CLOUDED JUDGMENT? AIR POLLUTION, COGNITION, AND INVALID VOTING*

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This version: May 2026

Abstract. Air pollution impairs cognition, and voting is a cognitively demanding task, yet the link between the two has received little attention. Using mayoral elections in Bogotá and an instrument based on election-day wind blowing from the diesel corridors of the TransMilenio bus system, we estimate the effect of exposure to pollution on invalid voting. A one-standard-deviation increase in NOx during voting hours raises the share of invalid votes by 0.7 percentage points on average. This effect is concentrated among older voters, for whom it reaches 1.3 points, and is absent among younger ones. Turnout does not mediate this effect. Placebos varying the timing, direction, and pollutant of the instrument confirm that the effect arises only when wind carries pollution toward voters. Decomposing the ballot reveals a single cognitive shock with two sides: on the simple mayoral ballot it pollution produces a failure to mark at all, while on the complex city council ballot it produces spoiled marks. These results identify a cognitive channel through which environmental conditions shape elections, distinct from the emotional and turnout channels documented in prior work, and suggest that air quality shapes the accuracy with which citizens, especially vulnerable ones, record their preferences.

JEL Codes: D72, D91, I14, O18
Keywords: Air Pollution, Voting Behavior, Invalid Votes, Cognitive Decline.

*We thank Daniel Ariza for excellent research assistance. All errors are our own.
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1. Introduction

Economic theory views political participation as the product of choices that are consistent with rational and socially motivated voting (Edlin et al., 2007). These choices carry substantial consequences. In a democracy, they shape regime changes, policy adoption, and government accountability (Fujiwara, 2015; Ferraz and Finan, 2008; Olken, 2010). Yet, casting a vote is not only a choice; it is also a task that must be executed correctly under real-world conditions, and acute cognitive shocks can interfere with that execution, leading citizens to fail to record the preferences they hold. We document one such shock: elevated air pollution increases errors in the voting booth, in a major developing-country city.

There is increasing and robust evidence on the detrimental effects of bad air quality on health and economic outcomes, ranging from academic performance (Persico and Venator, 2019; Heissel et al., 2022; Duque and Gilraine, 2022), to labor and productivity (He et al., 2019; Fu et al., 2021), and even crime (Herrnstadt et al., 2021; Aguilar-Gomez et al., 2022). Most of the findings in this literature are driven by the impact of pollution on the brain, decision-making, and behavior, to the extent that exposure to unsafe levels of pollutants is associated with cognitive impairment and high cognitive processing costs (Chen, 2019), higher rates of depressive symptoms (Zhang et al., 2017), rising healthcare costs and mortality (Deryugina et al., 2019; Deryugina and Reif, 2023). Because casting a valid vote is itself a cognitively demanding task, this evidence suggests that pollution may impair voters' ability to record their preferences accurately, a possibility we examine directly.

We study Bogotá, Colombia, where the BRT system TransMilenio relied predominantly on a diesel fleet (Euro-II and Euro-III engines) during most of our study period, gradually transitioning toward cleaner vehicles by the end. Diesel combustion produces nitrogen oxides (NOx), a marker of diesel exhaust that is elevated near the corridors and dissipates with distance (EPA, 1999). Engineering estimates attribute 30 to 50

percent of the city's PM2.5 emissions to TransMilenio (Belalcazar-Cerón et al., 2021). Bogotá's air quality is poor by international standards. For instance, its PM2.5 levels have exceeded WHO guidelines by a wide margin, comparable to Mexico City and well above cities such as New York and Los Angeles (IQAir, 2023). We estimate the effect of NOx, our primary pollutant, on invalid voting using Bogotá's mayoral results for the 2015, 2019, and 2023 elections.

Estimating the causal effect of pollution on voting is challenging because pollution exposure is not random: polluted areas differ systematically in income, infrastructure, and demographics, any of which could independently affect voting. We address this with an instrumental-variables strategy. Our strategy exploits exogenous variation in wind direction, interacted with distance to the bus corridors, as instruments for pollution exposure. Specifically, we use two instruments: the share of voting hours during which wind blows from the nearest TransMilenio corridor toward the polling place, and its interaction with the logarithm of distance to that corridor. Polling places more frequently downwind of high-traffic BRT routes, and closer to them, receive higher NOx concentrations and the interaction with distance captures the attenuation of this pollution as it travels from the corridor. 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 twofold: we apply this design to a public transit system in a major Latin American city, where diesel BRT corridors serve as localized, measurable pollution sources; and we exploit not only wind direction but its interaction with distance, capturing the spatial attenuation of the pollution and sharpening identification.

Contrary to much of the literature that links pollution to behavior relying on variation across cities or regions, we exploit variation within a single city. Across-region measures confound pollution with the many economic, political, and demographic factors that differ across places, and we instead use the variation to try to isolate the effect

from other possible factors that might contaminate our estimation. Our identification compares polling places in the same locality and year that differ in their exposure to the TransMilenio pollution diffusion because of election-day wind direction and their distance to the corridors. This within-locality-year design absorbs any factor common to a locality in a given election, isolating the effect of localized, plausibly exogenous variation in pollution.

Our estimates show that polling places exposed to more wind-borne pollution from BRT corridors record a higher share of invalid votes in mayoral elections. The instrumental-variable estimates indicate that a one-standard-deviation increase in election-day NOx raises the invalid-vote share by 0.72 percentage points, about 29 percent of the sample mean. This effect is concentrated in tables that register older voters and is absent among younger ones. However, this age heterogeneity only holds on the simple mayoral ballot, but on the complex council ballot the effect reaches younger voters as well. Decomposing the ballot, we find that task complexity governs both the form the error takes and who is susceptible to it. The effect does not operate through participation, as turnout is unchanged by pollution, so the increase reflects errors in completing the ballot rather than changes in who votes.

A literature in political economy links environmental conditions to elections through two channels. The first is participation: Gomez et al. (2007) show that rain and snow reduce voter turnout in the U.S. presidential elections, potentially affecting outcomes. The second is preferences, typically via emotions: Meier et al. (2019) find that rain reduces support for political change in Switzerland by lowering risk tolerance, and Bellani et al. (2024a) find that election-day pollution in Germany shifts votes from incumbents to the opposition through negative emotions. This literature thus asks whether citizens vote and what they choose. We study a third channel that has received little attention: whether citizens record their chosen preference correctly. By impairing cognition at the moment of voting, pollution can cause errors in completing the ballot,

independently of preferences or the decision to turn out. To our knowledge, this is the first evidence that air pollution affects elections through an acute cognitive channel operating on the execution of the vote.

Importantly, invalid votes are not politically neutral. When voters spoil their ballots, their preferences go unrecorded, and a growing literature shows that this kind of disenfranchisement falls disproportionately on disadvantaged groups and can shape policy. Fujiwara (2015) shows that introducing electronic voting in Brazil, by reducing the invalid votes cast by less-educated citizens, effectively enfranchised millions and shifted public spending toward the poor. We document a force operating in the opposite direction. Air pollution, by impairing the act of completing a ballot, increases invalid voting, and does so disproportionately among older voters. Thus, widespread environmental exposure appears to modulate who effectively exercises the franchise, linking air quality to the quality of democratic representation.

This paper makes two contributions. First, it provides the first causal estimate of the effect of BRT-related air pollution on electoral outcomes in a major city outside the United States and Europe. The study closest related to ours is Bellani et al. (2024b), who find, using election data from Germany, that air pollution in the form of higher concentrations of PM10 reduces the vote share for incumbent parties and increases the support for the opposition, a result driven mainly by negative emotions such as anger and sadness. However, The source of pollution is not identified. We isolate the effect of a single, identifiable pollution source, the diesel BRT fleet, using within-city variation in wind exposure. Second, unlike other settings, in which cumulative exposure matters, like in education where kids spend most of their time at school (Marcotte, 2017), weekly particulate matter and labor supply (Aragón et al., 2017), or sustained exposure to air pollution and mortality (Anderson, 2020), we demonstrate that bad air quality concentrations on the day of the election, rather than cumulative or post-election pollution, drive the positive effects on invalid votes.

Another set of papers has focused specifically on the cognitive effects of poor air quality. Burton and Roach (2026) show how fine particulate matter increases fatal crashes in the U.S., an effect derived by shocks to cognitive ability that influences demanding driving tasks. Künn et al. (2019) find a higher probability that chess players make a meaningful error in tournaments with venues that exhibited worst levels of PM2.5 and CO2, and Zhang et al. (2018) examine the impact of air pollution on cognitive performance measured by verbal and math tests taken by Chinese families and find negative results as people age, particularly within those with less than primary school completed.

Our findings relate to several strands of the literature on environmental shocks and behavior. Fujiwara et al. (2016) test how rainfall on US presidential election days is linked to voting in the future, as habit formation. The authors find that current and past rainfall actually reduces voter turnout, a result expressed through the change in the 'civic duty' benefits from the act of voting. Having access to information on pollution can lead to a substantive modification of people's behavior, as in the case of China. Barwick et al. (2024) show that the efforts of the Chinese government to monitor and disseminate pollution-related information motivated pollution avoidance and reduced mortality linked to cardiovascular and respiratory causes. In London, revealing real-time information on indoor air pollution reduced PM2.5 levels through increased ventilation by households (Metcalfe and Roth, 2025). Similar to other cities with high pollution levels, Bogotá's Secretary of the Environment issues warnings when the air quality index shows dangerous levels; nevertheless, this only happens a few times a year, at best, and not all citizens are aware of these alerts.

The rest of the paper proceeds as follows. Section 2 describes Bogotá's TransMilenio system and the mayoral election process and presents the pollution and election data. Section 3 develops the empirical strategy. Section 4 reports the main results, and Section 5 concludes.

2. Background and Data

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). Replacing a fragmented network of competing private bus operators, TransMilenio started operation in 2000. Although the network extended in additional corridors in 2003-2006 and 2012, no new corridors have been added since 2013. Therefore our bus-line corridor is fixed throughout our study period (Cracknell, 2003).

TM buses are a major source of urban air pollution. The fleet accounts for 30 to 50 percent of PM2.5 emissions in Bogotá, producing between 0.8 and 3.7 μg/min depending on the corridor (Belalcazar-Cerón et al., 2021). Diesel combustion also generates nitrogen oxides (NOx), a direct marker of diesel exhaust that is present at elevated concentrations along the corridors and dissipates with distance from them. Until around 2019, the fleet ran predominantly on diesel engines (Euro-II and Euro-III standards) (Castillo-Camacho et al., 2020). The city subsequently began a gradual transition toward compressed natural gas and filter-equipped vehicles (Morales Betancourt et al., 2022), though the diesel fleet remained substantial through the end of our study period. NOx therefore tracks TransMilenio activity throughout our sample. The first-stage relationship holds in both the pre-transition period (through 2019) and afterward: the interaction between wind and distance, which carries the identification, is strong and significant in both subsamples.[1] This confirms that the wind continues to instrument NOx near the corridors even as the fleet transitioned, consistent with the gradual nature of that transition and with the corridors remaining major traffic arteries.

[1]Appendix Table A-2 reports the first stage separately by period. The wind-distance interaction, which carries the identification, is negative and significant both through 2019 and in 2023. Because the 2023 estimates rely on a single election year with nearly saturated fixed effects, we treat the pre-2019 evidence as the more robust; both point in the same direction.

2.2. **Elections in Bogotá.** Local elections in Colombia are held every four years, in October, to choose local authorities. In Bogotá, voters elect the mayor, the city council (Concejo), and the local administrative boards (Juntas Administradoras Locales) of each locality on the same day. Voting therefore, involves several separate ballots, making the act of voting cognitively demanding. We study the mayoral races of 2015, 2019, and 2023; the 2011 election is excluded for lack of reliable pollution data for that election day.

For our analysis, we exploit an institutional feature of Colombia's electoral arrangement. Voters are assigned to voting tables (mesas de votación) nested within polling places (puestos de votación), and within each polling place, they are ordered sequentially by national ID number (cédula). This ordering maps closely to voter age. Older citizens hold eight-digit cédulas issued in chronological order, so lower numbers correspond to earlier registration and thus to older voters. Citizens who obtained their national ID from 2000 onward were instead issued ten-digit NUIP numbers (Número Único de Identificación Personal), which are necessarily larger than any eight-digit cédula. The legacy numbering also varied by gender and region, but this variation is small relative to the cohort differences that dominate the ordering. Taken together, a table's position within its polling place serves as a proxy for the relative age of its voters: lower-numbered tables tend to register older voters, and higher-numbered tables younger ones. We use this feature to examine whether the effect of pollution on invalid voting differs by voter age.

Detailed mayoral and council election results in Bogotá come from the Registraduría Nacional del Estado Civil (National Registry), the Colombian institution in charge of organizing elections, collecting and publishing results nationwide. From the Registry, we have information on votes for each candidate at the polling place, distributed throughout the city. Our outcome is the share of invalid votes in the mayoral race,

which captures errors in marking the ballot, as distinct from blank votes, a deliberate choice not to select a candidate.

2.2.1. *Defining invalid votes.* When a citizen receives a ballot, the electoral authority records the choice in one of several mutually exclusive categories. Beyond a valid vote for a candidate or list, three outcomes can arise. A voter may cast a null vote by making an active but invalid mark, such as overmarking, marking outside the designated boxes, or otherwise spoiling the ballot in a way that cannot be assigned to any option. A voter may select the blank option, a designated box that registers an affirmative choice to abstain from endorsing any candidate while still participating. Finally, a ballot may be left unmarked, with no box of any kind filled in. These three categories differ in what they reveal about the voter, and that difference is central to our interpretation. A null vote reflects an attempt to mark that fails.

A blank vote is a deliberate, executed choice as the voter locates the blank box and marks it. An unmarked ballot reflects the absence of any completed mark at all. Crucially, the blank option is a distinct box on the ballot, not the same as leaving the ballot empty. A voter who wishes to register "none of the above" has an explicit, active way to do so. This distinction leads us to treat the two races differently. For the mayoral race, we define spoiled votes as both null and unmarked ballots, and exclude blank votes. The reasoning is twofold. This combined measure is our main outcome, which Section 4.3 decomposes into its components. An unmarked mayoral ballot, by contrast, is difficult to rationalize as a deliberate expression of preference: with a small number of candidates and a clearly visible blank option available to any voter who wishes to abstain, leaving the ballot entirely empty is hard to reconcile with a voter who intended to participate. We therefore interpret unmarked mayoral ballots as a failure to execute an intended mark rather than as genuine indifference.

For the city council race, we take the opposite approach and restrict the outcome to active null votes, excluding unmarked ballots. Here, the logic of the mayoral case

is not the same. The council ballot presents several competing lists, and the cognitive cost of forming and locating a preference among them is high. An unmarked council ballot may therefore reflect a genuine absence of any formed preference rather than a failure of execution, and we do not want to attribute it to error. The active null vote, however, retains a clean interpretation in both races: it is an attempt to mark that did not produce a valid choice.

2.3. **Air pollution.** Bogotá's Secretary of the Environment operates eleven air quality monitoring stations across the city. Five began recording in 2000, with the remaining six added between 2004 and 2010. Each station reports hourly concentrations of PM2.5, PM10, and nitrogen oxides (NOx), among other pollutants, along with meteorological variables including wind direction, wind speed, temperature, and precipitation. Figure A-1 shows the spatial setting of our study: the TransMilenio network and stations, the eleven monitors, and the polling places across Bogotá. Polling places are distributed throughout the city at varying distances from the corridors, while the monitors are relatively sparse.

Because eleven stations cannot directly measure pollution at each polling place in a city of eight million, we assign pollution using ordinary Kriging, a geostatistical interpolation method that predicts the concentration at an unobserved location as a weighted average of the monitor readings (Shad et al., 2009; Jerrett et al., 2005; Beelen et al., 2009). Unlike simple distance-based interpolation, Kriging derives the weights from the estimated spatial covariance structure of the pollutant: it first fits a variogram describing how the correlation between readings decays with distance, then chooses the weights that minimize the variance of the prediction error, giving more weight to monitors that are closer and more spatially correlated with the target location. The resulting prediction is the best linear unbiased predictor at each location, with an associated prediction variance that quantifies its uncertainty. All tables within a polling place share the same assigned level.

We measure exposure during voting hours on election day, from 8 a.m. to 4 p.m. For each hour, Kriging yields a predicted NOx concentration and its prediction variance. We aggregate these hourly predictions into a single election-day measure using inverse-variance weighting, so that hours with more precise predictions receive greater weight and noisier hours contribute less. This prioritizes the most reliably estimated periods of the voting window and captures voters' exposure during the hours they cast their ballots. Kriging requires sufficient spatial coverage: a sparse network yields unreliable predictions. For this reason, our estimation sample covers the 2015, 2019, and 2023 mayoral elections but excludes 2011, when only three stations were operational, too few for reliable interpolation across the city.

Air pollution in Bogotá is substantial. During voting hours, average PM2.5 across polling places is 11 $\mu g/m^3$ (Appendix Table A-1). While this voting-hour average sits below the WHO 24-hour guideline of 15 $\mu g/m^3$, it is more than double the WHO annual guideline of 5 $\mu g/m^3$, and the highest-exposure polling places exceed even the 24-hour threshold. Our focus is NOx, a marker of diesel combustion that, while lacking a single WHO threshold, is elevated and also varies markedly across the city (from 9 to 44 $\mu g/m^3$), with the highest-exposure locations recording more than 4 times the levels of the lowest. This spatial variation in exposure is a precondition for our design, which isolates the portion of NOx attributable to emissions from TransMilenio corridors. Consistent with TransMilenio being a localized source of diesel emissions, NOx concentrations are higher near the corridors and fall with distance from them, even within localities and years (Appendix Figure A-2).

3. Empirical Strategy

3.1. **Identification Strategy.** We estimate the causal effect of traffic-related air pollution on invalid voting using an instrumental variable strategy. Let i index voting

tables, j index polling place, l index localities, t index election years, and g index 100-metre grid cells. Each table i belongs to polling place j; all tables within the same place share identical pollution exposure. We use grid-cell fixed effects rather than polling place fixed effects because polling places occasionally shift by a few metres between elections, while a 100-metre grid cell is large enough to track the same location across elections even when the place address changes slightly. The second stage is:

$$Y_{ijt} = \alpha \, \widehat{P}_{jt} + \mu_g + \mu_{lt} + \varepsilon_{ijt}, \tag{3.1}$$

where Y_{ijt} is the share of invalid votes at table i in polling place j (in percentage points), $\widehat{P}_{jt}$ is the fitted value of standardized NOx concentration at place j during voting hours, μ_g are 100-metre grid-cell fixed effects, and μ_{lt} are locality-by-year fixed effects that control for locality-specific shocks common to all tables in a given year and locality. Standard errors are clustered at the polling-place-year level.

We instrument P_{jt} with two variables. The first is the wind share W_{jt}, defined as the fraction of voting hours (8 a.m. to 4 p.m.) on election day during which wind speed is below 3 m/s and blows from the nearest TransMilenio route toward place j. The second instrument is the interaction of the wind share with the log distance from place j to the nearest TransMilenio route, $W_{jt} \times \ln d_j$, which captures the attenuation of the wind-pollution relationship with distance. The first stage is:

$$P_{jt} = \gamma_1 \, W_{jt} + \gamma_2 \, (W_{jt} \times \ln d_j) + \mu_g + \mu_{lt} + \eta_{jt}. \tag{3.2}$$

The identifying assumption is that, conditional on fixed effects, wind direction on election day is unrelated to factors that independently affect invalid voting. Wind direction is determined by large-scale atmospheric circulation patterns and is plausibly orthogonal to local political or socioeconomic conditions. We provide five validity checks. First, we replace the voting-hour instruments with analogous instruments

computed for the vote-counting period (4 p.m. to 8 p.m.), after polling places have closed, and use the corresponding NOx measure as the endogenous variable. Since ballots are already cast at that point, any effect would indicate confounding rather than a pollution channel. Second, we replace election-day NOx with NOx averaged over the five days prior to the election, together with the corresponding wind instrument. Third, we replace W_{jt} with the wind share computed using wind blowing in the opposite direction (180 degrees), which should not affect local pollution from TransMilenio and therefore should produce no second-stage effect. Fourth, we replace W_{jt} with the wind share computed using wind blowing perpendicular to the route (90 degrees), which should also carry no emissions toward the polling place. Fifth, we replace NOx with SO_2, a pollutant not emitted by TransMilenio, for which the wind instrument should have no first-stage power.

3.2. **First Stage.** Figure A-3 in the appendix presents four placebo first stages. The top row alters timing: counting-period wind and NOx (Panel A) and 5-day prior wind and NOx (Panel B). Both reproduce a distance gradient similar to the main first stage, so the wind instruments NOx equally well at these times. These placebos therefore isolate the moment of exposure. Pollution at those times should not affect invalid voting: in the counting period, ballots have already been cast, and in the prior days, voters have not yet voted. A genuine cognitive effect should appear only when pollution coincides with the act of voting, whereas a confound operating through ambient pollution would show up at these other times as well. The strong first stage combined with a null effect at these times, which we document below, is the pattern our mechanism predicts. The bottom row alters direction: wind blowing in the opposite direction (Panel C) and perpendicular wind (Panel D) produce flat profiles, confirming that the main gradient reflects directional transport of emissions from TransMilenio rather than a general correlation between wind and ambient pollution.

Figure A-4 assesses whether the wind instrument captures the TransMilenio air pollution flow specifically, rather than ambient pollution in general. We re-estimate the first stage using each pollutant in turn as the dependent variable. The spatial signature of the air pollution flow, a significant declining gradient with distance, appears clearly only for NOx. Pollutants from sources unrelated to the transportation system do not reproduce it: SO_2, which diesel engines barely emit, shows no gradient, and CO, associated with dispersed gasoline traffic citywide rather than with TransMilenio, is flat. Fine particulate matter ($PM_{2.5}$), dominated by a large diffuse background, likewise shows no significant gradient.

Two pollutants merit comment. PM10, also a diesel byproduct, displays a weaker air pollution flow signature: its distance gradient carries the same negative sign as NOx but does not reach conventional significance, and the instrument is correspondingly weaker. This is consistent with PM_{10} tracking TransMilenio emissions more noisily than NOx, given its larger background component. Ozone, by contrast, declines toward the bus line, the opposite of an air pollution flow: fresh NOx near combustion sources titrates O_3, so this inverse gradient corroborates rather than contradicts the presence of fresh diesel emissions near TransMilenio. Taken together, these patterns indicate that the instrument isolates the directional transport of the air pollution flow. NOx is the cleanest tracer, which is why it serves as our endogenous pollutant; PM_{10} points in the same direction more weakly, and pollutants from other sources show no air pollution flow signature.

4. Results

Table 1 reports the main results. Column 1 shows that a one-standard-deviation increase in election-day NOx exposure raises the share of invalid votes by 0.72 percentage points, significant at the 5% level. Relative to the sample mean of approximately 2.44 percentage points, this is an economically meaningful effect of roughly 29% of

the mean. Because the effective first-stage F-statistic is moderate (12.11), we assess inference robust to weak instruments. The conditional likelihood ratio test rejects the null of no effect ($p = 0.028$), with a confidence interval that excludes zero, so the result does not rest on the strength of the first stage.

Columns 2 to 6 report placebo specifications, each altering a single dimension of the baseline. The effect on invalid voting is significant only in column 1; none of the placebos produces a significant effect.

Columns 2 and 3 alter timing. Column 2 uses NOx and wind measured during the vote-counting period (4 p.m. to 8 p.m.), after polls close. Buses continue to operate, so the air pollution flow is still present at counting time. Because ballots are already cast, counting-hour exposure cannot affect invalid voting, and indeed, it does not. Column 3 uses NOx averaged over the five days prior to the election, together with the corresponding wind instrument. Pre-election exposure is plausibly similar in magnitude, but ballots have not yet been cast, so any effect would indicate a general pollution effect rather than an election-day cognitive shock. Neither timing placebo produces an effect, isolating election-day voting hours as the relevant window.

Columns 4 and 5 alter wind direction. Wind blowing in the opposite direction (180°) and perpendicular wind (90°) do not carry the air pollution flow toward the polling place, and neither produces an effect on invalid voting. This shows that our results are not specific to the relation of the polling place and the TransMilenio route but a directional pattern that fits the physical transmission of bus emissions due to the wind. Column 6 alters the pollutant. SO_2 is not emitted by TransMilenio, and the wind does not instrument it. This near-zero first stage is itself informative: it confirms that the instrument captures the air pollution flow specifically rather than ambient pollution, since wind predicts pollutant exposure only for a pollutant the system actually emits.

Table A-3 re-estimates the model using each pollutant as the endogenous variable, reporting both stages. Only NOx combines a strong, distance-gradient first stage

with a significant second-stage effect. The wind does not instrument SO_2 (first-stage $F = 0.40$), consistent with TransMilenio not emitting it. CO is strongly predicted by wind but through its level rather than its interaction with distance, consistent with dispersed gasoline traffic citywide rather than a localized air pollution flow; its second-stage effect is null. PM_{10} points in the same direction as NOx but more weakly, with a distance gradient of the same sign that does not reach significance, consistent with its larger diffuse background. Ozone displays an inverse gradient, consistent with titration of O_3 by fresh NOx near combustion sources.

4.1. **Heterogeneous Effects.** Table 2 examines heterogeneity by voter age. Within each polling place, we split tables by their position in the ID-based ordering: lower-numbered tables, which register older voters, versus higher-numbered tables, which register younger voters. If pollution raises invalid voting through a cognitive channel, the effect should concentrate among older voters, who are more susceptible to the cognitive effects of air pollution and less adaptable to changes in ballot format across elections. The results support this prediction. Among older-voter tables (column 2), a one-standard-deviation increase in NOx raises invalid voting by 1.29 percentage points, significant at the 1% level, with a weak-instrument-robust 90% confidence interval that excludes zero. Among younger-voter tables (column 3), the effect is indistinguishable from zero. When we analyze the same patterns for the turnout, we find no significant movement in this variable. We can argue then that concentration effects are not the result of the turnout. Columns 4 to 6 use log total votes as the outcome: pollution does not raise turnout among older-voter tables, so the increase in invalid voting reflects errors in completing the ballot rather than changes in who votes. The pattern is consistent with a cognitive mechanism in which pollution increases the rate at which older voters spoil their ballots.

Among older-voter tables, a one-standard-deviation increase in election-day NOx raises the share of invalid votes by 1.3 percentage points. This is a large effect relative

to the group mean of 2.8 percentage points, and it is consistent with older voters' greater susceptibility to the cognitive effects of pollution and their lower adaptability to changes in ballot format across elections. The estimate is imprecise, as expected given a single-day instrument and a relatively rare outcome: the weak-instrument-robust 90% confidence interval runs from 0.4 to 2.6 percentage points. Even at its lower bound, however, the effect remains economically meaningful, implying a non-trivial increase in spoiled ballots among older voters. Similar negative results among the older population as a consequence of concentrated pollution are also found in the case of chess players (Künn et al., 2019) and standardized math and verbal tests (Zhang et al., 2018).

4.2. **Robustness.** More broadly, the strength of the instrument is part of the identifying argument. Wind strongly instruments NOx only in the configuration that transports the air pollution flow, during voting hours, toward the polling place. That we don't find a significant relation in the placebo columns (from 2 to 6) is consistent with our hypothesis and the absence of directional transport of diesel pollution in those configurations. Identification rests on this coherent pattern, namely that the effect appears only with the right pollutant, direction, and timing, rather than on any single coefficient.

Table A-4 assesses robustness to election-day weather. Columns 1 to 3 add rainfall, available for nearly the full sample; columns 4 to 6 add both rainfall and temperature, which restricts the sample because temperature has incomplete spatial coverage. Two patterns stand out. First, controlling for rainfall leaves the results essentially unchanged: the average effect remains 0.93 (column 1), and the effect among older-voter tables remains large and significant at 1.50 (column 2), with an Anderson-Rubin interval that excludes zero. Second, adding temperature attenuates the average effect (column 4), but this reflects the change in sample rather than confounding: temperature data are missing disproportionately for polling places near TransMilenio, which

carry most of the identifying variation in the air pollution flow gradient. In this reduced sample, the estimate is similar with and without weather controls, so the attenuation is not driven by temperature itself. Crucially, the effect among older-voter tables is robust throughout. It remains significant at the 1% level under both weather specifications, 1.50 with rainfall and 0.95 with rainfall and temperature, with Anderson-Rubin intervals that exclude zero in both. The concentration of the effect among older voters, our central finding, therefore survives the most demanding specification, even where the average effect weakens. The effect among younger-voter tables is indistinguishable from zero throughout.

Table A-5 varies the grid-cell size from 25 to 500 metres. The average effect (Panel A) is stable in magnitude (0.63 to 0.77) across all cell sizes. The effect among older-voter tables (Panel B) is more robust still: it remains between 1.15 and 1.36 and significant at all cell sizes, including the finest 25-metre grid, which absorbs essentially all within-neighbourhood geography. The effect among younger tables (Panel C) is indistinguishable from zero throughout. The stability of the age gradient across grid resolutions indicates that it does not reflect fixed locational characteristics correlated with proximity to TransMilenio.

Our estimate is a local average treatment effect, identified from polling places whose pollution exposure responds to election-day wind. These are predominantly places near TransMilenio, where the pollution transmission is strong enough for wind direction to shift exposure materially. The effect should therefore be understood as the effect of pollution on invalid voting among voters near the corridors, not as a citywide average. This local character interacts with our design in a specific way. Identification comes from the interaction of wind with distance, which requires variation in distance to have power. Comparing how wind shifts NOx near versus far from the corridors is what traces the pollution. Restricting the sample to nearby polling places would eliminate this contrast and weaken the instrument. The full range of distances is thus necessary

for identification, even though the effect itself materializes near the corridors. Consistent with this, the estimate attenuates when the sample is restricted to places far from TransMilenio, where exposure varies little.

Because relatively few polling places lie very close to the corridors, the effect is identified from a limited mass of high-exposure observations, which contributes to the wide confidence intervals reported throughout. We therefore rely on weak-instrument-robust inference: as noted above, the conditional likelihood ratio test rejects the null with a confidence interval that excludes zero, confirming that the result does not hinge on the strength of the first stage.

4.3. **Mechanism.** The average effect documented above is consistent with a cognitive channel, but it does not tell us how the shock translates into an invalid vote. Table 3 decomposes the ballot into its components and shows that the answer depends on the structure of the voting task. Consider first the mayoral contest, where the ballot is simple, it is a handful of candidates and a clearly visible blank option. Panel A shows that pollution raises unmarked ballots among older voters by 1.11 percentage points, while Panel B shows no effect on active null votes in any group. Omission drives entirely the increase in invalid mayoral votes, not spoiled marks. This makes sense given the task. With so few options, marking incorrectly is hard, and a degraded ability to execute the intended choice shows up as a failure to mark at all rather than as an invalid mark.

Panel C sharpens this interpretation. Among older voters, pollution reduces blank votes by 1.32 percentage points, an amount that closely matches the increase in unmarked ballots in the same group. The two move together: the older voter who would have marked the blank box no longer completes that mark and leaves the ballot empty instead. The intention to participate does not disappear into a valid vote or into abstention; what fails is the conversion of that intention into an executed mark. This pattern is difficult to reconcile with a purely physical channel. If pollution worked

through discomfort or haste, the natural response would be to mark the blank box, which is the fastest and most visible mark on the ballot. A voter in a hurry does not stop voting; a voter who feels unwell still completes the single quickest action available. That older voters instead fail to complete any mark points to a breakdown in executing the voting task itself, not to a shortened or unpleasant visit to the booth. The age pattern reinforces this reading. Younger voters show no increase in unmarked ballots (Panel A) and no change in null votes (Panel B). The shock does not degrade their execution of the simple task. Whatever reduction in blank voting they exhibit is not redirected into omission.

The city council contest provides a complementary test. Here, the ballot is complex, with several competing lists and a preferential-vote structure that leaves ample room for an attempted mark to come out invalid. Panel D shows that pollution raises active null votes by 1.34 percentage points overall, with significant effects across age groups. When the task is complex enough to permit it, the same shock manifests as commission rather than omission as voters attempt to mark and produce an invalid mark.

Taken together, the two contests describe a single perturbation with two faces. On a simple ballot, where erroneous marking is hard, the cognitive shock surfaces as omission, and it does so only among the vulnerable group. On a complex ballot, where the task itself creates room for error, the shock surfaces as commission, and the higher cognitive load extends the effect beyond older voters. Task complexity thus governs both the form the error takes and who is susceptible to it.

5. Conclusions

This paper shows that air pollution increases errors in the voting booth. Using mayoral elections in Bogotá and an instrument based on election-day wind blowing from TransMilenio's diesel corridors, we find that a one-standard-deviation increase in NOx during voting hours raises the share of invalid votes by 0.72 percentage points.

The effect is concentrated among older voters and absent among younger ones, and it does not operate through turnout. A battery of placebos, varying the timing, direction, and pollutant of the instrument, confirms that the effect appears only when wind carries the diesel pollution toward voters during the hours they cast their ballots. Together, these results point to an acute cognitive channel: pollution impairs voters' ability to complete the ballot correctly, rather than changing their preferences or their decision to vote.

Our findings suggest that air quality has an unrecognized political dimension. Because pollution raises invalid voting and concentrates this effect among older voters, it may subtly shape whose preferences are recorded on election day. Although our effects are modest and locally identified, we argue that pollution can affect representation quality. We document an acute cognitive channel that operates precisely when citizens complete their ballots, pointing to a mechanism through which environmental conditions can interact with democratic participation, particularly for vulnerable groups. Whether mitigating election-day exposure would meaningfully improve the accuracy of recorded preferences is a question for future work.

Several features of our setting bound the interpretation. The effect is local to voters near TransMilenio's corridors, and identified from a single day's exposure, so it speaks to acute rather than chronic effects on voting. Our age proxy captures relative, not absolute, age. These features point to natural extensions: whether the effect generalizes to other electoral systems and ballot designs, whether chronic exposure compounds the acute effect we identify, and whether targeted mitigation on election day, in heavily exposed precincts, could measurably improve the accuracy of recorded votes. More broadly, our results invite attention to the civic costs of air pollution, alongside its well-documented effects on health and productivity.

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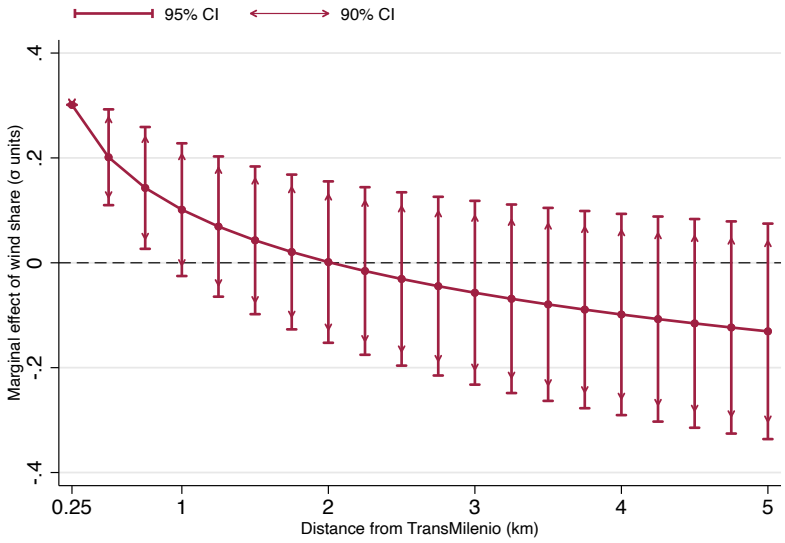
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Tables and Figures

Figure 1. First-Stage Effect of Wind Share on NOx by Distance from TransMilenio



Notes: First-stage marginal effect of the wind share on standardized NOx concentration by distance to TransMilenio, in standard-deviation units, with 90% and 95% confidence intervals. The wind share is the fraction of voting hours (8 a.m. to 4 p.m.) when wind below 3 m/s blows from the nearest TransMilenio bus line toward the polling place. Fixed effects: year, 100m grid, and locality-by-year. Standard errors clustered at the polling-place-year level.

TABLE 1. Effect of Traffic Pollution on Invalid Votes

	(1) NOx Main	(2) NOx Counting hrs	(3) NOx 5-day prior	(4) NOx Wind 180°	(5) NOx Wind 90°	(6) SO_2 Main
Pollution	0.7154**	−0.1326	−0.0873	0.1589	−1.2314	0.9540
	(0.3557)	(0.2338)	(0.1700)	(0.2208)	(0.7682)	(1.7308)
Observations	47235	47235	47235	47235	47235	47235
KP F-statistic	12.11	5.49	11.17	12.65	2.36	0.40
Hansen J (p-val)	0.616	0.311	0.279	0.044	0.999	0.076
Year FE	✓	✓	✓	✓	✓	✓
Grid FE (100m)	✓	✓	✓	✓	✓	✓
Locality × Year FE	✓	✓	✓	✓	✓	✓

Notes: The dependent variable is the share of invalid votes at the polling place, in percentage points. All pollutants are standardized to mean zero and unit variance over the estimation sample. NO_x is instrumented by the *wind share*, the fraction of voting hours (8 a.m. to 4 p.m.) during which wind below 3 m/s blows from the nearest TransMilenio bus line toward the polling place, together with its interaction with log-distance to that line. Column (1) is the main specification. Columns (2) to (6) each alter a single dimension of the baseline: (2) NOx and wind measured during vote-counting hours (4 p.m. to 8 p.m.); (3) NOx and wind averaged over the five days prior to the election; (4) wind blowing in the opposite direction (180°); (5) perpendicular wind (90°); and (6) SO_2, a pollutant not primarily emitted by TransMilenio. All specifications include year, 100 m-grid, and locality-by-year fixed effects. Standard errors clustered at the polling-place-year level in parentheses. KP F is the Kleibergen-Paap F-statistic; Hansen J reports the p-value of the overidentification test. $^{*}\,p < 0.10$, $^{**}\,p < 0.05$, $^{***}\,p < 0.01$.

Table 2. Heterogeneous Effects of Traffic Pollution

	(1)	(2)	(3)	(4)	(5)	(6)
	Invalid votes (%)			ln(total votes)		
	All	Old tables	Young tables	All	Old tables	Young tables
Pollution	0.7154**	1.2859***	0.0937	0.0224	0.0092	0.0422
	(0.3557)	(0.4876)	(0.4206)	(0.0139)	(0.0090)	(0.0266)
	[0.048, 1.631]	[0.447, 2.559]	[-0.827, 1.113]	[0.019, 0.042]	[0.001, 0.028]	[0.007, 0.102]
Observations	47235	24083	22924	47234	24082	22924
KP F-statistic	12.11	11.60	11.84	12.11	11.60	11.84
Hansen J (p-val)	0.616	0.485	0.967	0.036	0.078	0.095
Year FE	✓	✓	✓	✓	✓	✓
Grid FE (100m)	✓	✓	✓	✓	✓	✓
Locality × Year FE	✓	✓	✓	✓	✓	✓

Notes: Columns 1 to 3 use the share of invalid votes as the dependent variable. Columns 4 to 6 use the log of total votes cast at the voting table. NOx is standardized over the regression sample from 2015 to 2023. Instruments are the share of election-day voting hours when wind below 3 meters per second blows from the nearest TransMilenio route toward the polling place, and its interaction with the log distance to that route. Old-voter tables are those in the lower half of the table-number ranking within the polling place, which tend to register older voters. Young-voter tables are those in the upper half. Polling places with a single table are excluded from columns 2, 3, 5, and 6. Standard errors clustered at the polling-place-year level in parentheses. Anderson-Rubin 90 percent confidence intervals, robust to weak instruments, in brackets. KP F: Kleibergen-Paap F-statistic. Hansen J: p-value of the overidentification test. * significant at 10 percent, ** at 5 percent, *** at 1 percent.

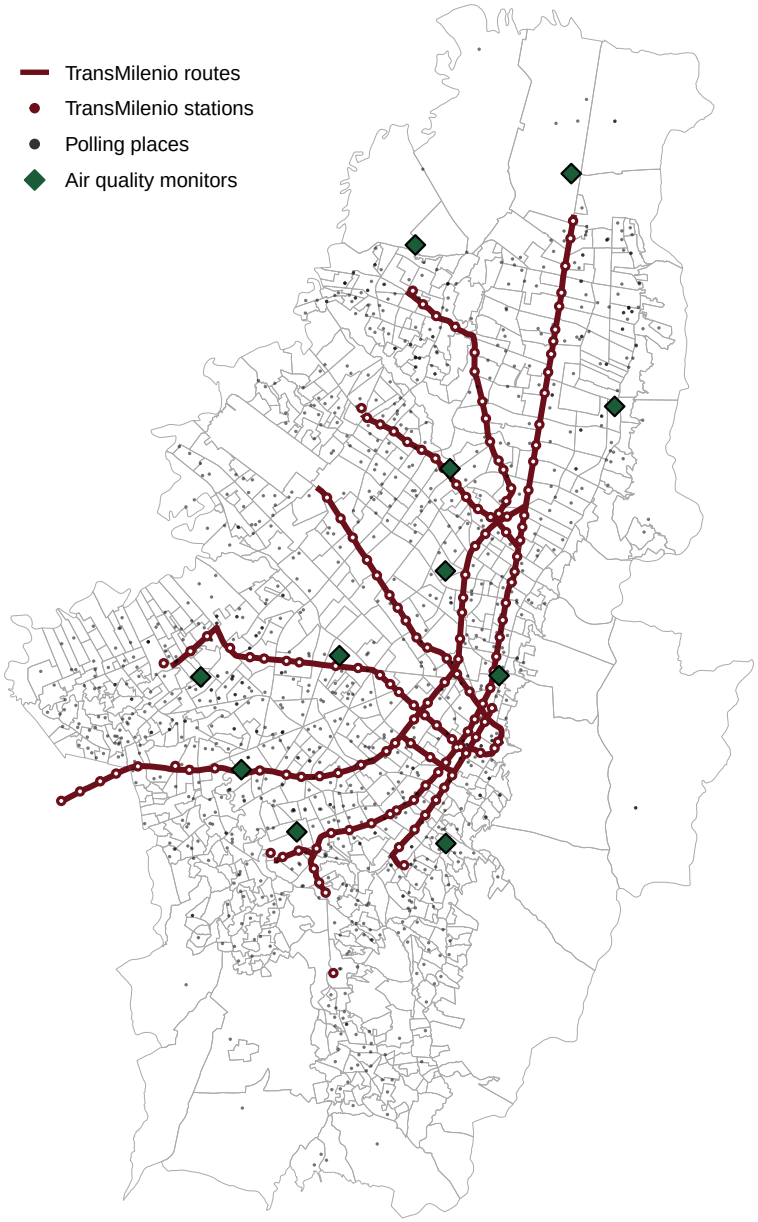
TABLE 3. Effect of Traffic Pollution on Ballot Components, by Contest and Voter Age

	(1) All	(2) Old tables	(3) Young tables
Panel A: Mayoral ballot — Unmarked only			
Pollution	0.5396**	1.1111***	−0.0541
	(0.2281)	(0.3548)	(0.2201)
	[0.093, 1.166]	[0.474, 2.050]	[-0.399, 0.306]
Panel B: Mayoral ballot — Pure null only			
Pollution	0.1758	0.1748	0.1477
	(0.2511)	(0.3012)	(0.3622)
	[-0.309, 0.759]	[-0.413, 0.947]	[-0.593, 0.968]
Panel C: Mayoral ballot — Blank votes			
Pollution	−1.6328**	−1.3179**	−1.9794*
	(0.6737)	(0.6038)	(1.0717)
	[-2.917, -0.566]	[-2.667, -0.300]	[-4.125, -0.138]
Panel D: Council ballot — Pure null only			
Pollution	1.3429***	1.1560*	1.5183**
	(0.5071)	(0.6697)	(0.6425)
	[0.474, 2.678]	[-0.161, 2.860]	[0.537, 3.155]
Observations	47235	24083	22924
KP F-statistic	12.11	11.60	11.84
Year FE	✓	✓	✓
Grid FE (100m)	✓	✓	✓
Locality × Year FE	✓	✓	✓

Notes:Panels A and B decompose invalid mayoral votes into unmarked ballots and active null votes, respectively. Panel C reports blank votes in the mayoral race. Panel D reports active null votes in the city council race. All outcomes are expressed as percentages of total votes cast at the voting table. NOx is standardized over the regression sample from 2015 to 2023. Instruments are the share of election-day voting hours when wind below 3 meters per second blows from the nearest TransMilenio route toward the polling place, and its interaction with the log distance to that route. Old-voter tables are those in the lower half of the table-number ranking within the polling place; young-voter tables are those in the upper half. Standard errors clustered at the polling-place level in parentheses. Anderson-Rubin 90 percent confidence intervals, robust to weak instruments, in brackets. KP F: Kleibergen-Paap F-statistic. * p<0.10, ** p<0.05, *** p<0.01.

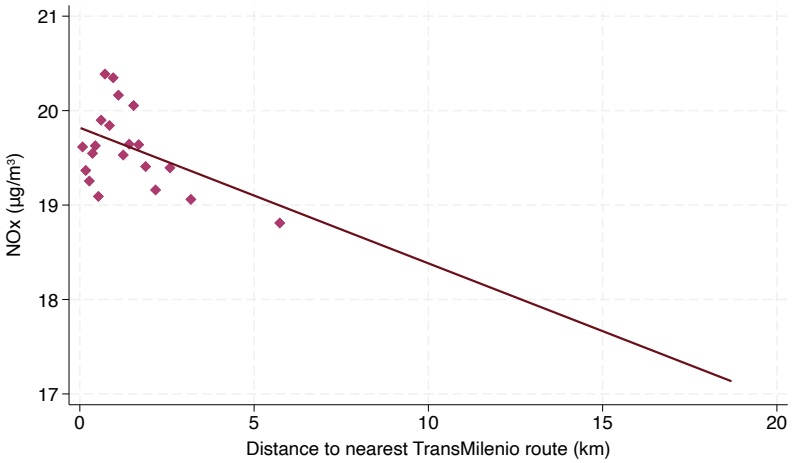
Appendix A. Appendix

Figure A-1. TransMilenio, Air Quality Monitors and Polling Places



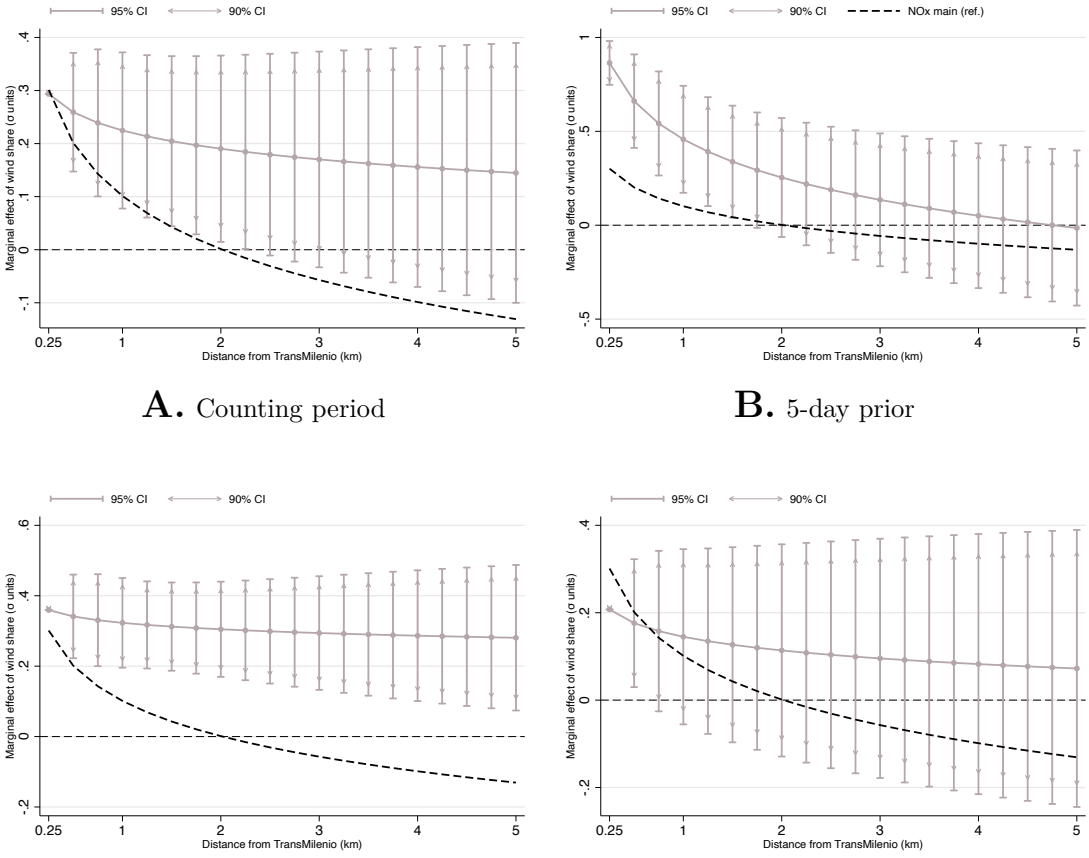
Notes: Spatial distribution of TransMilenio, polling places, and air quality monitors in Bogotá. The figure shows the TransMilenio bus routes (lines) and stations (red points), the polling places used in our analysis (grey points), and the eleven air quality monitoring stations operated by the Secretaría Distrital de Ambiente (green diamonds).

FIGURE A-2. Pollutants and Distance to Bus Stations



Notes: Binned scatter of NOx concentration against distance to the nearest TransMilenio route, for polling places in the estimation sample (2015, 2019, and 2023 mayoral elections). NOx is residualized on locality-by-year fixed effects and expressed in $\mu g/m^3$. Each point represents the mean NOx concentration within a bin of the distance distribution; the dashed line is the linear fit. Within localities and years

FIGURE A-3. First-Stage Effect of Wind on NOx by Distance: Placebo Specifications



A. Counting period

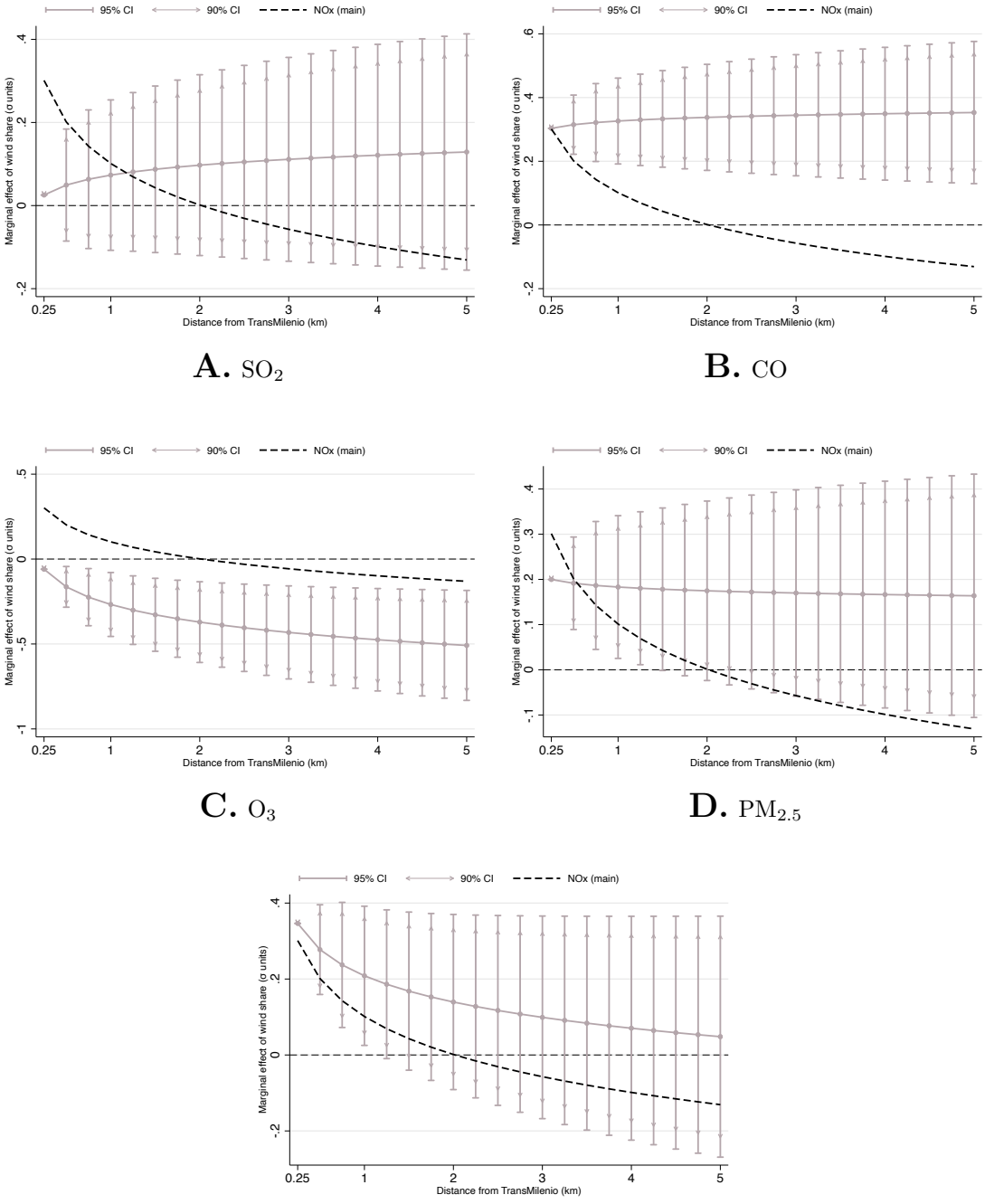
B. 5-day prior

C. Opposite-direction wind (180°)

D. Perpendicular wind (90°)

Notes: First-stage marginal effect of the wind share on standardized NOx concentration by distance to TransMilenio, in standard-deviation units, with 90% and 95% confidence intervals. Top row: timing placebos. Panel A uses counting-period wind and NOx (4 p.m. to 8 p.m., after polls close). Panel B uses wind and NOx averaged over the five days prior to the election. Bottom row: direction placebos. Panel C uses wind blowing in the opposite direction (180°). Panel D uses perpendicular wind (90°). The dashed line in all panels reproduces the main estimate from Figure 1. Fixed effects: year, 100m grid, and locality-by-year. Standard errors clustered at the polling-place-year level.

FIGURE A-4. First-Stage Effect of Wind on Alternative Pollutants by Distance



Notes: First-stage marginal effect of the wind share on alternative pollutants by distance to TransMilenio, in standard-deviation units, with 90% and 95% confidence intervals. Each panel uses a different pollutant as the dependent variable: Panel A, SO_2; Panel B, CO; Panel C, O_3; Panel D, $PM_{2.5}$; Panel E, PM_{10}. The dashed line reproduces the main NOx estimate for reference. Fixed effects: year, 100m grid, and locality-by-year. Standard errors clustered at the polling-place-year level.

TABLE A-1. Descriptive Statistics

	N	Mean	SD	Min	Max
Panel A: Outcome, instruments, and distance					
Invalid votes (%)	47,235	2.443	2.242	0.000	22.222
Older tables	24,083	2.820	2.467	0.000	19.632
Younger tables	22,924	2.045	1.897	0.000	22.222
Log total votes	47,234	5.193	0.451	1.099	5.935
Older tables	24,082	5.364	0.324	1.099	5.922
Younger tables	22,924	5.018	0.489	1.386	5.935
Wind share	47,235	0.082	0.149	0.000	1.000
Wind share × ln(dist.)	47,235	-0.020	0.163	-2.219	0.915
Distance to TransMilenio (km)	47,235	1.374	1.392	0.017	19.445
Panel B: Pollutants (raw units)					
NOx	47,235	20.960	5.269	9.073	44.139
SO_2	47,235	1.381	0.434	0.280	3.516
CO	47,235	0.480	0.120	0.290	0.984
O_3	47,235	14.915	4.266	5.519	30.321
$PM_{2.5}$	47,235	10.990	2.286	4.887	23.079
PM_{10}	47,235	21.838	5.705	10.053	42.683
Panel C: Weather (voting hours)					
Rainfall (mm)	46,090	0.033	0.165	0.000	0.950
Temperature (°C)	41,060	18.563	1.390	15.538	21.125

Notes: Sample restricted to polling places with non-missing NOx and distance to TransMilenio, election years 2015–2023. Invalid votes reported as percentage of total votes cast. All pollutants are in raw units. Wind share is the fraction of election-day voting hours when wind speed is below 3 m/s and blows from the nearest TransMilenio route toward the polling place. Older tables are those in the lower half of the table-number ranking within the polling place; younger tables are those in the upper half. Weather variables are averaged over voting hours (8 a.m. to 4 p.m.) on election day.

TABLE A-2. First Stage: NOx and Wind Exposure

	(1) Full sample	(2) 2015–2019	(3) 2023
Wind share	0.1013	−0.2387***	−0.1482***
	(0.0646)	(0.0660)	(0.0185)
Wind share × ln(distance)	−0.1442***	−0.2282***	−0.2980***
	(0.0385)	(0.0566)	(0.0289)
Observations	47235	29436	17743
F-statistic	12.11	8.89	62.25
Year FE	✓	✓	✓
Grid FE (100m)	✓	✓	✓
Locality × Year FE	✓	✓	✓

Notes: The dependent variable is standardized NOx during voting hours. The wind share is the fraction of voting hours (8 a.m. to 4 p.m.) during which wind below 3 m/s blows from the nearest TransMilenio trunk route toward the polling place. Identification is carried by the interaction of the wind share with log-distance, which is negative and significant in all columns; the wind share alone does not consistently predict NOx. Column (1) uses the full estimation sample (2015, 2019, and 2023 elections); column (2) restricts to the 2015 and 2019 elections; column (3) uses only the 2023 election. Because column (3) covers a single year, its fixed effects absorb most of the variation, so its estimates should be read as consistent with, rather than independent confirmation of, the full-sample first stage. Standard errors clustered at the polling-place-year level in parentheses. The F-statistic is the clustered joint F on both excluded instruments. F-statistic is the clustered joint F on both excluded instruments. * significant at 10 percent, ** at 5 percent, *** at 1 percent.

TABLE A-3. Robustness: Alternative Pollutants

	(1) NOx	(2) SO_2	(3) CO	(4) O_3	(5) $PM_{2.5}$	(6) PM_{10}
Panel A: Second stage						
Pollution	0.7154**	0.9540	0.4189	−0.1993	0.7806	0.6179*
	(0.3557)	(1.7308)	(0.2638)	(0.3052)	(0.5349)	(0.3273)
Panel B: First stage						
Wind share	0.1013	0.0733	0.3264***	−0.2674***	0.1831**	0.2085**
	(0.0646)	(0.0924)	(0.0688)	(0.0960)	(0.0806)	(0.0935)
Wind share × ln(dist)	−0.1442***	0.0346	0.0165	−0.1498**	−0.0120	−0.0995
	(0.0385)	(0.0500)	(0.0409)	(0.0601)	(0.0495)	(0.0617)
Observations	47235	47235	47235	47235	47235	47235
KP F-statistic	12.11	0.40	12.90	4.78	3.68	6.32
Hansen J (p-val)	0.616	0.076	0.157	0.022	0.366	0.837
Year FE	✓	✓	✓	✓	✓	✓
Grid FE (100m)	✓	✓	✓	✓	✓	✓
Locality × Year FE	✓	✓	✓	✓	✓	✓

Notes: Dependent variable is share of invalid votes. Each column uses a different pollutant as the endogenous variable: NOx (1), SO_2 (2), CO (3), O_3 (4), $PM_{2.5}$ (5), and PM_{10} (6). All regressions use the NOx estimation sample (observations with non-missing NOx, 2015–2023). Instruments are the wind share and its interaction with log-distance to the nearest TransMilenio route. All pollutants standardized over the regression sample. Standard errors clustered at the polling-place-year level in parentheses. KP F: Kleibergen-Paap F-statistic. Hansen J: p-value of the overidentification test. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

Table A-4. Robustness to Weather Controls

	(1)	(2)	(3)	(4)	(5)	(6)
		Rainfall			Rainfall + Temperature	
	All	Older tables	Younger tables	All	Older tables	Younger tables
Pollution	0.9296**	1.5009***	0.3050	0.4375*	0.9517***	−0.1649
	(0.4178)	(0.5694)	(0.4664)	(0.2619)	(0.3663)	(0.3134)
	[0.205, 1.983]	[0.536, 3.136]	[-0.640, 1.354]	[-0.060, 1.032]	[0.293, 1.790]	[-0.877, 0.529]
Observations	46090	23502	22365	39915	20354	19356
KP F-statistic	10.09	9.64	9.85	16.80	16.26	16.24
Hansen J (p-val)	0.424	0.602	0.446	0.481	0.492	0.687
Year FE	✓	✓	✓	✓	✓	✓
Grid FE (100m)	✓	✓	✓	✓	✓	✓
Locality × Year FE	✓	✓	✓	✓	✓	✓

Notes: Dependent variable is the share of invalid votes at the polling place, in percentage points. NOx is standardized over the regression sample. Instruments are the voting-hour wind share and its interaction with log-distance to the nearest TransMilenio route. All columns include election-day weather controls averaged over voting hours. Columns (1)–(3) add rainfall; columns (4)–(6) add rainfall and temperature. Within each group, columns split the sample by table position within the polling place: older-voter tables (lower half of the table-number ranking) and younger-voter tables (upper half). Polling places with a single table are excluded from the age-split columns. Standard errors clustered at the polling-place-year level in parentheses. Anderson-Rubin 90% confidence intervals, robust to weak instruments, in brackets. KP F: Kleibergen-Paap F-statistic. Hansen J: p-value of the overidentification test. $^{*}\,p < 0.10$, $^{**}\,p < 0.05$, $^{***}\,p < 0.01$.

Table A-5. Robustness: Grid Fixed-Effect Cell Size

	(1) 25 m	(2) 50 m	(3) 100 m	(4) 200 m	(5) 300 m	(6) 400 m	(7) 500 m
Panel A: All tables							
NOx	0.6782*	0.7016**	0.7154**	0.7138*	0.7673**	0.6412*	0.6268
	(0.3655)	(0.3555)	(0.3557)	(0.3680)	(0.3703)	(0.3631)	(0.3995)
Observations	47,233	47,234	47,235	47,236	47,241	47,247	47,253
KP F-statistic	11.71	11.99	12.11	11.77	11.95	12.51	12.06
Hansen J	0.669	0.600	0.616	0.732	0.859	0.765	0.709
Panel B: Older-voter tables							
NOx	1.2614**	1.2784***	1.2859***	1.2801**	1.3600***	1.1837**	1.1484**
	(0.5006)	(0.4896)	(0.4876)	(0.4976)	(0.5046)	(0.4829)	(0.5311)
Observations	24,078	24,080	24,083	24,087	24,091	24,094	24,107
KP F-statistic	11.14	11.46	11.60	11.32	11.51	12.12	11.57
Hansen J	0.575	0.478	0.485	0.633	0.672	0.665	0.525
Panel C: Younger-voter tables							
NOx	0.0791	0.1089	0.0937	0.0933	0.1183	0.0490	0.0712
	(0.4366)	(0.4218)	(0.4206)	(0.4279)	(0.4259)	(0.4271)	(0.4537)
Observations	22,916	22,918	22,924	22,930	22,944	22,954	22,977
KP F-statistic	11.47	11.72	11.84	11.53	11.74	12.28	11.82
Hansen J	0.999	0.987	0.967	0.895	0.774	0.889	0.824
Year FE	✓	✓	✓	✓	✓	✓	✓
Grid FE	25 m	50 m	100 m	200 m	300 m	400 m	500 m
Locality × Year FE	✓	✓	✓	✓	✓	✓	✓

Notes: Dependent variable is the share of invalid votes at the polling place, in percentage points. Each column varies the cell size of the grid fixed effect. NOx is standardized over the regression sample (2015–2023). Instruments are the voting-hour wind share and its interaction with log-distance to the nearest TransMilenio route. Panel A uses the full sample. Panel B restricts to older-voter tables (lower half of the table-number ranking within the polling place) and Panel C to younger-voter tables (upper half). Polling places with a single table are excluded from Panels B and C. Standard errors clustered at the polling-place-year level in parentheses. KP F: Kleibergen-Paap F-statistic. Hansen J: p-value of the overidentification test. $^{*}\,p < 0.10$, $^{**}\,p < 0.05$, $^{***}\,p < 0.01$.