A Cleaner Grid: Child Health Effects of Ontario's Coal Phase-Out*

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Abstract

This paper estimates the health effects of Ontario's coal-fired power plant phase-out, one of North America's largest greenhouse-gas-reduction policies. By linking population birth records, childhood hospital admissions, tax files, gridded weather, and modelled air pollution data, I use a difference-in-differences design to compare households living in areas that were more versus less frequently downwind of their nearest coal-fired power plant before closure. Plant closures reduced sulphur dioxide (SO_2), improved infant health and reduced health inequality: birth weight rose by 43 grams, low birth weight fell by 0.69 percentage points, and preterm birth fell by 0.68 percentage points. Childhood respiratory hospitalisations fell by 1.04 percentage points, with no changes in placebo hospitalisations. The results show that retiring coal plants can produce meaningful early-life health gains, even in a relatively low-pollution, universal-health-care setting.

Keywords: air pollution; environmental regulation; maternal and infant health; health inequality
JEL Classification: I12, I14, J13, Q53, Q58

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1 Introduction

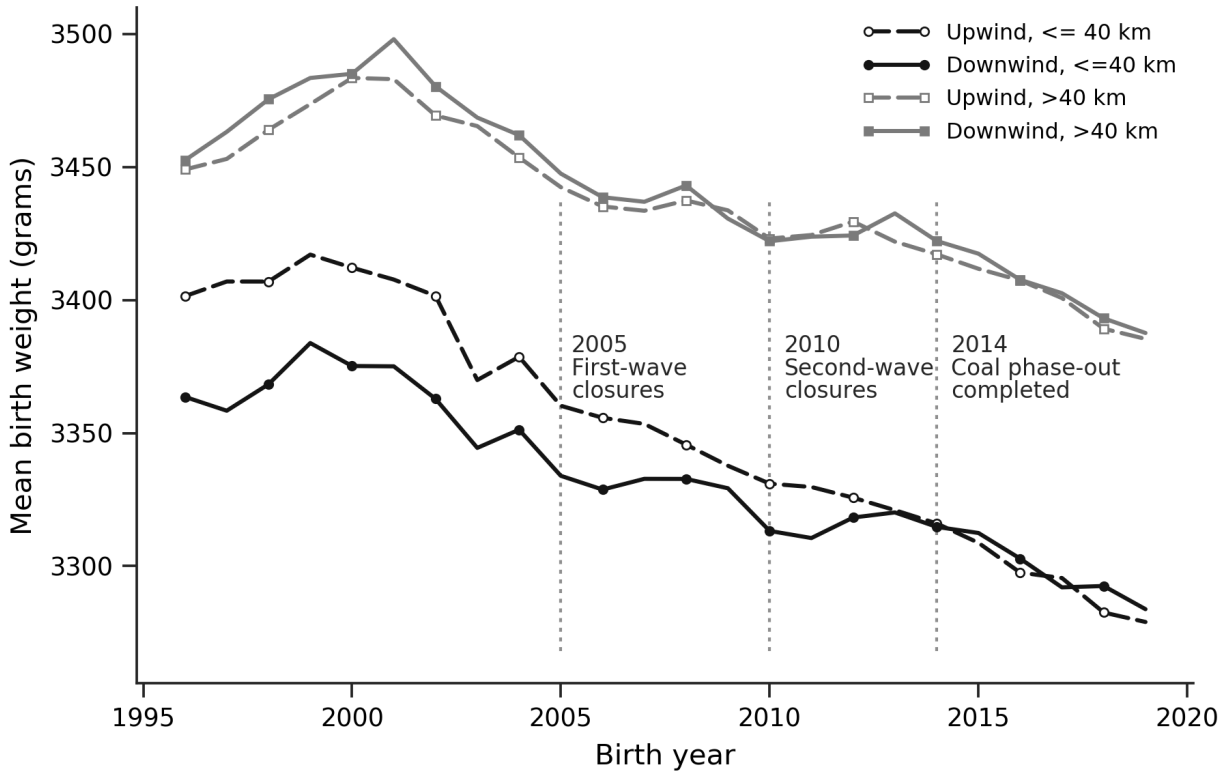
Since the early 2000s, electricity generation in many high-income economies has largely shifted away from coal, contributing to substantial improvements in air quality. In the United States, sulphur dioxide (SO_2) emissions from power plants have fallen by more than 90 percent in the twenty-first century. Yet coal has not disappeared from the policy frontier. The Trump administration has promoted "beautiful clean coal" and substantially delayed scheduled retirements of coal-fired power plants through emergency orders, regulatory exemptions, and over $700 million in federal support for the coal industry. In 2025, the United States had planned to retire 8.5 gigawatts of capacity but retired only 2.6 gigawatts, the lowest annual total since 2010 (U.S. Energy Information Administration, 2026). Coal still generated about 17 percent of U.S. utility-scale electricity in 2025, up from 15.6 percent in 2024, compared with only 4 percent in Canada. Coal also remains central in other major economies, accounting for about 54 percent of electricity generation in China and more than 74 percent in India. Continued reliance on coal, new investment in coal-fired capacity, and delays in planned retirements are often justified by rising electricity demand, including demand from data centre expansions. But they also raise a critical policy question: do governments fully account for the health costs of coal-fired generation, particularly when those costs are unequally borne by exposed communities? This paper studies these costs and the resulting health inequalities, using the large-scale, province-wide phase-out of coal-fired electricity generation in Ontario, Canada.

Coal power plants are harmful to public health. Coal-fired power plants are the main emitters of SO_2, which is causally linked to respiratory symptoms and exacerbations (U.S. Environmental Protection Agency, 2017). SO_2 is also a key precursor to fine particulate matter ($PM_{2.5}$). Higher exposure to coal emissions is linked to asthma attacks, asthma-related emergency department (ED) visits, and hospitalisations (Casey et al., 2020). On the other hand, the evidence on exposure to SO_2 and birth outcomes is mixed (U.S. Environmental Protection Agency, 2017). A large and well-established body of literature has shown that birth outcomes are key indicators of human capital development and long-term health, including IQ, educational attainment, earnings, adult health status, and later-life socioeco-

nomic status (Black et al., 2007; Oreopoulos et al., 2008; Figlio et al., 2014). If exposure to coal emissions from power plants worsens birth outcomes, the effects on health could persist.

Worse birth outcomes are also economically costly to the health care system. A low-birth-weight newborn costs about $33,096 in first-year health services in Canada, compared with $3,942 for normal-weight newborns (Thanh et al., 2015). In a setting with a universal health care system, such as in Canada, the adverse effects of coal emissions on birth outcomes can translate into large health care costs borne by the public.

Figure 1: Average Birth Weight in Ontario from 1996 to 2019: Downwind vs. Upwind Areas



Notes: The figure plots annual average birth weight in grams for live singleton births in Ontario from 1996 to 2019 using the Canadian Vital Statistics Birth Database. The darker two lines indicate newborns whose maternal residential postal-code centroid is within 40 km of the nearest coal-fired power plant, and lighter lines denote births farther away. Solid lines and dashed lines denote locations that are more and less frequently downwind of the nearest plant, respectively. Vertical dotted lines mark the closure waves in 2005 and 2010 and completion of the coal phase-out in 2014.

Coal-fired power plants likely worsen birth outcomes, with disproportionate effects on populations most exposed to their emissions. Figure 1 presents the average birth weight for all newborns in Ontario from 1996 to 2019, which spans the same years as the paper's birth

sample. The lower two lines represent the average birth weight for newborns who live in areas that are within 40 km of the nearest coal-fired power plant, and the upper two lines are for those who live farther away[1]. Figure 1 demonstrates two facts: (1) There is a gap in average birth weight between newborns who live within 40 km of the coal-fired power plants and those who live farther away. The gap is around 100 grams and persists over time; (2) There is also a gap of around 50 grams between newborns in the downwind regions and those in the upwind regions, even though they are all within 40 km of the coal-fired power plant. The gap shrinks when coal-fired power plants start to close in 2005 and eventually disappears in 2014 when the retirements are completed. Meanwhile, there is no similar pattern among newborns who live farther away, shown in the upper two lines. These facts are important. The first one indicates that simply comparing newborns who live near the emitters to those who live farther away may capture other factors that affect birth outcomes and health outcomes, because the residence location is endogenous. The second one suggests that downwind regions may be exposed to more emissions from the nearest emitter; thus, the coal-fired power plants generate inequality in birth outcomes.

The province-wide retirement of coal-fired power plants in Ontario provides a rare opportunity to study the health effects of exposure to SO_2 and the health benefits of transitioning away from coal. Ontario retired all of its coal-fired power plants by 2014, in what was one of the largest single greenhouse-gas-reduction policies in North America (Ontario Ministry of Energy, 2013). The phase-out was expected to generate large health benefits, with projected annual savings in health care exceeding $2.6 billion (Ontario Medical Association, 2005). However, little is known about the realized benefits of this policy. By focusing on the large-scale retirement of coal-fired power plants in Canada's most populous province, Ontario—home to over 14 million residents—I am able to combine Canadian administrative linkage datasets with novel gridded and modelled data on weather and air quality. Using these data, I provide the first causal evidence on the health effects of retiring coal-fired power plants and estimate the health benefits of transitioning from coal power to cleaner energy.

The paper proceeds as follows. Section 2 motivates the focus on coal-fired power plants and their health effects and situates the paper within the literature on air pollution, plant

[1]More than 50 percent of residents in Ontario live within 40 km of a coal-fired power plant.

closures, and early-life health. Next, Section 3 outlines Ontario's coal phase-out and the timing of plant closures. Section 4 describes the linked administrative records, weather data, and air pollution data used in the analysis. Section 5 presents the downwind exposure measure and empirical strategy. Sections 6 and 7 present the estimated effects on birth outcomes and childhood respiratory hospitalisations. Finally, Section 8 summarizes the main findings, monetizes the health gains, and discusses the policy implications.

2 Literature Review

A growing economics literature estimates the health costs of air pollution using regulatory changes, economic shocks, traffic patterns, and extreme pollution events (Chay and Greenstone, 2003; Currie and Neidell, 2005; Currie et al., 2009; Currie and Walker, 2011; Schlenker and Walker, 2016; Deryugina et al., 2019; von Hinke and Sørensen, 2023). Related work studies industrial plant openings and closings (Currie et al., 2015), power-plant desulphurization (Luechinger, 2014), coal-plant emissions and fetal health (Yang et al., 2017; Yang and Chou, 2018), power-plant closures and school absences (Komisarow and Pakhtigian, 2022), and broader energy transitions (Burney, 2020; Fraenkel et al., 2024; Clay et al., 2024). This literature shows that air pollution affects infant health, morbidity, and mortality, and that early-life exposure can have persistent effects on later health and human capital. However, evidence on the health effects of real-world policies that directly change fetal exposure remains relatively scarce (Almond and Currie, 2011). I address this gap by studying Ontario's coal phase-out, a province-wide policy that eliminated coal-fired electricity generation and substantially reduced exposure to coal-related air pollution in a modern, relatively low-pollution setting.

This paper links a real-world environmental policy to both infant health and later childhood health for the same cohorts. Prior work often relies on aggregate outcomes such as county-level mortality, school absences, housing values, or other area-level health measures, while studies of infant health typically observe birth outcomes but not later childhood health or family mobility (Yang and Chou, 2018; Komisarow and Pakhtigian, 2022; Fraenkel et al.,

2024). This evidence is informative, but these designs generally cannot follow the same children from birth into later childhood or directly connect fetal exposure to a pollution shock with later health outcomes. I build on this literature by linking population-level birth records to hospitalisation records and family tax files. This linkage allows me to study birth outcomes and childhood respiratory morbidity among children exposed to the coal phase-out while accounting for family income and residential mobility.

I use a novel measure of exposure to emissions from coal-fired power plants. A common approach defines exposure to air pollution using distance to a pollution source, comparing areas inside and outside a fixed radius (Currie et al., 2015; Tanaka et al., 2022; Komisarow and Pakhtigian, 2022; Clay et al., 2024; Fraenkel et al., 2024). Distance is useful, but it does not fully capture atmospheric transport: two communities located the same distance from a plant may face different pollution risks if one is frequently downwind while the other is rarely downwind. A related literature uses wind direction to isolate pollution exposure that is difficult to measure with distance alone. Deryugina et al. (2019) use daily wind variation to estimate the mortality and medical costs of air pollution, Anderson (2020) uses long-run downwind exposure near highways to study mortality, and Tanaka (2024) studies long-term downwind exposure to pollution from power plants and adult mortality. The studies closest to this paper use wind direction to define exposure to emissions from a single upwind coal plant (Yang et al., 2017; Yang and Chou, 2018). They compare monthly wind direction with the bearing from a coal plant to ZIP-code centroids in New Jersey and classify a ZIP code as downwind when wind blows from the plant toward the ZIP code for more than six months per year. A remaining challenge is that binary downwind classifications discard meaningful variation in exposure intensity. I address this issue by constructing a continuous, pre-closure measure of the number of days each postal area was downwind of its nearest coal-fired power plant, allowing treatment intensity to vary within nearby communities while keeping the measure fixed before any closure.

The paper also contributes to research on pollution measurement and environmental policy evaluation. I use both modelled and observed data on weather and air pollutant concentrations to measure exposure and estimate how coal-fired power plant closures changed local

pollutant concentrations. Many studies rely on monitor-based air quality or weather data, which can suffer from incomplete spatial coverage and nonrandom monitor placement (Currie and Neidell, 2005; Currie et al., 2009; Knittel et al., 2016; Schlenker and Walker, 2016; Deschênes et al., 2017; Deryugina et al., 2019; Luechinger, 2014; Yang et al., 2017; Yang and Chou, 2018; Komisarow and Pakhtigian, 2022; Ward, 2015). Recent work has increasingly combined administrative data with modelled or remotely sensed pollution data to improve exposure assignment. For example, Hansen-Lewis and Marcus (2025) use CMAQ-predicted exposure to study maritime emissions regulation, and Burney (2020) combines plant-unit changes with satellite- and monitor-based pollution surfaces. I build on this approach by using U.S. Environmental Protection Agency (EPA) EQUATES CMAQ daily air pollutant concentrations and ERA5 daily weather data, assigning each postal code to the nearest grid cell based on its centroid. This approach provides complete spatial coverage and a measurement strategy that can be adapted to other settings with gridded pollution, weather, plant-location, and closure data.

The paper further contributes source-specific evidence on coal-related pollution. Much of the pollution-health literature studies ambient $PM_{2.5}$ or regulations that affect multiple pollution sources at once. Coal-fired power plants, however, are major point sources of sulphur dioxide, a toxic air pollutant produced by burning sulphur-containing fossil fuels. This source specificity is useful because nitrogen oxides (NO_x) and $PM_{2.5}$ are also affected by daily local activities such as automobile emissions and construction dust. SO_2 also has a shorter atmospheric lifetime than many secondary pollutants, so the most direct exposure effects are likely to be concentrated near emitters before sulphur transforms into secondary aerosols such as $PM_{2.5}$. The remaining gap is that policy evaluations often measure the average effects of broad improvements in ambient air quality rather than isolating health changes caused by retiring coal-fired electricity generation. I use the timing of plant closures and predetermined downwind exposure to estimate how retiring coal plants changed SO_2, infant health, and childhood respiratory morbidity.

Finally, the paper contributes to the evidence on the distributional health effects of clean-energy transitions. Pollution exposure is shaped by residential sorting, local amenities, and

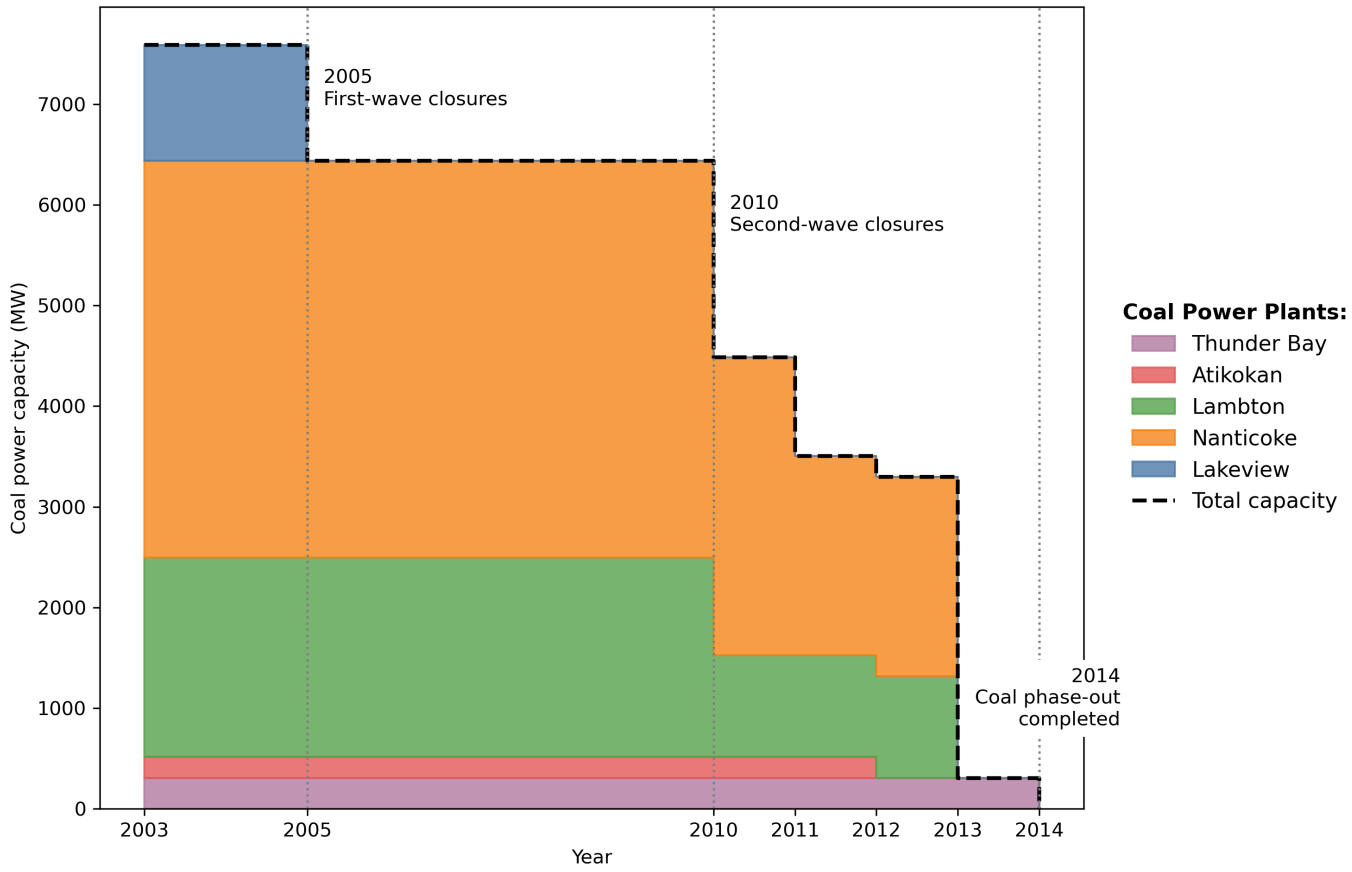
environmental justice concerns (Currie et al., 2015; Pan, 2023; Tanaka, 2024), but less is known about whether coal-retirement health gains differ across families. By linking birth, tax, and hospitalisation records, I estimate heterogeneity by pre-birth family income and residential location. The results therefore connect coal retirement to early-life health inequality in a high-income, universal-health-care setting. The setting is also policy relevant beyond Canada: coal remains a major source of electricity in China and India, and recent U.S. data show that some planned coal retirements have been delayed or cancelled. The estimates should therefore be interpreted as evidence from a clean-power transition in a high-income and universal health care setting, while the measurement approach is designed to be portable to other coal-reliant contexts.

3 Institutional Background

Ontario's coal phase-out was a province-wide electricity-sector reform that eliminated coal-fired power generation from Ontario's supply mix between 2005 and 2014. In 2003, the provincial government committed to closing all coal-fired power plants. At that time, Ontario operated five coal-fired generating stations—Lakeview, Nanticoke, Lambton, Atikokan, and Thunder Bay—which accounted for roughly one-quarter of Ontario's electricity supply.

The reform was motivated by concerns over air quality, greenhouse-gas emissions, and public health. Coal combustion emits sulphur dioxide (SO_2) and nitrogen oxides (NO_x), and these pollutants also contribute to secondary fine particulate matter through atmospheric reactions that form fine particulates such as $PM_{2.5}$. These pollutants are directly relevant for child health. Short-term SO_2 exposure is associated with asthma exacerbations and respiratory hospital admissions, especially among children, and prenatal SO_2 exposure has been linked to low birth weight and preterm birth (Bobak, 2000; Sunyer et al., 2003; Lin et al., 2004; Zheng et al., 2021). Fine particulate matter is associated with respiratory and cardiopulmonary morbidity and with adverse birth outcomes (Dominici et al., 2006; Pope and Dockery, 2006; Dadvand et al., 2013; Pedersen et al., 2013). Evidence on $PM_{2.5}$ composition further suggests that combustion-related and sulphur-containing fine-particle components

Figure 2: Staged Closure of Coal-Fired Power Plants in Ontario, 2003 to 2014



Notes: Author's calculation based on Ontario power plant retirement dates and generating capacity records. The figure shows the remaining coal-fired generating capacity in Ontario by plant from 2003 to 2014. Coloured areas report plant-specific capacity, and the dashed black line reports total remaining coal capacity. Vertical dotted lines mark the 2005 first-wave closures, the 2010 second-wave closures, and the completion of the coal phase-out in 2014.

are associated with respiratory admissions and reduced birth weight (Ostro et al., 2009; Basu et al., 2014).

The coal phase-out started in 2005 and was implemented through a staged sequence of plant closures and unit retirements. Figure 2 presents the timing of closures and the remaining coal-fired capacity between 2003 and 2014. Lakeview Generating Station, located in the Greater Toronto Area, was the first major coal plant to close, ceasing operations in April 2005. Nanticoke Generating Station, the province's largest coal facility, retired units in 2010 and 2011 and closed fully in 2013. Lambton Generating Station retired units in

2010 and 2012 and ceased coal operations in 2013. Atikokan, a smaller northern facility, stopped burning coal in 2012. Thunder Bay was the last coal-fired plant in the province and burned its last coal in April 2014. The policy therefore generated large reductions in coal-fired capacity, with total coal capacity falling from roughly 7.6 GW in 2003 to zero by 2014.

The reform was one of the largest single greenhouse-gas-reduction policies in North America (Ontario Ministry of Energy, 2013). Ontario was also the first North American jurisdiction to eliminate coal-fired electricity generation, while maintaining grid reliability through replacement capacity from lower-emitting sources, including nuclear, hydro, natural gas, renewables, and conservation. The staged nature of the phase-out generated spatially uneven reductions in exposure to coal-related emissions, which helps separate local changes in pollution around specific plants from province-wide trends in electricity demand, economic activity, and environmental policy.

4 Data and Sample

In this paper, I combine confidential Canadian administrative microdata and gridded data on weather and air pollutant concentrations. The administrative data provide individual-level birth and hospitalisation outcomes and are accessed through the Statistics Canada Research Data Centre. The gridded weather and air pollution data provide complete daily coverage for Ontario at the finest geographical level, which allows me to assign wind patterns, air pollution levels, and other weather-related variables to every postal code in the sample rather than relying only on the locations of monitoring stations.

4.1 Birth Data - Canadian Vital Statistics–Birth (CVSB)

The main dataset for birth outcomes comes from the confidential Canadian Vital Statistics–Birth Database (CVSB). CVSB covers all births in Canada and includes the date of birth, birth weight, gestational age, maternal characteristics, and the residential postal code at the time of birth. I use the Postal Code Conversion File Plus (PCCF+) to assign each

residential postal code the longitude and latitude of its centroid. These coordinates are used to calculate both the distance to the nearest coal-fired power plant and the bearing from the plant to the postal-code centroid.[2]

The main birth sample consists of live singleton births in Ontario from 1996 to 2019. Singleton births account for more than 96 percent of live births in the data, and the restriction avoids mechanically lower birth weights among multiple births. I restrict the sample to births to mothers aged 20–55 and to infants whose residential postal code centroid lies within 40 kilometres of the nearest coal-fired power plant.[3] I also exclude pregnancies whose gestational period overlaps with the closure date of the nearest plant. Thus, pre-closure births are fully exposed to emissions from coal-fired power plants before closure, and post-closure births are conceived after closure.[4] The resulting sample includes roughly 1.3 million live singleton births.

I construct five birth outcomes using birth weight and gestational age: low birth weight, equal to one if birth weight is below 2,500 grams; very low birth weight, equal to one if birth weight is below 1,500 grams; preterm birth, equal to one if gestational age is below 37 weeks; very preterm birth, equal to one if gestational age is below 32 weeks; and extremely preterm birth, equal to one if gestational age is below 28 weeks.

4.2 Discharge Abstract Database (DAD)

I use the administrative Discharge Abstract Database (DAD) from 1996 to 2019 to measure childhood respiratory-related hospitalisations and analyze the medium- and long-term health effects of coal-fired power plant closures. The DAD is an administrative hospital database that contains inpatient separations from acute care hospitalisations in all Canadian provinces and territories, except Quebec, as reported to the Canadian Institute for Health Information

[2]Canadian postal codes identify small geographic areas, similar to ZIP codes in the U.S. but generally at a much finer geographic level.

[3]I discuss the selection of the 40-kilometre threshold in more detail in Appendix A.1. I exclude newborns whose residential postal-code centroids lie within 1 kilometre of the nearest plant because their families may take precautionary measures to limit exposure.

[4]In the robustness check, I use newborns who are exposed to coal-fired power plant pollution only during the first, second, and third trimesters to assess which periods are most important for birth outcomes and early-childhood health outcomes.

(CIHI). The DAD contains patient demographics, residential postal codes, admission and discharge dates, and up to 25 diagnosis codes and 15 intervention codes. For this analysis, I use the Ontario hospitalisation records contained in the DAD.

I link children in the birth records to DAD hospitalisations from birth through age 17, to the extent permitted by the 1996–2019 sample period. The main hospitalisation outcomes of interest are binary indicators for inpatient admissions related to acute respiratory disease and asthma. Because the DAD captures inpatient hospitalisations, these outcomes identify severe respiratory events requiring admission. They do not include outpatient physician visits or emergency department visits that do not lead to admission. The hospitalisation analysis therefore focuses on the severe margin of childhood respiratory morbidity, so the estimated effects provide a lower bound on the total respiratory health effects of eliminating coal-fired generation.[5]

The linked DAD sample used in the analysis contains approximately 1.5 million hospitalisation records for over 90 percent of children in the birth sample. Summary statistics for CVSB and DAD samples between 1996 and 2019 will be presented in the appendix tables in the final version of the paper in accordance with the disclosure rules of the Research Data Centre.

4.3 Tax Files

I supplement the analysis with linked T1 family tax files from Statistics Canada. These longitudinal files cover over 90 percent of the working population in Canada and provide annual information on family income, maternal earnings, government transfers, and residential location for tax filers and their families. By linking the tax files to the vital statistics, I can measure pre-birth family socioeconomic status, follow residential mobility over time, and test whether the effects of closing coal plants vary by the residential location and income of families living near coal-fired power plants.

[5] Acute inpatient data exclude milder forms of respiratory morbidity, such as asthma exacerbations managed in primary care and respiratory infections treated in physicians' offices. Nevertheless, I focus on admissions because they capture the most severe events, entailing high treatment costs and potentially lasting consequences.

4.4 Weather Data

Weather data come from the Copernicus Climate Change Service ERA5 daily statistics (Copernicus Climate Change Service, 2024). ERA5 is a global reanalysis product that combines weather observations with a numerical weather model to produce spatially and temporally complete measures of atmospheric conditions. I use ERA5 because the empirical design requires daily weather and wind information for every postal area in Ontario, including areas without nearby weather stations. ERA5 provides data on a $0.25° \times 0.25°$ grid level, corresponding to grid cells on the order of 20 km in Ontario. These grid-based data are better suited to this setting than the monitor-based data.[6]

I construct a balanced Census Forward Sortation Area (CFSA)-day panel for Ontario from 1996 to 2019.[7] For each CFSA, I assign weather from the ERA5 grid cell nearest to the CFSA centroid. The panel contains daily 2-metre temperature, 2-metre dew point temperature, precipitation, and 10-metre wind components. Temperatures are converted to degrees Celsius, total precipitation is converted to millimetres of water, and wind speed is calculated from the eastward and northward wind components and expressed in kilometres per hour. I also recover wind direction from the wind components. This procedure yields a balanced CFSA-day panel of local weather conditions measured consistently across Ontario.

The wind data are used to construct the measure of downwind exposure in the empirical strategy. For each CFSA, I identify the nearest coal-fired power plant within 40 kilometres and calculate the bearing from the plant to the CFSA centroid.[8] I then compare this bearing with the daily wind direction from ERA5. A CFSA is classified as downwind of its nearest plant on day t if the wind is blowing from the plant toward the CFSA within a 120-degree angular window:

$$Downwind_{cpt} = 1\left\{\Delta(\theta_{ct}, b_{cp}) \leq \kappa\right\}, \tag{1}$$

where θ_{ct} is the direction in which the wind blows, b_{cp} is the bearing from the plant p to

[6] The correlation between the ERA5 grid data and monitor-based data is reported in Appendix Table A1.

[7] A CFSA is the geographic area identified by the first three characters of the Canadian postal code.

[8] The bearing from the plant to the CFSA centroid is a proxy for the direction of travel from the power plant to the postal code of residence.

CFSA c, and $\Delta(\cdot)$ is the smallest angular difference between them.[9] I then aggregate this daily indicator to the annual level by counting the number of downwind days in each CFSA in the years prior to any coal-fired power plant closures.

The main downwind measure is fixed for each postal code using only the pre-treatment period. Specifically, for each CFSA, I calculate the average annual number of downwind days before the closure of its nearest plant:

$$Downwind_{cp}^{pre} = \frac{1}{|Year_p^{pre}|} \sum_{y \in Year_p^{pre}} \sum_{t \in y} Downwind_{cpt}. \tag{2}$$

This measure captures how frequently an area was meteorologically positioned downwind of the nearest coal-fired power plant before closure. Since it is constructed only from pre-closure wind patterns, it is not affected by post-closure changes in pollution, health, or residential sorting. Ontario is in the prevailing westerlies, and wind patterns are relatively stable over time, so the pre-closure wind patterns do not vary much within the period of analysis.[10]

The ERA5 weather data are also used to construct control variables because temperature and precipitation are associated with birth and health outcomes (Chay and Greenstone, 2003; Currie and Neidell, 2005; Schlenker and Walker, 2016).

To assess the quality of the ERA5 measures, I compare them with monitor-based weather data from Environment and Climate Change Canada. I collapse hourly station observations from Ontario weather monitors to daily measures of temperature, dew point, relative humidity, precipitation, and wind patterns. I then match the station-based measures to the corresponding local ERA5 measures for 2002–2019. Appendix Table A1 reports the correlations between ERA5 and monitor-observed weather variables.

[9] I also use alternative angular windows to define downwind exposure. The results are presented in Table 3 and are similar across specifications.

[10] I show the measure is consistent before and during the phase-out in Appendix Figure A2.

4.5 Air Pollution Data–EPA EQUATES

I measure ambient air pollution using the EPA EQUATES CMAQ air-quality grid data (US EPA, 2021). EQUATES provides a harmonized historical air-quality time series generated using EPA's Community Multiscale Air Quality model. The grid data combine emissions inventories, meteorology, atmospheric chemistry, transport, and deposition processes to produce spatially complete daily pollution fields.

I use daily surface air pollution concentrations for Ontario from 2002 to 2019. The pollutants used in the analysis are sulphur dioxide (SO_2), fine particulate matter ($PM_{2.5}$), and ozone (O_3). EQUATES reports these measures on a 12-kilometre by 12-kilometre grid. I convert the raw files into a grid-cell-day panel containing pollutant concentration, date, year, month, and grid-cell centre coordinates. I then assign each CFSA to the nearest EQUATES grid cell based on centroid distance.[11] The air pollution data is a CFSA-day panel for 2002–2019. Each observation contains the CFSA identifier, date, and daily pollutant concentrations. These data provide complete daily pollution coverage for Ontario at the CFSA level, avoiding the sparse and non-random spatial coverage of ground monitors.[12].

5 Empirical Strategy

I am interested in estimating the effect of coal-fired power plant closures on local air pollution, infant birth outcomes, and childhood health outcomes. A simple comparison of average outcomes before and after closures is unlikely to be credible because Ontario's air quality, economic conditions, health care use, and residential patterns were changing over the same period as the coal phase-out. These changes could affect both areas near coal plants and areas farther away differently, making it difficult to construct a credible comparison group using distance alone.

[11] Because the assignment is based on CFSA centroids, small urban CFSAs may share the same 12 km grid cell and therefore the same pollution value.

[12] I also use the monitor-based air pollution data from the National Air Pollution Surveillance (NAPS) program between 2002 and 2019. The correlation between the monitor-based measures and the EQUATES measures is presented in Appendix Table A1

The empirical design therefore combines proximity to coal-fired power plants with predetermined wind exposure. Proximity-based designs are useful for studying local pollution sources (Currie et al., 2015), but locations at the same distance from a plant can face different exposure depending on whether emissions are transported toward or away from them. Building on studies that use wind direction to identify exposure to power plant emissions (Yang et al., 2017; Yang and Chou, 2018), I compare areas near the same coal-fired power plant that were more versus less frequently downwind of the plant prior to its closure. This comparison is motivated by atmospheric transport: previous work finds that SO_2 can be about 3–15 times higher downwind of a power plant than upwind (García-Portugués et al., 2013), which could translate into substantial differences in health risk.

5.1 First-Stage Analysis: Effects on Air Pollution

I first examine whether coal-fired power plant closures reduced local air pollution in nearby areas. The analysis uses daily pollution measures at the CFSA level and exploits variation in predetermined downwind exposure to each CFSA's nearest coal-fired power plant. I estimate the following two-way fixed effects (TWFE) specification:

$$Y_{cpt} = \gamma_{cp} + \theta_t + \beta \cdot Post_{cpt} \times Downwind_{cp}^{pre} + \Phi X_{cpt} + \epsilon_{cpt} \tag{3}$$

where Y_{cpt} is the daily concentration of SO_2 in CFSA c assigned to the nearest coal plant p on day t; X_{cpt} is a vector of weather controls, including temperature, dew point temperature, total precipitation, and wind speed; γ_{cp} denotes CFSA-by-plant fixed effects, which absorb time-invariant local characteristics such as distance to the nearest plant and neighbourhood quality; and θ_t denotes calendar-date fixed effects, which absorb province-wide daily shocks such as extreme weather, seasonality, and concurrent economic conditions. Post_{cpt} equals one after plant p has closed, and $Downwind_{cp}^{pre}$ is the pre-closure downwind exposure measure defined in Section 4.4. Standard errors are clustered at the CFSA-plant level.

The coefficient of interest, β, captures the differential change in SO_2 after a plant closure for areas that were more frequently downwind of the nearest plant, relative to areas that

were less frequently downwind. The identifying variation comes from two sources: staged closure timing across plants and differences in pre-closure downwind exposure among CFSAs assigned to the same plant.

The key identifying assumption is that, absent coal-fired power plant closure, pollution in more and less frequently downwind CFSAs assigned to the same plant would have evolved similarly, conditional on CFSA-plant fixed effects, calendar-date fixed effects, and weather controls. This assumption would be threatened if pre-closure downwind exposure were correlated with other local determinants of changing pollution, such as differential changes in industrial activity, urban growth, or traffic patterns.

I assess this assumption using an event-study version of Equation 3. Figure 3 plots TWFE event-study estimates for SO_2 concentrations around coal-fired power plant closures. The estimating equation is

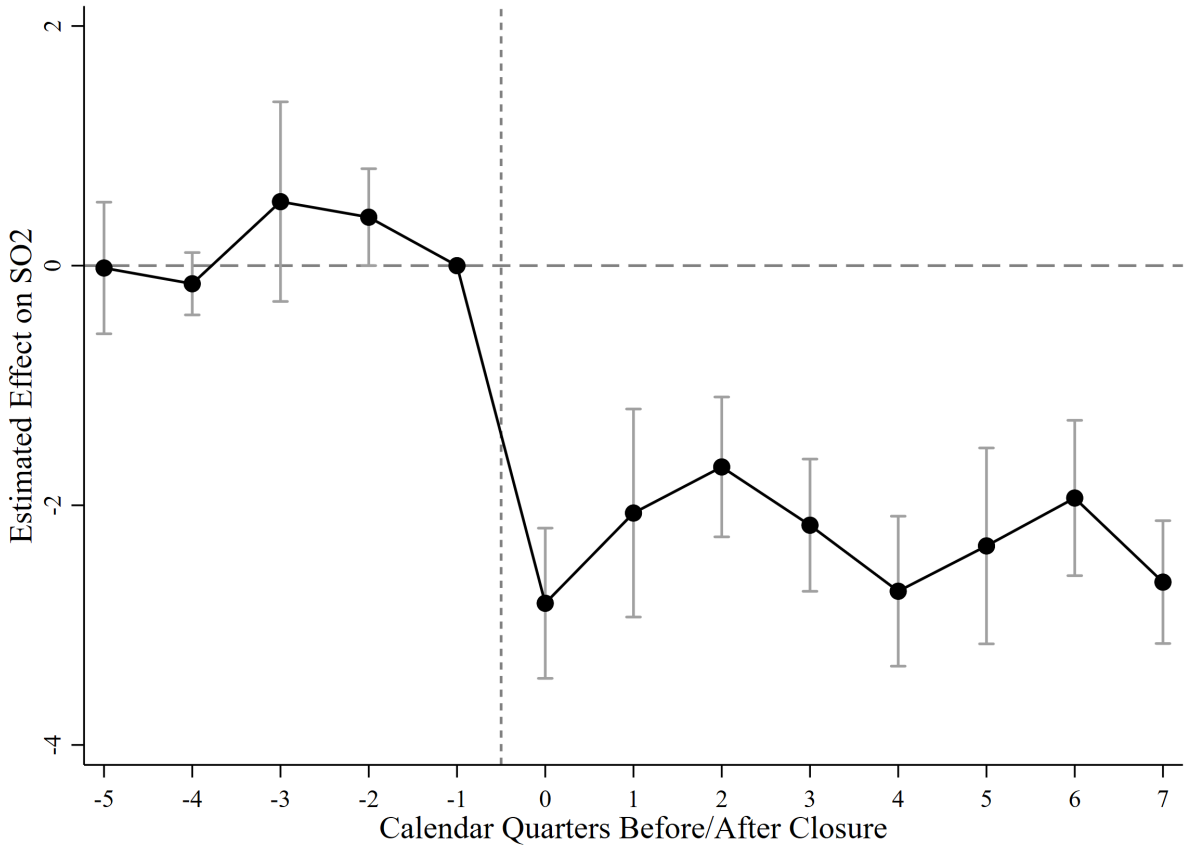
$$Y_{cpt} = \gamma_{cp} + \theta_t + \sum_{s \neq -1} \beta_s \times \mathbf{1}[D_{pt} = s] \times Downwind_{cp}^{pre} + \Phi X_{cpt} + \epsilon_{cpt} \tag{4}$$

where variables are defined as in Equation 3, except for the event-time indicators. $D_{pt} = s$ denotes the event time for plant p on date t, measured in calendar quarters relative to the closure quarter, with event quarter $s = -1$ omitted as the reference period. Thus, β_s measures the differential change in pollution in more frequently downwind CFSAs, relative to less frequently downwind CFSAs, in event quarter s compared with the omitted quarter immediately before closure. I assess the parallel trends assumption by testing whether the pre-closure coefficients β_s for $s < -1$ are individually and jointly indistinguishable from zero.

In Figure 3, the estimated SO_2 coefficients are statistically indistinguishable from zero before the nearest coal-fired power plants close. I cannot reject the null hypothesis of no differential pre-closure trends. Beginning in the closure quarter (period 0), SO_2 concentrations fall sharply by 2.28 ppb in areas that were more frequently downwind of the nearest plant, more than 77 percent of the pre-closure mean. The effects persist in subsequent quarters.

Recent advances in the difference-in-differences literature highlight potential biases in the TWFE estimators under staggered treatment adoption, especially when treatment effects are heterogeneous over time (Goodman-Bacon, 2021; Callaway and Sant'Anna, 2021; de Chaise-

Figure 3: Event-Study Analysis of Coal-Fired Power Plant Closures and SO_2 Concentrations



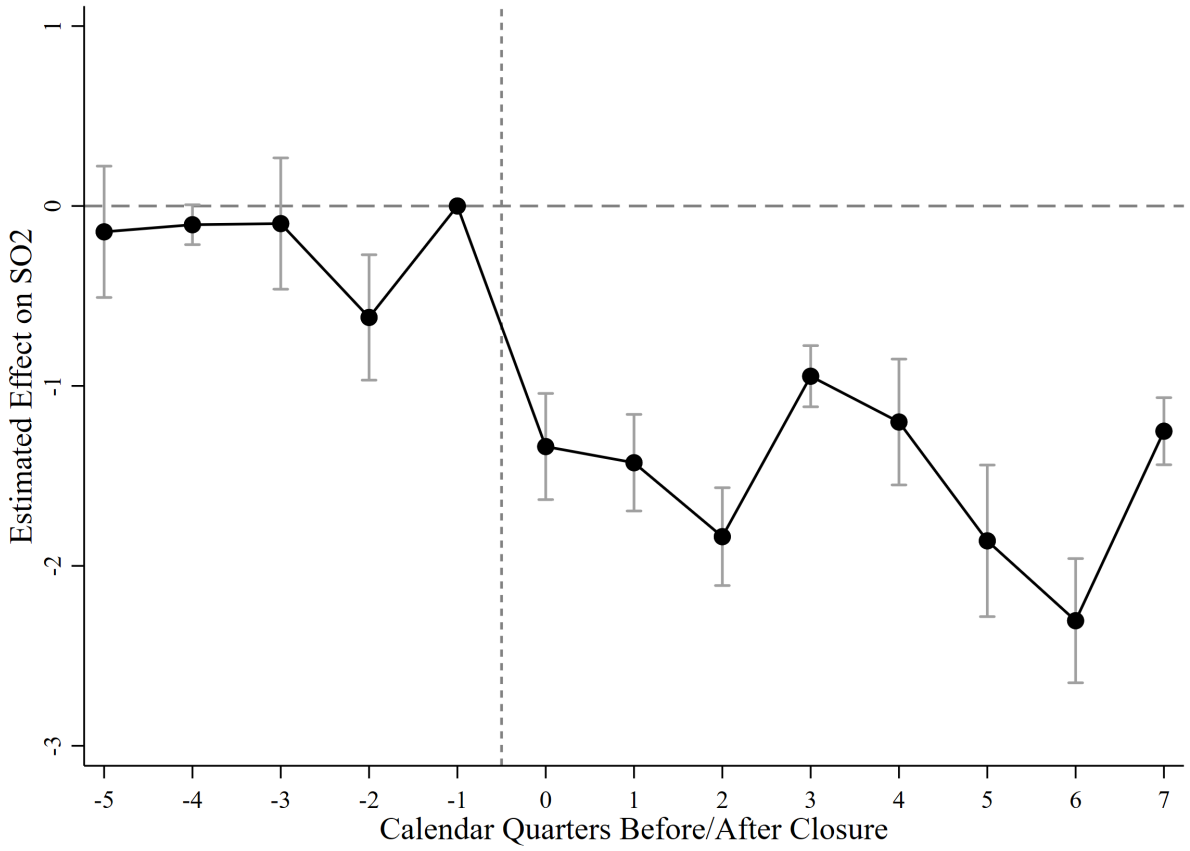
Notes: This figure plots event-study estimates from Equation 4. The outcome is the daily SO_2 concentration measured in parts per billion (ppb). Event time is measured in quarters relative to the closure quarter of the nearest coal-fired power plant, and quarter -1 is omitted. Estimates are scaled to a 10^{th}-to-90^{th} percentile increase in pre-closure downwind exposure. Vertical bars show 95 percent confidence intervals. Standard errors are clustered at the CFSA-plant level.

martin and D'Haultfœuille, 2020, 2024). The concern is that already-treated units can serve as controls for later-treated units. When treatment effects vary over time, these comparisons can receive negative weights and lead to biased estimates (Borusyak et al., 2024).

This concern is mitigated, though not eliminated, by the structure of my design. The main comparison is between more and less frequently downwind CFSAs assigned to the same nearest plant that share one closure date, and the CFSA-plant fixed effects absorb time-invariant differences in proximity and local characteristics. However, because the TWFE specification still uses variation from staggered closure timing across plants, I also imple-

ment the estimator proposed by de Chaisemartin and D'Haultfœuille (2020). The results in Figure 4 are broadly consistent with the TWFE estimates, suggesting that potential bias from staggered adoption is not driving the first-stage findings.

Figure 4: Event-Study Analysis of Coal-Fired Power Plant Closures and SO_2 Concentrations Using the de Chaisemartin and D'Haultfœuille (2020) Estimator



Notes: This figure plots event-study estimates using the de Chaisemartin and D'Haultfœuille (2020) estimator. The outcome is the daily SO_2 concentration measured in parts per billion (ppb). Event time is measured in quarters relative to the closure quarter of the nearest coal-fired power plant, and quarter -1 is omitted. Estimates are scaled to a 10^{th}-to-90^{th} percentile increase in pre-closure downwind exposure. Vertical bars show 95 percent confidence intervals.

Table 1 shows the average first-stage effects of coal-fired power plant closures on local SO_2 concentrations. Estimating Equation 3 on the 2002–2019 pollution sample, I find that a 10^{th}-to-90^{th} percentile increase in pre-closure downwind exposure is associated with a 1.36 ppb larger decline in SO_2 after the nearest coal-fired power plant closes. This effect is about 38 percent of the pre-closure mean of 3.60 ppb. The estimate is not directly comparable

to the event-study estimates in Figure 3 because Table 1 pools all post-closure dates into a single post-period coefficient.

The effect is concentrated within 40 km of the plant. When I include areas farther from the plant, the estimate is close to zero. This distance gradient is consistent with the atmospheric behaviour of SO_2, which is relatively short-lived and can oxidize into sulphate particulates as it is transported.[13] As a placebo test, I replace the downwind measure with a comparable measure that captures the share of days on which a CFSA lies perpendicular to the prevailing wind from the plant. The perpendicular-wind estimate is close to zero. Together, these results support the interpretation that the main estimates capture changes in exposure to air pollution from coal-fired power plants rather than broader spatial trends.

Table 1: First-Stage Effects of Coal-Fired Power Plant Closures on SO_2

	Full Data (1)	Baseline, 40 km (2)	Perpendicular Wind, 40 km (3)
Downwind after closure	−0.0992	−1.3608***	0.0997
	(0.1122)	(0.1871)	(0.1180)
Observations	3,418,480	1,130,728	1,130,728
Outcome mean		3.5962	3.5962
Percent change		−37.84%	2.77%

NOTES—This table reports TWFE estimates from the first-stage analysis of the effects of coal-fired power plant closures on local SO_2 concentrations. The outcome is the daily SO_2 concentration measured in parts per billion (ppb). The downwind-after-closure coefficient is the interaction between post-closure status and the pre-closure downwind exposure measure, scaled from the 10^{th} to the 90^{th} percentile. Column (1) uses the full sample. Column (2) restricts CFSAs to within 40 km of the nearest coal-fired power plant. Column (3) uses the perpendicular-wind placebo exposure measure. All columns include CFSA-plant fixed effects, calendar-date fixed effects, and weather controls. Standard errors are clustered at the CFSA-plant level and reported in parentheses. Percent change is calculated by dividing the estimate by the pre-closure outcome mean. Statistical significance is denoted by $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

[13] In Appendix Figure A1, I estimate the predicted SO_2 concentrations using the observed monitor-based data and a cubic function of distance to the nearest coal-fired power plant. The pattern suggests that predicted SO_2 concentrations decline sharply up to roughly 40 km and are relatively flat beyond.

5.2 Reduced-Form Health Effects

The first-stage results show that coal-fired power plant closures reduced SO_2 concentrations in areas that were more frequently downwind of the nearest plant before closure. I next examine whether these exposure reductions translated into improvements in children's health.

The health analyses use the same source of variation as the first-stage analysis. For births and childhood hospitalisations, I compare individuals in CFSAs that are more versus less frequently downwind of the nearest plant before and after the plant's closure. I estimate the following reduced-form specification:

$$Y_{icpt} = \gamma_{cp} + \theta_t + \beta \cdot Post_{ipt} \times Downwind_{cp}^{pre} + \Phi X_{icpt} + \epsilon_{icpt}, \tag{5}$$

where Y_{icpt} is the outcome for child i residing in CFSA c assigned to nearest plant p at time t. For the baseline birth-outcome analysis, $Post_{ipt}$ equals one for births conceived after the closure of the nearest plant. The fixed effects and downwind measure are defined as in Equation 3, and coefficients are scaled to a 10^{th}-to-90^{th} percentile increase in pre-closure downwind exposure. These estimates are reduced-form effects of coal-fired power plant closures on health. They should not be interpreted as the effects of exposure to SO_2, because plant closures can affect several pollutants and the relevant biological exposure may occur over different prenatal and postnatal windows.

For the health-effect analysis, I exclude pregnancies whose gestational period overlaps with the closure date of the nearest plant. This restriction makes the baseline comparison cleaner: pre-closure births are fully gestated while the nearest plant is operating, and post-closure births are conceived after the nearest plant has closed. I then separately examine births exposed to closures during pregnancy to study trimester-specific timing. For childhood respiratory hospitalisations, I interpret the estimates as the combined effect of lower prenatal exposure and lower postnatal exposure after birth because the data do not separately identify these two channels.

6 Results on Birth Outcomes

Table 2 presents the estimated effects on birth weight and two binary indicators of low birth weight in Panel A, and on three measures of preterm birth in Panel B. The main sample includes births within 40 km of the nearest coal-fired power plant. As in the first-stage analysis, I use perpendicular wind exposure as a placebo test. For easier interpretation, all coefficients are scaled to reflect a 10^{th}-to-90^{th} percentile increase in pre-closure downwind exposure, corresponding approximately to a move from upwind to downwind areas.

Table 2: Estimated Effects of Coal-Fired Power Plant Closures on Birth Outcomes

	Birth Weight (1)	Low Birth Weight (2)	Very Low Birth Weight (3)
Panel A: Birth Weight Outcomes			
Downwind after closure	43.5256***	−0.0069***	−0.0015***
	(7.0030)	(0.0015)	(0.0004)
Perpendicular wind after closure	−4.0085	0.0011	−0.0005
	(7.7910)	(0.0030)	(0.0012)
Outcome mean	3347.01	0.0518	0.0079
Percent change	1.30%	−13.32%	−18.99%
Observations	[N]	[N]	[N]
	Preterm Birth (4)	**Very Preterm Birth (5)**	**Extremely Preterm Birth (6)**
Panel B: Preterm Birth Outcomes			
Downwind after closure	−0.0068***	−0.0019***	−0.0010***
	(0.0018)	(0.0005)	(0.0003)
Perpendicular wind after closure	0.0006	0.0009	−0.0000
	(0.0034)	(0.0012)	(0.0007)
Outcome mean	0.0644	0.0087	0.0035
Percent change	−10.56%	−21.84%	−28.57%
Observations	[N]	[N]	[N]

NOTES—This table reports estimates of the effect of coal-fired power plant closures on birth outcomes among births within 40 km of the nearest plant. The main treatment compares births in downwind areas before and after plant closure. The perpendicular-wind specification provides a placebo test using areas not expected to experience the same change in pollution transport. Standard errors are reported in parentheses. Outcome means are measured over the relevant comparison period. Percent changes are calculated by dividing the treatment estimate by the corresponding outcome mean and multiplying by 100. Statistical significance is denoted by $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

Panel A shows that coal-fired power plant closures increased birth weight by 43.5 grams more for newborns in more frequently downwind areas than for newborns in less frequently downwind areas. This increase is equivalent to approximately 1.3 percent of the pre-closure mean birth weight. Closures also reduced the incidence of low birth weight (defined as birth weight below 2,500 grams) by 0.69 percentage points, a 13.3 percent decline relative to the pre-closure mean of 5.2 percent. The incidence of very low birth weight (defined as birth weight below 1,500 grams) declined by 0.15 percentage points, corresponding to a 19.0 percent decrease relative to the mean. These findings indicate that coal-fired power plant closures improved birth outcomes more in areas that were more frequently downwind. Importantly, the contrast between the moderate increase in average birth weight and the larger declines in low and very low birth weight suggests that the benefits were concentrated in the lower tail of the birth-weight distribution. A modest rightward shift among vulnerable infants can have a limited effect on the overall mean while moving a meaningful share of births above clinically important thresholds such as 2,500 and 1,500 grams.

Panel B provides further evidence of improved birth outcomes. After closures, the incidence of preterm birth (defined as gestation of less than 37 weeks) declined by 0.68 percentage points more in more frequently downwind areas. This estimate corresponds to a 10.6 percent reduction relative to the pre-closure mean. Very preterm and extremely preterm births declined by 0.19 and 0.10 percentage points, respectively. As with birth weight, these effects suggest that the health benefits of plant closures were concentrated among infants at higher risk.

6.1 Robustness Checks

Table 3 reports robustness checks for the main birth-outcome estimates. Column 1 excludes covariates, while Column 2 reports the preferred specification with weather controls. The estimates are nearly identical across the two columns, suggesting that the identifying variation comes primarily from closure timing and predetermined wind exposure rather than from short-run weather fluctuations, especially after accounting for CFSA-plant and calendar-time fixed effects. In Column 3, I restrict the sample to births with a gestational age between

20 and 44 weeks. The results remain unchanged across the three outcomes, indicating that extremely short or long gestations do not drive the main findings.

Columns 4 and 5 examine whether the results depend on the definition of downwind exposure. Instead of the preferred 60-degree angle, these columns define a birth as downwind of the nearest plant only when the angle between wind flow and the plant-to-residence direction falls within a narrower 45-degree or 30-degree angle. The estimated effects remain statistically significant and have the same sign as the preferred estimates, although their magnitudes decline modestly. With the 45-degree definition, birth weight increases by 38.8 grams and the probabilities of low birth weight and preterm birth fall by 0.61 and 0.57 percentage points. With the 30-degree definition, the corresponding estimates are 32.6 grams, 0.52 percentage points, and 0.46 percentage points. The smaller but consistent estimates across alternative downwind definitions indicate that the main findings are not sensitive to reasonable choices of angular window. Thus, the identifying variation comes primarily from coal-fired power plant closures, rather than from the specific angle used to define areas downwind.

6.2 Heterogeneity

I next explore whether the estimated effects on birth outcomes differ by neighbourhood income. I divide CFSAs into lower- and higher-income neighbourhoods according to whether their median household income is below or above the median within the corresponding city. Table 4 reports estimates from the preferred reduced-form specification separately for lower- and higher-income neighbourhoods.

Birth weight increases and low birth weight declines in both lower- and higher-income neighbourhoods, with a larger point estimate for birth weight in higher-income neighbourhoods. The clearest differences appear for more severe adverse birth outcomes. In lower-income neighbourhoods, very low birth weight falls by 0.26 percentage points and extremely preterm birth falls by 0.13 percentage points, while the estimates for higher-income neighbourhoods are smaller and not statistically significant. The estimates for preterm birth and very preterm birth are also larger for lower-income neighbourhoods.

Table 3: Robustness of Estimated Effects on Birth Outcomes

	No Covariates (1)	Preferred Specification (2)	Gestation 20–44 Weeks (3)	Downwind 45 Degrees (4)	Downwind 30 Degrees (5)
Panel A: Birth Weight					
Downwind after closure	43.5257***	43.5256***	43.5420***	38.7656***	32.6429***
	(7.0093)	(7.0030)	(7.0014)	(6.9325)	(6.5685)
Observations	[N]	[N]	[N]	[N]	[N]
Panel B: Low Birth Weight					
Downwind after closure	−0.0069***	−0.0069***	−0.0069***	−0.0061***	−0.0052***
	(0.0015)	(0.0015)	(0.0015)	(0.0014)	(0.0014)
Observations	[N]	[N]	[N]	[N]	[N]
Panel C: Preterm Birth					
Downwind after closure	−0.0068***	−0.0068***	−0.0068***	−0.0057***	−0.0046**
	(0.0018)	(0.0018)	(0.0018)	(0.0019)	(0.0019)
Observations	[N]	[N]	[N]	[N]	[N]

NOTES—This table reports robustness checks for the estimated effect of coal-fired power plant closures on birth outcomes among births within 40 km of the nearest plant. Column (1) excludes covariates. Column (2) reports the preferred specification with weather controls. Column (3) restricts the sample to births with gestational age between 20 and 44 weeks. Columns (4) and (5) define downwind exposure using 45-degree and 30-degree angular windows, respectively. Standard errors are clustered at the CFSA-plant level and reported in parentheses. Statistical significance is denoted by $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

These results are consistent with the main finding that coal-fired power plant closures improve infant health, while also suggesting that the gains may be distributed unevenly across socioeconomic groups. One possible explanation is that lower-income neighbourhoods are more vulnerable to air pollution because of differences in housing quality, baseline health, access to avoidance technologies, or other protective investments. In this case, retiring coal-fired power plants may be especially important for preventing severe outcomes such as very low birth weight and extremely preterm birth.

6.3 Trimester Effects

The baseline birth analysis compares births that were fully gestated while the nearest coal-fired power plant was operating with births conceived after the plant had closed. I next

Table 4: Heterogeneity by Neighbourhood Income

	Lower-Income neighbourhoods (1)	Higher-Income neighbourhoods (2)
Birth weight	29.2172***	50.1121***
	(7.7599)	(8.1643)
Low birth weight	−0.0063***	−0.0069***
	(0.0020)	(0.0020)
Very low birth weight	−0.0026***	−0.0005
	(0.0007)	(0.0006)
Preterm birth	−0.0067**	−0.0053***
	(0.0027)	(0.0019)
Very preterm birth	−0.0024***	−0.0014**
	(0.0007)	(0.0006)
Extremely preterm birth	−0.0013***	−0.0005
	(0.0004)	(0.0004)
Observations	[N]	[N]

NOTES—This table reports heterogeneity in the estimated effect of coal-fired power plant closures by neighbourhood income. Lower-income neighbourhoods are 3-digit postal code areas with median household income below the median within the corresponding city; higher-income neighbourhoods are defined analogously. Columns (1) and (2) report estimates from separate subsamples using the preferred reduced-form specification. Standard errors are clustered and reported in parentheses. Statistical significance is denoted by $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

examine whether the timing of exposure reductions during pregnancy matters. The fetal origins literature suggests that prenatal development is sensitive to environmental conditions and that adverse exposures during specific gestational windows can have persistent effects on infant health (Almond and Currie, 2011). Air pollution may therefore affect birth outcomes through cumulative exposure over the full pregnancy, through exposure during biologically sensitive trimesters, or both.

The coal-fired power plant closure setting provides policy-driven variation in the timing of exposure reductions, making it useful for studying whether effects differ depending on the stage of pregnancy at which the closure occurred. Compared with analyses that rely only on short-run fluctuations in observed pollution, this design is less likely to be driven by avoidance behaviour correlated with contemporaneous pollution levels.

Table 5: Estimated Effects by Trimester of Exposure

	Birth Weight (1)	Low Birth Weight (2)	Preterm Birth (3)
Closure during first trimester	18.6073	−0.0041	−0.0013
	(12.4981)	(0.0045)	(0.0053)
Closure during second trimester	18.6328	0.0018	−0.0049
	(11.2940)	(0.0048)	(0.0052)
Closure during third trimester	14.3951	−0.0074	−0.0060
	(14.5032)	(0.0055)	(0.0078)
Observations	[N]	[N]	[N]

NOTES—This table reports estimates of the effect of coal-fired power plant closures by trimester of exposure among births within 40 km of the nearest plant. The first-, second-, and third-trimester indicators correspond to closures occurring during weeks 0–13, 14–27, and 28–41 of gestation, respectively. The specification follows the preferred reduced-form design. Standard errors are clustered at the CFSA-plant level and reported in parentheses. Statistical significance is denoted by $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

Table 5 reports the estimated effects of coal-fired power plant closures according to the trimester in which the closure occurred for three birth outcomes: birth weight, low birth weight, and preterm birth. The point estimates provide suggestive, though not statistically significant, evidence that closures during pregnancy improved birth outcomes. Closures occurring in each trimester are associated with higher birth weight and a lower incidence of preterm birth. The low-birth-weight estimates are negative for first- and third-trimester closures but small and positive for second-trimester closures. The absence of a clear trimester-specific pattern suggests that the main health gains may reflect cumulative reductions in pollution exposure over pregnancy rather than changes in exposure during a single critical trimester window.

These results should be interpreted cautiously. Because the trimester design divides treated births into narrower exposure windows, the sample size within each window is much smaller than in the main analysis, reducing statistical power. Thus, the lack of statistical significance does not necessarily imply the absence of trimester-specific effects. Rather, the estimates are most consistent with the broader interpretation that reduced exposure to emissions from coal-fired power plants improves infant health, while the available data do

not allow for a precise distinction across gestational timing.

7 Results on Acute Respiratory Disease

I now turn to the analysis of whether the health gains from coal-fired power plant closures extend beyond birth outcomes. Respiratory disease is a natural downstream outcome because emissions from coal-fired power plants directly affect local air quality, and children are especially vulnerable to air pollution during fetal development and early childhood. This analysis also speaks to the fetal origins literature, which emphasizes that early-life health conditions can shape later health and socioeconomic outcomes (Almond and Currie, 2011). While much of the evidence on severe prenatal pollution exposure comes from rare acute events, such as the London smog, less is known about the long-term health effects of large-scale environmental policies. Ontario's coal phase-out provides such a setting.

Table 6: Estimated Effects of Coal-Fired Power Plant Closures on Respiratory hospitalisations

	Respiratory hospitalisations			Placebo hospitalisations	
	Any Acute Respiratory	Acute Bronchiolitis	Acute Croup	Bone Fracture	Acute Appendicitis
	(1)	(2)	(3)	(4)	(5)
Downwind after closure	-0.0104^{***}	-0.0044^{***}	-0.0009^{**}	-0.0001	0.0005
	(0.0018)	(0.0008)	(0.0004)	(0.0008)	(0.0008)
Outcome Mean	0.0479	0.0125	0.0030	–	–
Percent Change	-21.71%	-35.20%	-30.00%	–	–
Observations	[N]	[N]	[N]	[N]	[N]

NOTES—This table reports reduced-form estimates of the effect of coal-fired power plant closures on childhood hospitalisations diagnosed before age 17 within 40 km of the nearest plant. Columns (1)–(3) report respiratory hospitalisation outcomes. Columns (4)–(5) report placebo outcomes that are not expected to respond directly to changes in air pollution. The preferred specification includes CFSA-plant fixed effects, calendar-date fixed effects, and weather controls. Standard errors are clustered at the CFSA-plant level and reported in parentheses. Outcome means are measured over the relevant comparison period. Percent changes are calculated by dividing the treatment estimate by the corresponding outcome mean and multiplying by 100. Statistical significance is denoted by $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

The analysis uses linked hospitalisation records from the DAD and follows children after

birth. Table 6 reports the results. Coal-fired power plant closures reduced acute respiratory hospitalisations by 1.04 percentage points, relative to a baseline mean of 4.79 percent. This corresponds to a 21.7 percent decline. The effects are also negative for more specific respiratory diagnoses. Acute bronchiolitis hospitalisations, which are most common among children younger than two, fell by 0.44 percentage points, or 35.2 percent relative to the mean. Acute croup hospitalisations, which are common among children younger than six, fell by 0.09 percentage points, or 30.0 percent relative to the mean. These estimates indicate that coal-fired power plant closures led to meaningful reductions in childhood respiratory morbidity.

Columns 4 and 5 provide placebo tests using bone fractures and acute appendicitis, outcomes that should not respond directly to changes in air pollution. The estimated effects are small in magnitude and statistically insignificant. This pattern supports the interpretation that the main estimates capture improvements in respiratory health rather than broader changes in hospitalisation patterns or differential trends between downwind and upwind areas.

One caveat is that the estimated effects may reflect both lower prenatal exposure, which could affect fetal development and respiratory-system formation, and lower postnatal exposure, which could directly reduce respiratory illness after birth. The empirical design does not separately identify these two channels, but both are policy-relevant consequences of shutting down nearby coal-fired power plants.

8 Conclusion

This paper studies the health effects of Ontario's coal phase-out, a large-scale retirement of coal-fired power plants between 2005 and 2014. I combine linked administrative birth records, childhood hospitalisation records, family tax files, gridded weather, and modelled air pollution data with plant closure dates and wind direction. I compare newborns near coal-fired power plants who lived in areas that were more versus less frequently downwind of their nearest plant before closure. This approach uses the spatial path of emissions,

rather than distance alone, to identify the health effects of retiring coal-fired power plants. Placebo tests using perpendicular wind exposure and health outcomes that are not expected to respond to emissions support the validity of the research design.

The results show that coal plant closures generated meaningful early-life health gains. In areas within 40 km of the nearest plant, closures reduced SO_2 concentrations in more frequently downwind areas and improved birth outcomes. After closure, moving from the 10^{th}-to-90^{th} percentile of pre-closure downwind exposure was associated with increased birth weight and reduced low birth weight and preterm birth. The declines are proportionally larger for severe outcomes such as very low birth weight and extremely preterm birth, suggesting that the benefits were concentrated among infants at greater health risk. Heterogeneity by neighbourhood income further suggests that retiring coal-fired power plants may be especially important for preventing severe consequences in lower-income neighbourhoods.

The health benefits also extended beyond birth. Coal plant closures reduced acute respiratory hospitalisations during childhood by 1.04 percentage points, or 21.7 percent relative to the baseline mean. hospitalisations for acute bronchiolitis and acute croup also declined, while placebo outcomes such as bone fractures and acute appendicitis did not change. These patterns support the interpretation that the estimates capture improvements in pollution-related child health rather than broader changes in health care use or local trends.

Taken together, the findings indicate that the health costs of coal-fired electricity are economically important even in a relatively low-pollution setting with universal health care in Canada. The results also speak to current energy-policy debates. Delaying coal retirements may preserve generating capacity in the short run, but it also prolongs exposure to emissions that affect fetal development and childhood respiratory health. Thus, retiring coal plants can produce local health gains that are realized quickly and that are especially relevant for communities most exposed to emissions. Accounting for these early-life benefits is therefore central to evaluating the full benefits of clean-electricity transitions.

References

Almond, Douglas, and Janet Currie 2011. "Killing me softly: The fetal origins hypothesis." *Journal of Economic Perspectives* 25 (3): 153–172.

Anderson, Michael 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.

Basu, Rupa, Maria Harris, Lillian Sie, Brian Malig, Rachel Broadwin, and Rochelle Green 2014. "Effects of fine particulate matter and its constituents on low birth weight among full-term infants in California." *Environmental Research* 128, 42–51.

Black, Sandra E., Paul J. Devereux, and Kjell G. Salvanes 2007. "From the Cradle to the Labor Market? The Effect of Birth Weight on Adult Outcomes." *Quarterly Journal of Economics* 122 (1): 409–439.

Bobak, Martin 2000. "Outdoor air pollution, low birth weight, and prematurity." *Environmental Health Perspectives* 108 (2): 173–176.

Borusyak, Kirill, Xavier Jaravel, and Jann Spiess 2024. "Revisiting Event-Study Designs: Robust and Efficient Estimation." *The Review of Economic Studies* 91 (6): 3253–3285.

Burney, Jennifer A. 2020. "The downstream air pollution impacts of the transition from coal to natural gas in the United States." *Nature Sustainability* 3 (2): 152–160.

Callaway, Brantly, and Pedro H. C. Sant'Anna 2021. "Difference-in-differences with multiple time periods." *Journal of Econometrics* 225 (2): 200–230.

Casey, Joan A., Jason G. Su, Lucas R. F. Henneman et al. 2020. "Improved Asthma Outcomes Observed in the Vicinity of Coal Power Plant Retirement, Retrofit and Conversion to Natural Gas." *Nature Energy* 5 (5): 398–408.

de Chaisemartin, Clément, and Xavier D'Haultfœuille 2020. "Two-way fixed effects estimators with heterogeneous treatment effects." *American Economic Review* 110 (9): 2964–2996.

——— 2024. "Difference-in-differences estimators of intertemporal treatment effects." *The Review of Economics and Statistics*, 1–45.

Chay, Kenneth Y., and Michael Greenstone 2003. "The impact of air pollution on infant mortality: Evidence from geographic variation in pollution shocks induced by a recession." *The Quarterly Journal of Economics* 118 (3): 1121–1167.

Clay, Karen, Joshua Lewis, and Edson Severnini 2024. "Canary in a coal mine: Infant mortality and tradeoffs associated with mid-20th century air pollution." *The Review of Economics and Statistics* 106 (3): 698–711.

Copernicus Climate Change Service 2024. "ERA5 post-processed daily-statistics on single levels from 1940 to present." 10.24381/cds.4991cf48, Accessed on 15-Jan-2026.

Currie, Janet, Lucas Davis, Michael Greenstone, and Reed Walker 2015. "Environmental health risks and housing values: Evidence from 1,600 toxic plant openings and closings." *American Economic Review* 105 (2): 678–709.

Currie, Janet, and Matthew 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, Janet, Matthew Neidell, and Johannes F. Schmieder 2009. "Air pollution and infant health: Lessons from New Jersey." *Journal of Health Economics* 28 (3): 688–703.

Currie, Janet, and Reed Walker 2011. "Traffic congestion and infant health: Evidence from E-ZPass." *American Economic Journal: Applied Economics* 3 (1): 65–90.

Dadvand, Payam, Jennifer Parker, Michelle L. Bell, Matteo Bonzini, Michael Brauer, Lyndsey A. Darrow et al. 2013. "Maternal exposure to particulate air pollution and term birth weight: A multi-country evaluation of effect and heterogeneity." *Environmental Health Perspectives* 121 (3): 367–373.

Deryugina, Tatyana, Garth Heutel, Nolan H. Miller, David Molitor, and Julian Reif 2019. "The mortality and medical costs of air pollution: Evidence from changes in wind direction." *American Economic Review* 109 (12): 4178–4219.

Deschênes, Olivier, Michael Greenstone, and Joseph S. Shapiro 2017. "Defensive investments and the demand for air quality: Evidence from the NOx Budget Program." *American Economic Review* 107 (10): 2958–2989.

Dominici, Francesca, Roger D. Peng, Michelle L. Bell, Luu Pham, Aidan McDermott, Scott L. Zeger, and Jonathan M. Samet 2006. "Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases." *JAMA* 295 (10): 1127–1134.

Figlio, David, Jonathan Guryan, Krzysztof Karbownik, and Jeffrey Roth 2014. "The Effects of Poor Neonatal Health on Children's Cognitive Development." *American Economic Review* 104 (12): 3921–3955.

Fraenkel, Rebecca, Josh Graff Zivin, and Sam Krumholz 2024. "The coal transition and its implications for health and housing values." *Land Economics* 100 (1): 51–65.

García-Portugués, Eduardo, Rosa M. Crujeiras, and Wenceslao González-Manteiga 2013. "Exploring wind direction and SO_2 concentration by circular–linear density estimation." *Stochastic Environmental Research and Risk Assessment* 27 (5): 1055–1067.

Goodman-Bacon, Andrew 2021. "Difference-in-differences with variation in treatment timing." *Journal of Econometrics* 225 (2): 254–277.

Hansen-Lewis, Jamie, and Michelle Marcus 2025. "Uncharted Waters: Effects of Maritime Emission Regulation." *American Economic Journal: Economic Policy* 17 (1): 37–69.

von Hinke, Stephanie, and Emil N. Sørensen 2023. "The long-term effects of early-life pollution exposure: Evidence from the London smog." *Journal of Health Economics* 92, 102827.

Knittel, Christopher R., Douglas L. Miller, and Nicholas J. Sanders 2016. "Caution, drivers! Children present: Traffic, pollution, and infant health." *The Review of Economics and Statistics* 98 (2): 350–366.

Komisarow, Sarah, and Emily L. Pakhtigian 2022. "Are power plant closures a breath of fresh air? Local air quality and school absences." *Journal of Environmental Economics and Management* 112, 102569.

Lin, Chih-Ming, Chung-Yi Li, Guang-Yang Yang, and I-Fang Mao 2004. "Association between maternal exposure to elevated ambient sulfur dioxide during pregnancy and term low birth weight." *Environmental Research* 96 (1): 41–50.

Luechinger, Simon 2014. "Air pollution and infant mortality: A natural experiment from power plant desulfurization." *Journal of Health Economics* 37, 219–231.

Ontario Ministry of Energy 2013. "2013 Long-Term Energy Plan: Achieving Balance." https://www.ontario.ca/document/2013-long-term-energy-plan, Archived Government of Ontario report.

Oreopoulos, Philip, Mark Stabile, Randy Walld, and Leslie L. Roos 2008. "Short-, Medium-, and Long-Term Consequences of Poor Infant Health: An Analysis Using Siblings and Twins." *Journal of Human Resources* 43 (1): 88–138.

Ostro, Bart, Lindsey Roth, Brian Malig, and Melanie Marty 2009. "The effects of fine particle components on respiratory hospital admissions in children." *Environmental Health Perspectives* 117 (3): 475–480.

Pan, Siyu 2023. "Health, air pollution, and location choice." *Journal of Environmental Economics and Management* 119, 102794.

Pedersen, Marie, Lise Giorgis-Allemand, Claire Bernard, Inmaculada Aguilera, Anne-Marie Nybo Andersen, Ferran Ballester et al. 2013. "Ambient air pollution and low birthweight: A European cohort study (ESCAPE)." *The Lancet Respiratory Medicine* 1 (9): 695–704.

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

Schlenker, Wolfram, and W. Reed Walker 2016. "Airports, air pollution, and contemporaneous health." *The Review of Economic Studies* 83 (2): 768–809.

Sunyer, Jordi, Richard Atkinson, Ferran Ballester et al. 2003. "Respiratory effects of sulphur dioxide: A hierarchical multicity analysis in the APHEA 2 study." *Occupational and Environmental Medicine* 60 (8): e2.

Tanaka, Shinsuke 2024. "Blowin' in the wind: Long-term downwind exposure to air pollution from power plants and adult mortality." *Journal of Environmental Economics and Management* 128, 103072.

Tanaka, Shinsuke, Kensuke Teshima, and Eric Verhoogen 2022. "North-south displacement effects of environmental regulation: The case of battery recycling." *American Economic Review: Insights* 4 (3): 271–288.

Thanh, Nguyen Xuan, Jennifer Toye, Anamaria Savu, Manoj Kumar, and Padma Kaul 2015. "Health service use and costs associated with low birth weight—A population level analysis." *The Journal of Pediatrics* 167 (3): 551–556.e3.

U.S. Energy Information Administration 2026. "U.S. coal-fired generating capacity retired in 2025 was the least in 15 years." Today in Energy, https://www.eia.gov/todayinenergy/detail.php?id=67427, April 13, 2026. Accessed July 11, 2026.

U.S. Environmental Protection Agency 2017. "Integrated Science Assessment (ISA) for Sulfur Oxides – Health Criteria." Technical ReportEPA/600/R-17/451, U.S. Environmental Protection Agency, Washington, DC: https://www.epa.gov/isa/integrated-science-assessment-isa-sulfur-oxides-health-criteria.

US EPA 2021. "EQUATESv1.0: Emissions, WRF/MCIP, CMAQv5.3.2 Data – 2002-2019 US_12km and NHEMI_108km." 10.15139/S3/F2KJSK, Dataset; accessed 15-Jan-2026. Used for the 12US1 CONUS 12-km domain, 299 rows x 459 columns x 35 layers.

Ward, Courtney J. 2015. "It's an ill wind: The effect of fine particulate air pollution on respiratory hospitalizations." *Canadian Journal of Economics* 48 (5): 1694–1732.

Yang, Muzhe, Rhea A. Bhatta, Shin-Yi Chou, and Cheng-I Hsieh 2017. "The impact of prenatal exposure to power plant emissions on birth weight: Evidence from a Pennsylvania power plant located upwind of New Jersey." *Journal of Policy Analysis and Management* 36 (3): 557–583.

Yang, Muzhe, and Shin-Yi Chou 2018. "The impact of environmental regulation on fetal health: Evidence from the shutdown of a coal-fired power plant located upwind of New Jersey." *Journal of Environmental Economics and Management* 90, 269–293.

Zheng, Xue-Yan, Pablo Orellano, Hua-Liang Lin, Mei Jiang, and Wei-Jie Guan 2021. "Short-term exposure to ozone, nitrogen dioxide, and sulphur dioxide and emergency department visits and hospital admissions due to asthma: A systematic review and meta-analysis." *Environment International* 150, 106435.

A Online Appendix

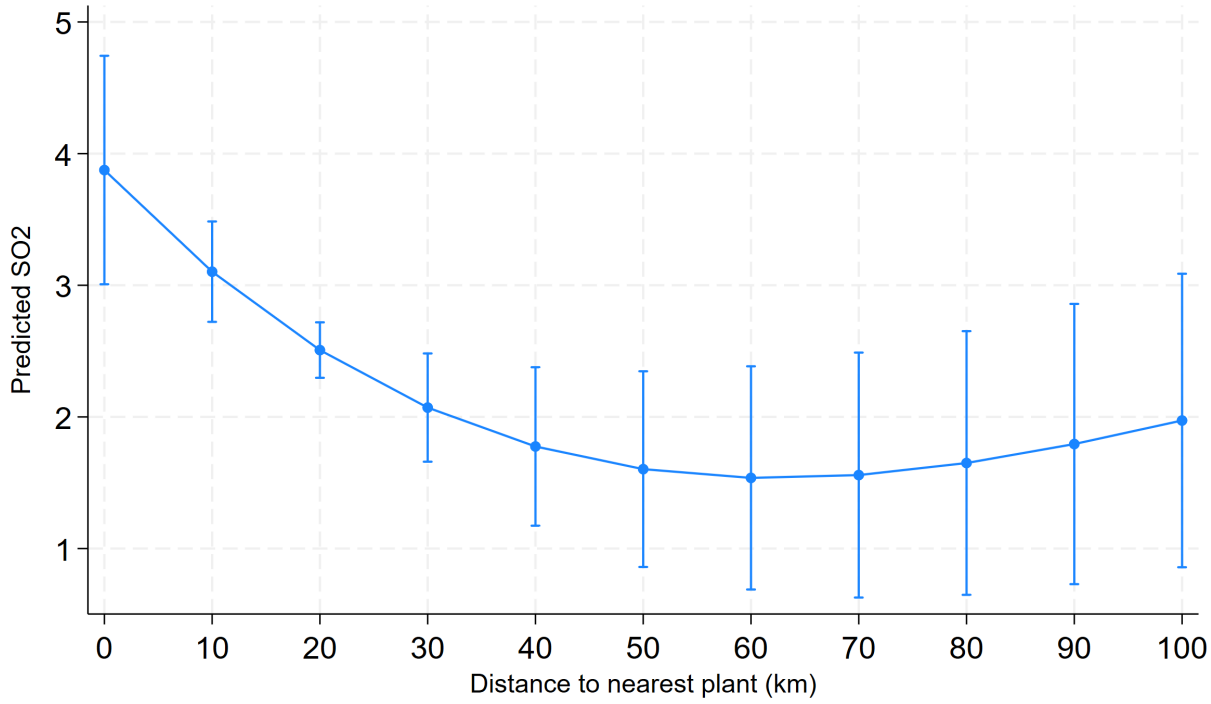
A.1 Selection of the 40-Kilometre Distance Threshold

There is no single distance threshold used in the literature on pollution from point sources to estimate the impacts of emissions on health and birth outcomes. The appropriate radius depends on how far the relevant emissions travel. For ground-level industrial sources, impacts are extremely local: Currie et al. (2015) find that the housing-value and infant-health effects of more than 1,600 toxic plants are concentrated within about one mile (1.6 kilometres) of the plant. Coal-fired power plants, in contrast, release emissions from tall stacks, so emissions disperse and touch down far from the source, generating measurable exposure over tens of kilometres. Yang and Chou (2018) find fetal-health effects of a Pennsylvania coal plant in downwind ZIP codes up to roughly 60 miles (95 kilometres) away.

Figure A1 plots predicted SO_2 concentrations from a regression of monitor-based SO_2 readings on a cubic polynomial of the distance between the monitor and the nearest coal-fired power plant. Predicted concentrations fall steeply over the first 40 kilometres, declining by more than half from roughly 3.9 parts per billion at the plant to about 1.8 ppb at 40 kilometres, and are essentially flat between 40 and 70 kilometres. Predictions beyond roughly 70 kilometres are imprecise, reflecting the small number of monitors at those distances. The figure therefore indicates that coal-related SO_2 mostly travels for approximately 40 kilometres before reacting or disappearing, consistent with the relatively short atmospheric lifetime of SO_2 and its oxidation into sulphate particulates during transport. The 40-kilometre threshold also retains most of the population, as more than half of Ontario residents live within 40 kilometres of a coal-fired power plant. In robustness checks, I re-estimate the main specifications using alternative distance thresholds of 20, 30, 50, and 60 kilometres to confirm that the results are not driven by this choice.

A.2 Additional Tables and Figures

Figure A1: Predicted SO_2 Concentrations by Distance to the Nearest Coal-Fired Power Plant



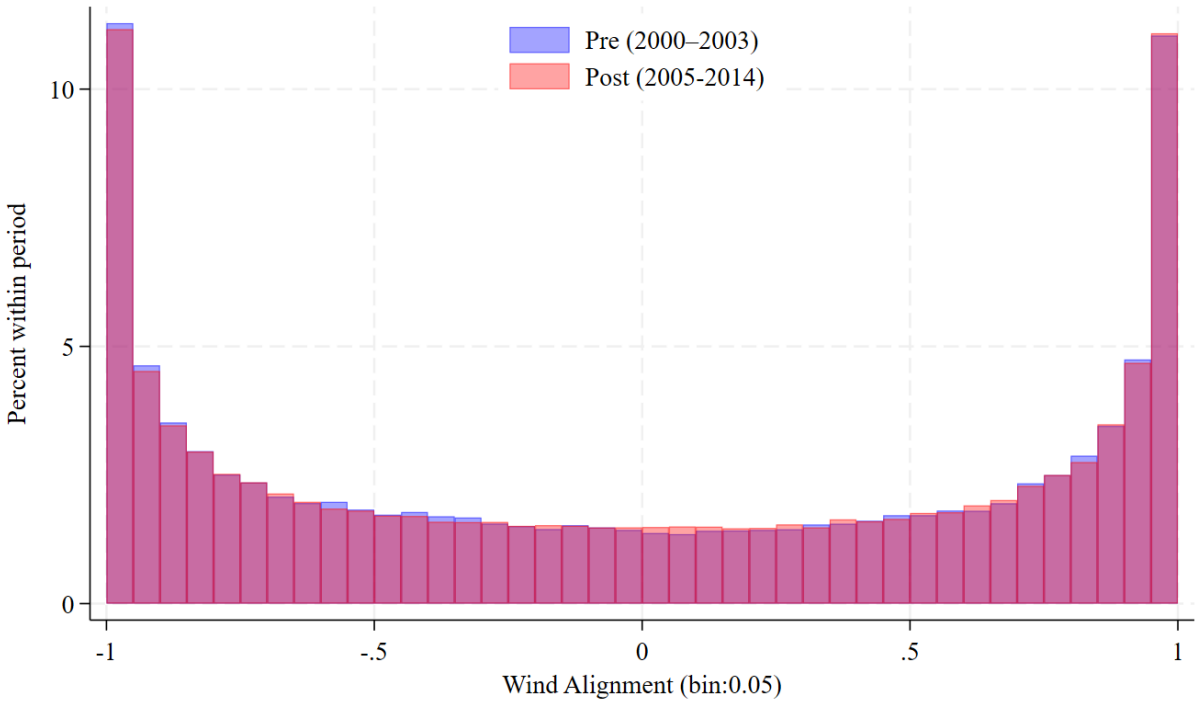
Notes: This figure plots predicted daily SO_2 concentrations (in parts per billion) from a regression of monitor-level SO_2 concentrations on a cubic polynomial of the distance between the monitor and the nearest coal-fired power plant, using Ontario air-quality monitor data from 1996 to 2019. Dots show predictions at 10-kilometre intervals; vertical bars are 95 percent confidence intervals.

Table A1: Correlation Between Weather Station Data and ERA5-Derived Data

Variable	Correlation
Temperature	0.996
Dew point	0.995
Wind direction	0.770
Wind speed	0.713
Precipitation vs. relative humidity	0.413
Downwind share measure	0.937

NOTES—This table reports correlations between monitor-based weather data and ERA5-derived data at the daily level. The upper panel compares individual weather variables. The precipitation row compares observed precipitation with ERA5-derived relative humidity, which is not the same definition. The lower panel compares the downwind share measure used in the empirical strategy, computed separately from monitor-based weather data and from ERA5-derived data.

Figure A2: Distribution of Daily Wind Alignment Before and After the Coal Phase-Out



Notes: The figure plots the distribution of the daily wind-alignment measure between each CFSA and its nearest coal-fired power plant, in bins of 0.05, separately for the pre-closure (2000–2003) and post-closure (2005–2014) periods. Ontario lies in the prevailing-westerlies zone, where winds blow predominantly from west to east. The two distributions are nearly identical, indicating that wind-alignment patterns did not change before and during the phase-out period.