel B: First-stage estimation



Notes: The figures show the result of randomizing the instrument across schools 1000 times. Panel A reports the reduced-form estimates and Panel B reports the first-stage estimates. The distributions in blue represent the placebo estimates and the vertical lines correspond to the baseline coefficients reported in Table 2.

FIGURE A-7. Randomized Pollution Levels by School: OLS Estimation



Notes: The figures show the result of randomizing the pollution levels across schools and estimating the OLS specification for each test score. The distribution in blue represents the estimates after 1000 iterations and the vertical line corresponds to the baseline OLS coefficients reported in Table 2.

TABLE A-1. Air Monitoring Stations

| Station name | Latitude | Longitude | Zone | Open year |
|----------------------------|-----------|------------|------------|-----------|
| Guaymaral | 4.7837501 | -74.044144 | Sub urbana | 2005 |
| Usaquen | 4.71035 | -74.030418 | Urbana | 2000 |
| Suba | 4.76125 | -74.09346 | Sub urbana | 2000 |
| Las Ferias | 4.6907001 | -74.082481 | Urbana | 2004 |
| Centro de alto rendimiento | 4.6584702 | -74.083969 | Urbana | 2004 |
| MinAmbiente | 4.6254902 | -74.066978 | Urbana | 2000 |
| Puente Aranda | 4.6317701 | -74.117477 | Urbana | 2000 |
| Kennedy | 4.6250501 | -74.161331 | Urbana | 2005 |
| Carvajal-Sevillana | 4.59583 | -74.148499 | Urbana | 2000 |
| Tunal | 4.57623 | -74.130959 | Urbana | 2006 |
| San Cristobal | 4.5725498 | -74.083809 | Urbana | 2010 |

Notes: The table lists the 11 air quality monitoring stations operated by Bogotá's Secretary of the Environment. Zone indicates whether the station is classified as urban or suburban. Each station reports hourly concentrations of PM2.5, PM10, NOx, O3, SO2, and CO, along with meteorological variables including wind direction, wind speed, temperature, relative humidity, and precipitation.

TABLE A-2. Pollutant Correlations

| | PM2.5 (1) | NOx (2) | O3 (3) | SO2 (4) | CO (5) |
|-----------|-----------------------|-----------------------|------------------------|------------------------|------------------------|
| PM10 | 0.2826*** (0.0012) | 0.5048*** (0.0028) | -0.0226*** (0.0005) | 0.0174*** (0.0001) | 0.0071*** (0.0000) |
| PM2.5 | -- -- | 1.0347*** (0.0054) | -0.0596*** (0.0009) | 0.0376*** (0.0002) | 0.0158*** (0.0001) |
| NOx | -- -- | -- -- | -0.0784*** (0.0005) | 0.0139*** (0.0001) | 0.0084*** (0.0000) |
| O3 | -- -- | -- -- | -- -- | -0.0315*** (0.0004) | -0.0136*** (0.0001) |
| SO2 | -- -- | -- -- | -- -- | -- -- | 0.0369*** (0.0006) |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Date FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Hour FE | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: This table reports regression results from a panel of schools between 2014 and 2018 with hourly pollutant measurements. Each cell represents a separate regression of one pollutant on another, controlling for school, date, and hour fixed effects. Standard errors are clustered at the school-year level and appear in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-3. First-Stage Estimates: Wind Share and Pollution Levels

| | PM10 (1) | PM2.5 (2) | NO _x (3) | O ₃ (4) | SO ₂ (5) | CO (6) |
|---|-----------------------|-----------------------|------------------------|-----------------------|------------------------|------------------------|
| Panel A: <i>TM sample</i> | | | | | | |
| Wind share blowing to the school × bus intensity | 7.4525*** (2.1530) | 2.5321*** (0.6358) | 17.7377*** (2.2444) | 0.3528 (0.2889) | -0.7832*** (0.1159) | -0.2142*** (0.0331) |
| Mean | 39.1384 | 16.7346 | 23.1226 | 5.2664 | 1.2219 | 0.6599 |
| SD | 6.2011 | 2.9878 | 7.3178 | 1.1412 | 0.4858 | 0.0566 |
| R2 | 0.8843 | 0.9670 | 0.9081 | 0.9017 | 0.9212 | 0.8101 |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Panel B: <i>Burn sample</i> | | | | | | |
| Wind share | 1.2555*** (0.1169) | 0.6296*** (0.0349) | 0.6652*** (0.0776) | -0.0326 (0.0257) | 0.0462*** (0.0081) | -0.0015 (0.0010) |
| Mean | 38.8662 | 16.6575 | 22.7503 | 5.3747 | 1.2459 | 0.6602 |
| SD | 5.9811 | 3.0218 | 7.2506 | 1.1346 | 0.4693 | 0.0553 |
| R2 | 0.8193 | 0.9111 | 0.9125 | 0.9331 | 0.8459 | 0.9285 |
| Observations | 336181 | 336181 | 336181 | 336181 | 336181 | 336181 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year. Panel A includes students whose schools are located within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor), while Panel B includes students whose schools are 6.5 km or more from the burning sites. All regressions control for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. In Panel A, wind share is defined as the percentage of time during sunlight hours when wind speeds are below 1 mph and winds blow from the TransMilenio route toward the school; in Panel B, it is defined as the percentage of time during sunlight hours when wind speeds are above 6 mph and winds blow from the burning locations toward the school. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-4. IV Estimates for PM10 and O3

| | PM10 | | | O3 | | |
|---------------------|-----------------------|---------------------|-----------------------|---------------------|---------------------|---------------------|
| | Math (1) | Lang. (2) | Global (3) | Math (4) | Lang. (5) | Global (6) |
| <i>IV estimates</i> | | | | | | |
| Pollution | -0.0345** (0.0139) | -0.0142 (0.0109) | -0.0315** (0.0123) | -0.7285 (0.6624) | -0.2994 (0.3384) | -0.6660 (0.6045) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 11.98 | 11.98 | 11.98 | 1.49 | 1.49 | 1.49 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. In each panel, the yearly average exposure to each pollutant is instrumented with the wind share interacted with bus intensity, as defined in Table 2. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-5. Effects of Air Pollution on Exam Scores – Nearest Station Assignment

| | PM 2.5 | | | | | NOx | | | |
|--|------------------------|------------------------|---------------------|------------------------|------------------------|------------------------|-----------------------|------------------------|---------------|
| | PM2.5 (1) | Math (2) | Lang. (3) | Global (4) | | NOx (5) | Math (6) | Lang. (7) | Global (8) |
| Panel A: <i>First-stage and reduced-form estimates</i> | | | | | | | | | |
| Wind share | 14.1544*** (1.8051) | -0.2279** (0.0945) | -0.1076 (0.0776) | -0.2012** (0.0814) | 52.5732*** (7.9686) | -0.4451*** (0.1321) | -0.2314** (0.1155) | -0.4103*** (0.1107) | |
| R2 | 0.9961 | 0.3121 | 0.2305 | 0.3519 | 0.9738 | 0.3007 | 0.2189 | 0.3394 | |
| Observations | 262784 | 262784 | 262784 | 262784 | 199848 | 199848 | 199848 | 199848 | |
| Panel B: <i>OLS estimates</i> | | | | | | | | | |
| Pollution | - - | -0.0041*** (0.0010) | -0.0016 (0.0012) | -0.0030*** (0.0011) | - - | -0.0000 (0.0003) | 0.0003 (0.0003) | 0.0001 (0.0002) | |
| R2 | | 0.3121 | 0.2305 | 0.3519 | | 0.3006 | 0.2189 | 0.3394 | |
| Observations | | 262784 | 262784 | 262784 | | 199848 | 199848 | 199848 | |
| Panel C: <i>IV estimates</i> | | | | | | | | | |
| Pollution | - - | -0.0161** (0.0068) | -0.0076 (0.0056) | -0.0142** (0.0059) | - - | -0.0085*** (0.0030) | -0.0044* (0.0025) | -0.0078*** (0.0026) | |
| Observations | | 262784 | 262784 | 262784 | | 199848 | 199848 | 199848 | |
| Kleibergen-Paap F | | 61.49 | 61.49 | 61.49 | | 43.53 | 43.53 | 43.53 | |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. In Panel C, the wind share is used as an instrument for a student's yearly average pollution exposure. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-6. Effects of Air Pollution on Health Outcomes

| | PM2.5 | | | NOx | | | | | | | | |
|---|-----------------------|-------------------------------|---------------------|-----------------------|---------------------------|------------------------|------------------------|-------------------------------|--------------------|------------------------|----------------------------|-------------------------|
| | PM2.5 (1) | Respiratory disease (2) | Allergy (3) | Any disease (4) | Emergency visit (5) | Stop routine (6) | NOx (7) | Respiratory disease (8) | Allergy (9) | Any disease (10) | Emergency visit (11) | Stop routine (12) |
| Panel A: <i>First-stage and reduced-form estimates</i> | | | | | | | | | | | | |
| Wind share blowing to the house \times bus intensity | 1.7760*** (0.4073) | 0.1309* (0.0680) | 0.0057 (0.0572) | -0.0775 (0.0811) | -0.0844 (0.0704) | -0.0326 (0.0733) | 25.9395*** (1.7856) | 0.1309* (0.0680) | 0.0057 (0.0572) | -0.0775 (0.0811) | -0.0844 (0.0704) | -0.0326 (0.0733) |
| R2 | 0.9677 | 0.1989 | 0.2013 | 0.1793 | 0.1719 | 0.1681 | 0.8608 | 0.1989 | 0.2013 | 0.1793 | 0.1719 | 0.1681 |
| Observations | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 |
| Panel B: <i>OLS estimates</i> | | | | | | | | | | | | |
| Pollution | -- | -0.0058 (0.0049) | -0.0047 (0.0047) | -0.0001 (0.0051) | -0.0066 (0.0059) | -0.0011 (0.0045) | -- | 0.0014** (0.0007) | 0.0000 (0.0007) | -0.0002 (0.0008) | -0.0013 (0.0009) | -0.0009 (0.0007) |
| R2 | 0.1987 | 0.2014 | 0.1792 | 0.1792 | 0.1719 | 0.1681 | 0.1990 | 0.1990 | 0.2013 | 0.1793 | 0.1720 | 0.1682 |
| Observations | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 | 15138 |
| Panel C: <i>IV estimates</i> | | | | | | | | | | | | |
| Pollution | -- | 0.0737* (0.0410) | 0.0032 (0.0322) | -0.0436 (0.0459) | -0.0475 (0.0395) | -0.0184 (0.0414) | -- | 0.0050* (0.0026) | 0.0002 (0.0022) | -0.0030 (0.0031) | -0.0033 (0.0027) | -0.0013 (0.0028) |
| Observations Kleibergen-Paap F | 15138 19.02 | 15138 19.02 | 15138 19.02 | 15138 19.02 | 15138 19.02 | 15138 19.02 | 15138 19.02 | 15138 211.02 | 15138 211.02 | 15138 211.02 | 15138 211.02 | 15138 211.02 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Sector FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 who live within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, household head education, family stratum, household size, presence of the mother and the father at home, the presence of a computer in the house, dummy of no residency change in the previous years, and school schedule interacted by year. The wind share is defined as in Table 2. In Panel C, the wind share is used as an instrument for a student's yearly average pollution exposure. The outcome variables are: diagnosis of any respiratory disease, diagnosis of an allergy, diagnosis of any disease in the previous 30 months, visit to the emergency room, and stopping routine due to illness. Standard errors are clustered at the building-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-7. Effects of Air Pollution on Health Outcomes – Heterogeneous Effects

| | PM2.5 | | | | | NOx | | | | |
|--------------------------------|-------------------------------|--------------------|-----------------------|---------------------------|------------------------|-------------------------------|---------------------|-----------------------|---------------------------|-------------------------|
| | Respiratory disease (1) | Allergy (2) | Any disease (3) | Emergency visit (4) | Stop routine (5) | Respiratory disease (6) | Allergy (7) | Any disease (8) | Emergency visit (9) | Stop routine (10) |
| Panel A: <i>Gender</i> | | | | | | | | | | |
| Pollution | 0.0745* (0.0409) | 0.0030 (0.0321) | -0.0440 (0.0457) | -0.0470 (0.0395) | -0.0185 (0.0412) | 0.0052** (0.0026) | 0.0001 (0.0022) | -0.0031 (0.0031) | -0.0030 (0.0027) | -0.0013 (0.0028) |
| Pollution x Male | -0.0003 (0.0003) | 0.0004 (0.0002) | 0.0001 (0.0004) | -0.0007* (0.0003) | -0.0000 (0.0003) | -0.0003 (0.0002) | 0.0003 (0.0002) | 0.0001 (0.0003) | -0.0005* (0.0003) | -0.0000 (0.0003) |
| Observations | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 |
| Kleibergen-Paap F | 9.56 | 9.56 | 9.56 | 9.56 | 9.56 | 105.68 | 105.68 | 105.68 | 105.68 | 105.68 |
| Panel B: <i>Family stratum</i> | | | | | | | | | | |
| Pollution | 0.0946* (0.0544) | 0.0015 (0.0408) | -0.0378 (0.0556) | -0.0498 (0.0481) | -0.0103 (0.0503) | 0.0091** (0.0045) | -0.0031 (0.0038) | -0.0085 (0.0056) | -0.0065 (0.0052) | -0.0051 (0.0049) |
| Pollution x Medium | 0.0052 (0.0040) | 0.0035 (0.0032) | 0.0022 (0.0041) | -0.0013 (0.0032) | 0.0027 (0.0037) | -0.0042 (0.0028) | 0.0049* (0.0026) | 0.0080** (0.0036) | 0.0044 (0.0037) | 0.0054* (0.0029) |
| Pollution x Poor | 0.0068 (0.0051) | 0.0028 (0.0043) | 0.0015 (0.0050) | -0.0021 (0.0044) | 0.0029 (0.0045) | -0.0064* (0.0036) | 0.0039 (0.0034) | 0.0086* (0.0048) | 0.0055 (0.0046) | 0.0060 (0.0041) |
| Observations | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 | 15132 |
| Kleibergen-Paap F | 3.79 | 3.79 | 3.79 | 3.79 | 3.79 | 26.27 | 26.27 | 26.27 | 26.27 | 26.27 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Sector FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: Same sample and controls as Table A-6. “Any disease” refers to diagnosis of any disease in the previous 30 months. “Emergency visit” is a visit to the emergency room. “Stop routine” indicates stopping routine activities due to illness. In Panel A, we estimate the differential effect by gender. In Panel B, we estimate the differential effect by family stratum, with high stratum (strata 5–6) as the omitted category. Standard errors are clustered at the building-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-8. Effects of Air Pollution on Health Outcomes – Elementary School

| | PM2.5 | | | | | NOx | | | | | | |
|---|----------------------|-------------------------------|---------------------|-----------------------|---------------------------|------------------------|------------------------|-------------------------------|---------------------|------------------------|----------------------------|-------------------------|
| | PM2.5 (1) | Respiratory disease (2) | Allergy (3) | Any disease (4) | Emergency visit (5) | Stop routine (6) | NOx (7) | Respiratory disease (8) | Allergy (9) | Any disease (10) | Emergency visit (11) | Stop routine (12) |
| Wind share blowing to the house \times bus intensity | 1.1035** (0.4521) | -0.1004 (0.0962) | -0.0503 (0.0574) | 0.1281 (0.0928) | -0.0547 (0.0876) | 0.0858 (0.0644) | 24.3052*** (2.0070) | -0.1004 (0.0962) | -0.0503 (0.0574) | 0.1281 (0.0928) | -0.0547 (0.0876) | 0.0858 (0.0644) |
| R2 | 0.9685 | 0.2440 | 0.2529 | 0.2358 | 0.2216 | 0.2191 | 0.8680 | 0.2440 | 0.2529 | 0.2358 | 0.2216 | 0.2191 |
| Observations | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 |
| Panel A: <i>First-stage and reduced-form estimates</i> | | | | | | | | | | | | |
| Pollution | -- | -0.0086 (0.0065) | -0.0041 (0.0046) | 0.0034 (0.0064) | -0.0078 (0.0077) | 0.0066 (0.0055) | -- | -0.0006 (0.0008) | -0.0007 (0.0008) | -0.0003 (0.0009) | -0.0001 (0.0009) | 0.0004 (0.0007) |
| R2 | 0.2441 | 0.2441 | 0.2529 | 0.2356 | 0.2217 | 0.2191 | 0.2439 | 0.2439 | 0.2529 | 0.2356 | 0.2216 | 0.2190 |
| Observations | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 |
| Panel B: <i>OLS estimates</i> | | | | | | | | | | | | |
| Pollution | -- | -0.0910 (0.1013) | -0.0456 (0.0528) | 0.1161 (0.0937) | -0.0496 (0.0798) | 0.0777 (0.0658) | -- | -0.0041 (0.0040) | -0.0021 (0.0024) | 0.0053 (0.0038) | -0.0023 (0.0036) | 0.0035 (0.0027) |
| Observations | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 | 11699 |
| Observations Kleibergen-Paap F | 5.96 | 5.96 | 5.96 | 5.96 | 5.96 | 5.96 | 5.96 | 146.66 | 146.66 | 146.66 | 146.66 | 146.66 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Sector FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: Same controls as Table A-6, but the sample is restricted to elementary school children (under 11 years of age). “Any disease” refers to diagnosis of any disease in the previous 30 months. “Emergency visit” is a visit to the emergency room. “Stop routine” indicates stopping routine activities due to illness. In Panel C, the wind share is used as an instrument for a student’s yearly average pollution exposure. Standard errors are clustered at the building-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-9. Effects of Nighttime Pollution on Exam Scores

| | PM2.5 | | | NOx | | |
|--------------------------|---------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | Math (1) | Lang. (2) | Global (3) | Math (4) | Lang. (5) | Global (6) |
| | <i>IV estimates</i> | | | | | |
| Pollution 6:00pm-11:00pm | 0.733 (0.810) | 0.324 (0.400) | 0.697 (0.760) | 0.034 (0.030) | 0.013 (0.020) | 0.032 (0.020) |
| Pollution 12:00am-5:00am | -0.288 (0.370) | -0.118 (0.180) | -0.274 (0.350) | -0.063 (0.040) | -0.026 (0.030) | -0.060 (0.040) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 0.44 | 0.44 | 0.44 | 2.64 | 2.64 | 2.64 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of test-takers aged 15 to 18 from 2014-2018 whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The instrumental variables are wind share as the percentage of time when wind speeds are below 1 mph, blowing from TransMilenio to the schools between 6:00 pm and 11:00 pm and the wind share measured between 12:00 am and 5:00 am. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-10. Effects of PM2.5 on Exam Scores – Weekends

| | PM2.5 Saturday (1) | PM2.5 Sunday (2) | Math (3) | Lang. (4) | Global (5) |
|--|--------------------------|------------------------|----------------------|---------------------|----------------------|
| <i>Panel A: First-stage and reduced-form estimates</i> | | | | | |
| Wind share Saturday | -3.5692*** (0.4681) | -0.6953*** (0.2655) | -0.0506 (0.0818) | -0.0718 (0.0760) | -0.0537 (0.0728) |
| Wind share Sunday | 4.6983*** (0.5277) | 1.3450*** (0.2977) | -0.0179 (0.0777) | 0.0316 (0.0725) | -0.0139 (0.0707) |
| R2 | 0.9029 | 0.9545 | 0.3153 | 0.2314 | 0.3550 |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 |
| <i>Panel B: OLS estimates</i> | | | | | |
| PM2.5 Saturday | -- | -- | -0.0072* (0.0043) | 0.0016 (0.0041) | -0.0039 (0.0040) |
| PM2.5 Sunday | -- | -- | 0.0059 (0.0081) | -0.0028 (0.0077) | -0.0014 (0.0076) |
| R2 | | | 0.3153 | 0.2314 | 0.3550 |
| Observations | | | 275987 | 275987 | 275987 |
| <i>Panel C: IV estimates</i> | | | | | |
| PM2.5 Saturday | -- | -- | 0.0525 (0.0459) | 0.0487 (0.0386) | 0.0534 (0.0399) |
| PM2.5 Sunday | -- | -- | -0.1968* (0.1180) | -0.1466 (0.0960) | -0.1970* (0.1022) |
| Observations | | | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | | | 6.83 | 6.83 | 6.83 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. In Panel C, the wind share is used as an instrument for a student's yearly average PM2.5 exposure. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-11. Effects of NOx on Exam Scores – Weekends

| | NOx Saturday (1) | NOx Sunday (2) | Math (3) | Lang. (4) | Global (5) |
|--|-------------------------|-------------------------|------------------------|---------------------|----------------------|
| <i>Panel A: First-stage and reduced-form estimates</i> | | | | | |
| Wind share Saturday | -10.1337*** (1.3840) | -23.8011*** (2.0972) | -0.0506 (0.0818) | -0.0718 (0.0760) | -0.0537 (0.0728) |
| Wind share Sunday | 12.1188*** (1.5127) | 27.8738*** (2.3515) | -0.0179 (0.0777) | 0.0316 (0.0725) | -0.0139 (0.0707) |
| R2 | 0.9299 | 0.8675 | 0.3153 | 0.2314 | 0.3550 |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 |
| <i>Panel B: OLS estimates</i> | | | | | |
| NOx Saturday | -- | -- | -0.0033*** (0.0012) | -0.0007 (0.0012) | -0.0017 (0.0012) |
| NOx Sunday | -- | -- | 0.0028*** (0.0010) | 0.0018* (0.0010) | 0.0022** (0.0010) |
| R2 | | | 0.3153 | 0.2314 | 0.3550 |
| Observations | | | 275987 | 275987 | 275987 |
| <i>Panel C: IV estimates</i> | | | | | |
| NOx Saturday | -- | -- | -0.3075 (0.6279) | -0.2093 (0.4572) | -0.3060 (0.6364) |
| NOx Sunday | -- | -- | 0.1330 (0.2779) | 0.0921 (0.2027) | 0.1326 (0.2818) |
| Observations | | | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | | | 0.12 | 0.12 | 0.12 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. In Panel C, the wind share is used as an instrument for a student's yearly average NOx exposure. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-12. Effects of Air Pollution on Exam Scores – Non-TransMilenio Routes

| | PM 2.5 | | | | | NOx | | | |
|--|--------------------|---------------------|----------------------|---------------------|--|-------------------------|---------------------|---------------------|---------------------|
| | PM2.5 (1) | Math (2) | Lang. (3) | Global (4) | | NOx (5) | Math (6) | Lang. (7) | Global (8) |
| <i>Panel A: First-stage and reduced-form estimates</i> | | | | | | | | | |
| Wind share | 2.3039 (1.8618) | -0.0908 (0.2761) | -0.1170 (0.2470) | -0.1962 (0.2546) | | 100.4192*** (7.6338) | -0.0908 (0.2761) | -0.1170 (0.2470) | -0.1962 (0.2546) |
| R2 | 0.9655 | 0.3332 | 0.2457 | 0.3749 | | 0.9090 | 0.3332 | 0.2457 | 0.3749 |
| Observations | 347042 | 347042 | 347042 | 347042 | | 347042 | 347042 | 347042 | 347042 |
| <i>Panel B: OLS estimates</i> | | | | | | | | | |
| Pollution | -- | -0.0017 (0.0030) | -0.0050* (0.0027) | -0.0042 (0.0028) | | -- | 0.0001 (0.0007) | 0.0009 (0.0007) | 0.0002 (0.0007) |
| R2 | | 0.3332 | 0.2457 | 0.3749 | | | 0.3332 | 0.2457 | 0.3749 |
| Observations | | 347042 | 347042 | 347042 | | | 347042 | 347042 | 347042 |
| <i>Panel C: IV estimates</i> | | | | | | | | | |
| Pollution | -- | -0.0394 (0.1236) | -0.0508 (0.1114) | -0.0851 (0.1294) | | -- | -0.0009 (0.0027) | -0.0012 (0.0025) | -0.0020 (0.0025) |
| Observations | | 347042 | 347042 | 347042 | | | 347042 | 347042 | 347042 |
| Kleibergen-Paap F | | 1.53 | 1.53 | 1.53 | | | 173.04 | 173.04 | 173.04 |
| Controls | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are above 1.16 km from the nearest TransMilenio route and within 1.86 km from the nearest route without TransMilenio. The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school during sunlight hours. In Panel C, the wind share is used as an instrument for a student's yearly average PM2.5 exposure. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-13. First-Stage Estimates: Wind Share and PM2.5 by Exposure Window

| | Year (1) | 5.5 Months (2) | 5 Months (3) | 4.5 Months (4) | 4 Months (5) | 3.5 Months (6) | 3 Months (7) | 2.5 Months (8) | 2 Months (9) |
|--|--|-----------------------|-----------------------|-----------------------|----------------------|---------------------|-----------------------|------------------------|------------------------|
| | <i>Panel A: Correlation year instrument with contamination</i> | | | | | | | | |
| Wind share blowing to the school \times bus intensity | 2.5300*** (0.6361) | 1.6543*** (0.6104) | 1.1339* (0.5847) | 1.9272*** (0.5995) | 1.0862** (0.5086) | 0.5932 (0.4798) | 6.1012*** (1.4060) | 2.0336* (1.2280) | -2.5628** (1.0127) |
| R2 | 0.9670 | 0.9688 | 0.9711 | 0.9466 | 0.9453 | 0.9422 | 0.9628 | 0.9598 | 0.9503 |
| Observations | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 | 262904 | 262904 | 262904 |
| | <i>Panel B: First stage</i> | | | | | | | | |
| Monthly wind share blowing to the school \times bus intensity | -- -- | 2.2278*** (0.6067) | 1.8128*** (0.5625) | 1.7061*** (0.6301) | 0.6536 (0.5056) | -0.3599 (0.4918) | -1.4479** (0.5991) | -2.0399*** (0.6185) | -3.7011*** (0.6866) |
| R2 | -- | 0.9689 | 0.9712 | 0.9465 | 0.9452 | 0.9422 | 0.9396 | 0.9332 | 0.9320 |
| Observations | -- | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during each interval of time before the exam when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-14. First-Stage Estimates: Wind Share and NOx by Exposure Window

| | Year (1) | 5.5 Months (2) | 5 Months (3) | 4.5 Months (4) | 4 Months (5) | 3.5 Months (6) | 3 Months (7) | 2.5 Months (8) | 2 Months (9) |
|--|--|------------------------|------------------------|------------------------|------------------------|------------------------|--------------------------|--------------------------|--------------------------|
| | <i>Panel A: Correlation year instrument with contamination</i> | | | | | | | | |
| Wind share blowing to the school \times bus intensity | 17.7103*** (2.2421) | 12.3340*** (1.7930) | 11.4253*** (1.7856) | 10.7651*** (1.8069) | 11.1437*** (2.0241) | 11.6239*** (2.2590) | 139.7145*** (18.4555) | 180.5623*** (23.7046) | 174.4383*** (21.3683) |
| R2 | 0.9080 | 0.9064 | 0.9270 | 0.9303 | 0.9133 | 0.9003 | 0.7507 | 0.5806 | 0.6027 |
| Observations | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 | 182247 | 182247 | 182247 |
| | <i>Panel B: First stage</i> | | | | | | | | |
| Monthly wind share blowing to the school \times bus intensity | - -- | 9.2612*** (1.7416) | 6.6509*** (1.6288) | 5.4011*** (1.5981) | 4.7820*** (1.7348) | 4.5504** (2.0528) | 7.2775** (2.8383) | 10.9664*** (4.2283) | 5.7816** (2.7066) |
| R2 | -- | 0.9054 | 0.9259 | 0.9293 | 0.9122 | 0.8991 | 0.8722 | 0.8382 | 0.9418 |
| Observations | -- | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 | 276108 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during each interval of time before the exam when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-15. Effects of Air Pollution – Distance to the Closest BRT

| | 1.25km (1) | 1.5km (2) | 1.75 km (3) | 2 km (4) | 2.25 km (5) | 2.5 km (6) | 2.75 km (7) | 3 km (8) |
|-----------------------|---------------------|------------------------|------------------------|------------------------|------------------------|-----------------------|-----------------------|----------------------|
| <i>IV estimates</i> | | | | | | | | |
| Panel A: <i>PM2.5</i> | | | | | | | | |
| Math | -0.0554 (0.0382) | -0.0991** (0.0439) | -0.1041** (0.0437) | -0.1079*** (0.0416) | -0.1245** (0.0634) | -0.0999* (0.0538) | -0.0953* (0.0510) | -0.0763 (0.0508) |
| Observations | 191207 | 225656 | 264980 | 287257 | 305723 | 315121 | 324735 | 330953 |
| Kleibergen-Paap F | 13.87 | 14.71 | 15.39 | 17.45 | 6.27 | 7.51 | 8.07 | 7.31 |
| Language | -0.0134 (0.0329) | -0.0249 (0.0327) | -0.0445 (0.0335) | -0.0423 (0.0313) | -0.0517 (0.0446) | -0.0465 (0.0399) | -0.0445 (0.0383) | -0.0288 (0.0398) |
| Observations | 191207 | 225656 | 264980 | 287257 | 305723 | 315121 | 324735 | 330953 |
| Kleibergen-Paap F | 13.87 | 14.71 | 15.39 | 17.45 | 6.27 | 7.51 | 8.07 | 7.31 |
| Global | -0.0505 (0.0346) | -0.0905** (0.0397) | -0.0958** (0.0391) | -0.0954*** (0.0366) | -0.1214** (0.0597) | -0.0987* (0.0509) | -0.0949** (0.0483) | -0.0772 (0.0483) |
| Observations | 191207 | 225656 | 264980 | 287257 | 305723 | 315121 | 324735 | 330953 |
| Kleibergen-Paap F | 13.87 | 14.71 | 15.39 | 17.45 | 6.27 | 7.51 | 8.07 | 7.31 |
| Panel B: <i>NOx</i> | | | | | | | | |
| Math | -0.0096 (0.0062) | -0.0160*** (0.0061) | -0.0151*** (0.0053) | -0.0163*** (0.0053) | -0.0140*** (0.0054) | -0.0127** (0.0056) | -0.0125** (0.0056) | -0.0098* (0.0058) |
| Observations | 191207 | 225656 | 264980 | 287257 | 305723 | 315121 | 324735 | 330953 |
| Kleibergen-Paap F | 38.99 | 48.69 | 59.53 | 62.79 | 61.17 | 58.00 | 59.02 | 56.51 |
| Language | -0.0023 (0.0056) | -0.0040 (0.0051) | -0.0064 (0.0046) | -0.0064 (0.0045) | -0.0058 (0.0046) | -0.0059 (0.0048) | -0.0058 (0.0048) | -0.0037 (0.0050) |
| Observations | 191207 | 225656 | 264980 | 287257 | 305723 | 315121 | 324735 | 330953 |
| Kleibergen-Paap F | 38.99 | 48.69 | 59.53 | 62.79 | 61.17 | 58.00 | 59.02 | 56.51 |
| Global | -0.0087 (0.0056) | -0.0146*** (0.0055) | -0.0139*** (0.0047) | -0.0144*** (0.0047) | -0.0137*** (0.0047) | -0.0125** (0.0050) | -0.0125** (0.0050) | -0.0099* (0.0053) |
| Observations | 191207 | 225656 | 264980 | 287257 | 305723 | 315121 | 324735 | 330953 |
| Kleibergen-Paap F | 38.99 | 48.69 | 59.53 | 62.79 | 61.17 | 58.00 | 59.02 | 56.51 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the distance indicated in each column header from the TransMilenio route. The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The instrument is the wind share, defined as the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-16. Wind Share and Demographic Characteristics

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|------------------------------------|------------------|-------------------|-------------------|-------------------|------------------|------------------|------------------|
| | Age | Female | Educ. Father | Educ. Mother | Stratum ≤ 2 | HH Size | HH Computer |
| <i>Reduced-form estimates</i> | | | | | | | |
| Panel A: <i>Wind share - Day</i> | | | | | | | |
| Wind share | 0.093 (0.080) | 0.038 (0.040) | -0.021 (0.040) | -0.024 (0.050) | 0.118 (0.080) | 0.060 (0.040) | 0.031 (0.040) |
| R2 | 0.0740 | 0.1180 | 0.2881 | 0.2870 | 0.4426 | 0.0671 | 0.1270 |
| Observations | 257874 | 257874 | 257874 | 257874 | 257874 | 257874 | 257874 |
| Panel B: <i>Wind share - Night</i> | | | | | | | |
| Wind share | 0.096 (0.160) | -0.005 (0.050) | -0.031 (0.050) | -0.023 (0.050) | 0.128 (0.090) | 0.056 (0.060) | 0.049 (0.060) |
| R2 | 0.0740 | 0.1180 | 0.2881 | 0.2870 | 0.4426 | 0.0671 | 0.1270 |
| Observations | 257874 | 257874 | 257874 | 257874 | 257874 | 257874 | 257874 |
| Distance Dummies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The outcomes in each column are children's and households' socioeconomic characteristics such as age, female, indicators for parents' education above high school, economic stratum below 2 (the median), household size, and presence of a computer in the house. All specifications include distance dummies to the nearest TransMilenio corridor and the whole set of demographic characteristics as controls, except when that variable is the outcome. In Panel A, the wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the schools at sunlight hours. In Panel B, the wind share is computed at night. Standard errors are clustered at the locality level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-17. Effects of Air Pollution on Older Test-Takers

| | PM2.5 | | | NOx | | |
|------------------------------------|-------------------|------------------|------------------|-------------------|------------------|------------------|
| | Math (1) | Lang. (2) | Global (3) | Math (4) | Lang. (5) | Global (6) |
| <i>IV estimates</i> | | | | | | |
| Panel A: <i>Wind share – Day</i> | | | | | | |
| Pollution | -0.011 (0.038) | 0.025 (0.043) | 0.027 (0.038) | -0.003 (0.009) | 0.006 (0.010) | 0.006 (0.009) |
| Observations | 28385 | 28385 | 28385 | 28385 | 28385 | 28385 |
| Kleibergen-Paap F | 19.28 | 19.28 | 19.28 | 41.35 | 41.35 | 41.35 |
| Panel B: <i>Wind share – Night</i> | | | | | | |
| Pollution | 0.110 (1.015) | 0.213 (1.235) | 0.948 (2.322) | 0.002 (0.019) | 0.004 (0.022) | 0.018 (0.021) |
| Observations | 28385 | 28385 | 28385 | 28385 | 28385 | 28385 |
| Kleibergen-Paap F | 0.20 | 0.20 | 0.20 | 6.21 | 6.21 | 6.21 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of test-takers aged 19 to 70 from 2014-2018 whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. In Panel A, the wind share is defined as in Table 2 (daytime, 7:00 am to 6:00 pm). In Panel B, the wind share is measured at night (7:00 pm to 11:00 pm). Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-18. Effects of Air Pollution on Exam Scores – Without Bus Intensity

| | PM 2.5 | | | | | NOx | | | |
|--|-----------------------|-----------------------|---------------------|-----------------------|--|-------------------------|-----------------------|---------------------|-----------------------|
| | PM2.5 (1) | Math (2) | Lang. (3) | Global (4) | | NOx (5) | Math (6) | Lang. (7) | Global (8) |
| Panel A: <i>First-stage and reduced-form estimates</i> | | | | | | | | | |
| Wind share | 6.4496*** (1.9751) | -0.7207** (0.3250) | -0.2785 (0.3000) | -0.6136** (0.2941) | | 115.4048*** (9.1319) | -0.7207** (0.3250) | -0.2785 (0.3000) | -0.6136** (0.2941) |
| R2 | 0.9668 | 0.3153 | 0.2314 | 0.3550 | | 0.9143 | 0.3153 | 0.2314 | 0.3550 |
| Observations | 275987 | 275987 | 275987 | 275987 | | 275987 | 275987 | 275987 | 275987 |
| Panel B: <i>OLS estimates</i> | | | | | | | | | |
| Pollution | -- | -0.0027 (0.0033) | -0.0016 (0.0032) | -0.0039 (0.0032) | | -- | 0.0003 (0.0008) | 0.0015* (0.0008) | 0.0006 (0.0008) |
| R2 | | 0.3152 | 0.2314 | 0.3550 | | | 0.3152 | 0.2314 | 0.3550 |
| Observations | | 275987 | 275987 | 275987 | | | 275987 | 275987 | 275987 |
| Panel C: <i>IV estimates</i> | | | | | | | | | |
| Pollution | -- | -0.1117* (0.0612) | -0.0432 (0.0487) | -0.0951* (0.0542) | | -- | -0.0062** (0.0029) | -0.0024 (0.0026) | -0.0053** (0.0026) |
| Observations | | 275987 | 275987 | 275987 | | | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | | 10.66 | 10.66 | 10.66 | | | 159.71 | 159.71 | 159.71 |
| Controls | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. In Panel C, the wind share is used as an instrument for a student's yearly average PM2.5 exposure. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-19. Effects of Air Pollution on Exam Scores – Controlling for other Pollutants

| | Math (1) | Lang. (2) | Global (3) | Math (4) | Lang. (5) | Global (6) | Math (7) | Lang. (8) | Global (9) |
|--|------------------------|---------------------|------------------------|-----------------------|---------------------|-----------------------|-----------------------|---------------------|-----------------------|
| Panel A: <i>Reduced-form estimates</i> | | | | | | | | | |
| Wind share x Bus Intensity | -0.2587*** (0.0875) | -0.1096 (0.0770) | -0.2375*** (0.0768) | -0.2200** (0.0881) | -0.0664 (0.0776) | -0.1894** (0.0771) | -0.2274** (0.0895) | -0.0918 (0.0796) | -0.1955** (0.0787) |
| R2 | 0.3153 | 0.2315 | 0.3550 | 0.3153 | 0.2315 | 0.3551 | 0.3153 | 0.2314 | 0.3550 |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Panel B: <i>PM 10</i> | | | | | | | | | |
| Pollution | -0.0350** (0.0140) | -0.0148 (0.0111) | -0.0321** (0.0125) | -0.0459* (0.0245) | -0.0138 (0.0172) | -0.0395* (0.0214) | -0.2950 (0.6571) | -0.1191 (0.2790) | -0.2535 (0.5655) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 11.82 | 11.82 | 11.82 | 5.43 | 5.43 | 5.43 | 0.19 | 0.19 | 0.19 |
| Panel C: <i>PM 2.5</i> | | | | | | | | | |
| Pollution | -0.1074** (0.0448) | -0.0455 (0.0346) | -0.0986** (0.0399) | -0.0968** (0.0471) | -0.0292 (0.0358) | -0.0834** (0.0412) | -0.0983** (0.0466) | -0.0397 (0.0370) | -0.0845** (0.0412) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 16.09 | 16.09 | 16.09 | 13.72 | 13.72 | 13.72 | 15.14 | 15.14 | 15.14 |
| Panel D: <i>NOx</i> | | | | | | | | | |
| Pollution | -0.0148*** (0.0052) | -0.0063 (0.0045) | -0.0135*** (0.0046) | -0.0115** (0.0048) | -0.0035 (0.0041) | -0.0099** (0.0042) | -0.0105** (0.0043) | -0.0043 (0.0038) | -0.0091** (0.0038) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 61.32 | 61.32 | 61.32 | 65.67 | 65.67 | 65.67 | 69.58 | 69.58 | 69.58 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| O3 | ✓ | ✓ | ✓ | | | | | | |
| SO2 | | | | ✓ | ✓ | ✓ | | | |
| CO | | | | | | | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-20. Effects of Air Pollution on Exam Scores – Controlling for Climate Variables

| | Math (1) | Lang. (2) | Global (3) | Math (4) | Lang. (5) | Global (6) | Math (7) | Lang. (8) | Global (9) |
|--|----------------------|---------------------|-----------------------|------------------------|---------------------|------------------------|-----------------------|---------------------|------------------------|
| Panel A: <i>Reduced-form estimates</i> | | | | | | | | | |
| Wind share x Bus Intensity | -0.1776* (0.0920) | -0.1250 (0.0820) | -0.2044** (0.0819) | -0.2523*** (0.0882) | -0.0990 (0.0777) | -0.2219*** (0.0776) | -0.2241** (0.0877) | -0.1156 (0.0779) | -0.2191*** (0.0773) |
| R2 | 0.3153 | 0.2314 | 0.3550 | 0.3153 | 0.2314 | 0.3550 | 0.3153 | 0.2314 | 0.3550 |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Panel B: <i>PM 10</i> | | | | | | | | | |
| Pollution | 0.0346 (0.0238) | 0.0244 (0.0191) | 0.0398* (0.0239) | -0.0976 (0.0767) | -0.0383 (0.0408) | -0.0859 (0.0672) | -0.0583* (0.0329) | -0.0301 (0.0241) | -0.0570* (0.0307) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 7.37 | 7.37 | 7.37 | 1.61 | 1.61 | 1.61 | 4.75 | 4.75 | 4.75 |
| Panel C: <i>PM 2.5</i> | | | | | | | | | |
| Pollution | -0.1090 (0.0718) | -0.0767 (0.0605) | -0.1254* (0.0712) | -0.1135** (0.0514) | -0.0445 (0.0382) | -0.0999** (0.0454) | -0.1087** (0.0545) | -0.0561 (0.0427) | -0.1063** (0.0501) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 6.32 | 6.32 | 6.32 | 12.17 | 12.17 | 12.17 | 11.04 | 11.04 | 11.04 |
| Panel D: <i>NOx</i> | | | | | | | | | |
| Pollution | -0.0349 (0.0222) | -0.0246 (0.0187) | -0.0402* (0.0218) | -0.0148*** (0.0054) | -0.0058 (0.0047) | -0.0131*** (0.0048) | -0.0191** (0.0082) | -0.0099 (0.0070) | -0.0187** (0.0074) |
| Observations | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | 7.23 | 7.23 | 7.23 | 56.90 | 56.90 | 56.90 | 43.96 | 43.96 | 43.96 |
| Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Temperature | ✓ | ✓ | ✓ | | | | | | |
| Precipitations | | | | ✓ | ✓ | ✓ | | | |
| Humidity | | | | | | | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

TABLE A-21. Effects of Extreme Pollution Episodes on Exam Scores

| | PM 2.5 | | | | | NOx | | | |
|--|-----------------------|------------------------|---------------------|------------------------|--|-----------------------|------------------------|---------------------|------------------------|
| | PM2.5 (1) | Math (2) | Lang. (3) | Global (4) | | NOx (5) | Math (6) | Lang. (7) | Global (8) |
| <i>Panel A: First-stage and reduced-form estimates</i> | | | | | | | | | |
| Wind share | 6.2395*** (1.4204) | -0.2570*** (0.0876) | -0.1056 (0.0771) | -0.2349*** (0.0770) | | 3.0056*** (0.6911) | -0.2570*** (0.0876) | -0.1056 (0.0771) | -0.2349*** (0.0770) |
| R2 | 0.9607 | 0.3153 | 0.2314 | 0.3550 | | 0.9974 | 0.3153 | 0.2314 | 0.3550 |
| Observations | 275987 | 275987 | 275987 | 275987 | | 275987 | 275987 | 275987 | 275987 |
| <i>Panel B: OLS estimates</i> | | | | | | | | | |
| Pollution Abnormality | -- | -0.0029* (0.0017) | 0.0011 (0.0016) | -0.0027 (0.0016) | | -- | -0.0003 (0.0024) | 0.0035 (0.0022) | 0.0017 (0.0022) |
| R2 | | 0.3153 | 0.2314 | 0.3550 | | | 0.3152 | 0.2314 | 0.3550 |
| Observations | | 275987 | 275987 | 275987 | | | 275987 | 275987 | 275987 |
| <i>Panel C: IV estimates</i> | | | | | | | | | |
| Pollution Abnormality | -- | -0.0412*** (0.0159) | -0.0169 (0.0131) | -0.0377*** (0.0140) | | -- | -0.0855** (0.0341) | -0.0351 (0.0271) | -0.0782** (0.0314) |
| Observations | | 275987 | 275987 | 275987 | | | 275987 | 275987 | 275987 |
| Kleibergen-Paap F | | 19.30 | 19.30 | 19.30 | | | 18.91 | 18.91 | 18.91 |
| Controls | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| School FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Municipality FE | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of students aged 15 to 18 from 2014-2018 who took the exam in the second half of the year and whose schools are within the BRT pollution gradient (1.86 km of the nearest TransMilenio corridor). The analysis controls for student age, gender, mother's education, family stratum, household size, and the presence of a computer in the house. The wind share represents the percentage of time during the year when wind speeds are below 1 mph, blowing from TransMilenio to the school at sunlight hours. In Panel C, the wind share is used as an instrument for a student's yearly average PM2.5 exposure. Standard errors are clustered at the school-year level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level. Pollution abnormality measures the percentage of pollution readings above the 90th percentile of all readings in the city during sunlight hours.

TABLE A-22. Effects of TransMilenio Corridor Openings on Pollution

| | PM10 (1) | PM2.5 (2) | NOx (3) | O3 (4) | SO2 (5) | CO (6) |
|------------------------------------|------------------|--------------------|---------------------|--------------------|-------------------|-------------------|
| <i>Daytime (6 AM – 5 PM)</i> | | | | | | |
| Panel A: <i>Next month</i> | | | | | | |
| Treatment x Post | 3.126 (1.225) | 1.242** (0.272) | 1.789*** (0.167) | −0.748 (0.308) | 0.138 (0.111) | 0.009 (0.010) |
| Observations | 3350 | 3350 | 3350 | 3350 | 3350 | 3350 |
| Panel B: <i>Next Quarter</i> | | | | | | |
| Treatment x Post | 4.033 (3.353) | 0.331* (0.113) | 1.478*** (0.099) | −0.655* (0.208) | 0.035 (0.019) | −0.012 (0.015) |
| Observations | 3350 | 3350 | 3350 | 3350 | 3350 | 3350 |
| Panel C: <i>Next Year</i> | | | | | | |
| Treatment x Post | 2.002 (1.470) | 0.238 (0.128) | 1.869*** (0.103) | 0.012 (0.043) | −0.081 (0.044) | −0.021 (0.015) |
| Observations | 3350 | 3350 | 3350 | 3350 | 3350 | 3350 |
| <i>Nighttime (Midnight – 5 AM)</i> | | | | | | |
| Panel D: <i>Next month</i> | | | | | | |
| Treatment x Post | 2.746 (1.412) | 0.905* (0.307) | 1.506 (0.588) | −0.517* (0.162) | 0.063 (0.084) | 0.016 (0.011) |
| Observations | 3350 | 3350 | 3350 | 3350 | 3350 | 3350 |
| Panel E: <i>Next Quarter</i> | | | | | | |
| Treatment x Post | 1.968 (2.495) | 0.731* (0.236) | 1.262 (0.557) | −0.554 (0.261) | 0.072 (0.049) | 0.005 (0.007) |
| Observations | 3350 | 3350 | 3350 | 3350 | 3350 | 3350 |
| Panel F: <i>Next Year</i> | | | | | | |
| Treatment x Post | 1.260 (0.999) | 1.204** (0.269) | 1.856 (0.735) | −0.386 (0.168) | −0.041 (0.067) | −0.008 (0.003) |
| Observations | 3350 | 3350 | 3350 | 3350 | 3350 | 3350 |
| Localidad x Month FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: The sample consists of a weekly panel of schools in the main sample between 2010 and 2018. The estimator is the Dube et al. (2023) LP-DiD approach using local projections to estimate the group-time ATT, identifying treated schools as those whose distance to the TransMilenio network decreased after a corridor expansion. Panels A–C report daytime pollution effects (6 AM to 5 PM) at one month, one quarter, and one year after opening. Panels D–F report nighttime effects (midnight to 5 AM) over the same horizons. We follow Borusyak, Jaravel, and Spiess (2024) and residualize the outcomes from the localidad-month fixed effects. Standard errors are clustered at the week level in parentheses. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.