Are Power Plant Closures a Breath of Fresh Air? Local Air Quality and School Absences

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March 12, 2021

Abstract

In this paper we study the effects of three large, nearly-simultaneous coal-fired power plant closures on school absences in Chicago. We find that the closures resulted in a 7 percent reduction in absenteeism in nearby schools relative to those farther away following the closures. For the typical elementary school in our sample, this translates into around 372 fewer absence-days per year in the aggregate, or around 0.71 fewer annual absences per student. We find that reductions in absences were larger in schools where pre-closure exposure to coal-fired power plants was more intense: namely, schools with low levels of air conditioning, schools more frequently in the wind path of the plants, and non-magnet (i.e., neighborhood) schools where students were more likely to live nearby. To explore potential mechanisms responsible for these absence reductions we investigate the effects of the closures on housing values and children's respiratory health. We do not find statistical evidence of endogenous migration into neighborhoods near the coal-fired power plants following the closures but do find declines in emergency department visits for asthma-related conditions among school-age children.

Keywords: Coal-fired power plants; Children; School absences
JEL codes: I10; I21; Q53

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1 Introduction

Despite dramatic declines in coal consumption and record numbers of coal-fired power plant closures in the United States (U.S.), coal continues to account for nearly one-quarter of the country's electricity-generating fuel portfolio (MacIntyre and Jell, 2018; Mobilia and Comstock, 2019; Johnson and Chau, 2019; EIA, 2019). The burning of coal emits air pollution, including pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM). Although a growing literature in economics examines the effects of exposure to these and other specific pollutants – either in isolation or simultaneously – on human health and birth outcomes, little is known about the effects of the cumulative exposure to coal-fired power plants on children.[1]

Exposure to coal-fired power plants may be more harmful to children's health and well-being than what previous evidence from the air pollution literature suggests for three reasons. First, in addition to plant emissions, other activities surrounding coal-fired power plants – including coal transport, storage, by-product, and disposal – negatively affect local air quality (Jha and Muller, 2018; Zierold and Odoh, 2020). Second, coal-fired power plants are known emitters of a host of pollutants – including mercury and other heavy metals – that have been shown to negatively affect children's health (Bose-O'Reilly et al., 2010) but that are typically not measured in emissions inventories nor by air quality monitors. Omitted measures of these pollutants could bias estimates of the effects of coal-fired power plants that are solely based on measured pollutants, particularly if unmeasured pollutants have different dispersion patterns or half-lives. Finally, children are potentially more vulnerable to the negative effects of exposure to air pollution than are adults due to their (immature) developmental status, breathing patterns, time spent outdoors, and time spent in activities that raise ventilation (breathing) rates (Gauderman et al., 2004; Schwartz, 2004; Bateson and Schwartz, 2007).

[1] We are aware of two studies that have examined the impacts of coal-fired power plant shut downs on infant health. See Yang et al. (2017) and Yang and Chou (2018).

In this paper, we address this gap in the literature by estimating the effect of exposure to coal-fired power plants on children in the short- and medium-run. We do this by exploiting a unique and previously unexplored context: public elementary schools' proximities to operational coal-fired power plants. This context has the advantages of providing a setting where children spend a substantial amount of time each day (second in terms of average minutes only following time spent sleeping) (U.S. Environmental Protection Agency, 2008) and in which a proxy for children's health status is widely and uniformly measured among the population of public school children (absences from school) (Weitzman, 1986; Currie et al., 2009). This context also allows for in-depth examination of a potential mechanism – school absences – that could help to explain existing evidence on the short-run effects of air pollution exposure on student achievement and long-run effects on educational attainment and earnings.[2]

We exploit variation induced by the closures of three large coal-fired power plants that were located in, or in close proximity to, Chicago, Illinois. During a six-month period in 2012, the Crawford, Fisk Street, and State Line Generating Stations all closed abruptly after decades of continuous operations. We use this natural experiment to estimate the effect of exposure to coal-fired power plants on school absences using data from fifteen Illinois school districts. This unique setting allows us to sharply identify short- and medium-term impacts on children who attended schools near the three coal-fired power plants. This natural experiment provides an ideal setting in which to study the effects of exposure to coal-fired power plants on school absences because the power plant closures were unexpected, induced large changes in local air quality, and had negligible impacts on employment in the Chicago area.

Using difference-in-differences and event-study approaches, we find that school-level rates of absences decreased by around 0.395 percentage points (7 percent) in schools located near the plants (within 10 kilometers) following the closures. In more readily interpretable units,

[2]See for example, Ebenstein et al. (2016), Gilraine (2020), Sanders (2012), and Isen et al. (2017).

this reduction translates into around 372 fewer absence-days annually for the typical-sized (median) treated elementary school in our sample, or around 0.71 fewer absence-days per student per year. For several reasons we discuss later, we believe this estimate is likely to be a lower bound of the effect. In addition to our results overall, we also investigate effects on absences for student subgroups. We consistently find evidence to suggest that absence reductions were larger for boys than for girls, which we believe to be consistent with descriptive evidence on boys' heightened underlying vulnerability (e.g., due to rates of diagnosed asthma, activity patterns, etc.). We find weaker evidence to suggest that absence reductions were larger for black students than for Hispanic students, although our estimates for subgroups by race/ethnicity are less precise and more sensitive to model specification.

To provide evidence supporting the internal validity of our estimated effects on absences, we investigate treatment heterogeneity based on the intensity of pre-closure exposure to coal-fired power plants within our group of treated schools. *Ex ante* we expected larger effects (in absolute terms) in schools where pre-closure exposure was higher (i.e., more intense). To explore this, we partitioned our treatment group of schools using three distinct measures to characterize "high" versus "low" exposure: wind intensity, air conditioning, and magnet status. Our three separate approaches yielded a pattern of results that was remarkably consistent: Reductions in absences were larger in schools with higher exposure. This exercise lends credibility to our identification strategy by ruling out that the possibility that schools near the plants were affected by unmeasured positive shocks to school quality, student enrollment, or other unobservables that improved student outcomes independently and that were correlated with distance from the plants.

To gain insight into the specific mechanisms underlying our estimated effects on school absences, we consider two possibilities suggested by previous literature: Endogenous migration of higher-income families to areas near the coal-fired power plants following their closures (mediated through housing prices) and improvements in children's respiratory health. We explore the possibility that higher-income (or otherwise socioeconomically advantaged) families moved into neighborhoods near the coal-fired power plants following their closures by examining housing values and the characteristics of students enrolled in nearby schools. We also explore the effects of the closures on children's respiratory health by examining whether rates of emergency department visits for asthma-related conditions among school-age children responded to the closures. We do not find any statistical evidence of endogenous migration, but we do find large and meaningful reductions in emergency department visits for asthma-related conditions among school-age children in areas near the three plants.

This paper contributes to the emerging literature on the effects of exposure to coal-fired power plants and produces estimates that capture the full extent to which exposure to the operations of coal-fired power plants affect children's health. A final contribution of this work is to examine the question of how exposure to coal-fired power plants affects children in a setting that has historically been characterized by inequality. It is well-documented in public health and environmental literatures that low-income and minoritized groups bear disproportionate burdens of exposure to poor air quality in the U.S.[3] We document that this phenomenon extends to the locations of public schools. In 2016, approximately 2.3 million elementary school children – in kindergarten through eighth grade – attended a public school located within 10 kilometers of an operational coal-fired power plant (around 7 percent of the public school population in this age range).[4] Among these 2.3 million children, 81 percent were eligible for free/reduced-price lunch, which is a proxy for low family income.[5] The context of our study, which we describe in more detail below, mirrors this national pattern. Our paper sheds light on an important issue in a setting that disproportionately affects children from disadvantaged backgrounds and, therefore, explores potential ways to reduce entrenched inequality.

[3]Recent examples of this work include Colmer et al. (2020), Hausman and Stolper (2020), and Richmond-Bryant et al. (2020).

[4]See Appendix Figure A1.

[5]Authors' calculations. Please see Appendix B.

2 Background

2.1 Air Pollution, Children's Health, and School Absences

Compared to adults, children are more susceptible to harm from exposure to air pollution because of their unique and ongoing physical development and because of their activity patterns. Children's lungs and immune systems are less developed than adults'. This may influence the penetration of fine particles within the lungs (when inhaled) and make them more vulnerable to permanent damage (Bateson and Schwartz, 2007; World Health Organization, 2011). Aside from developmental differences, children also breathe differently than adults, which increases their vulnerability. While adults commonly breathe through their noses (nasal breathing), children often breathe through their mouths (oral breathing). Oral breathing provides less air filtration and thus increases exposure, even when adults and children are in the same ambient environment (Bateson and Schwartz, 2007; Foos et al., 2007). Even conditional on nasal breathing – which increases as children age – children's noses may be less effective at air filtration due to differences in the anatomical structures of the nasal passage (Foos et al., 2007). A final difference comes from potentially higher rates of deposition of particles into the lower respiratory tract of the lungs, due to childhood conditions such as obesity, hay fever (allergic rhinitis), and asthma (Foos et al., 2007).

Children's activity patterns may also increase their exposure to air pollution. Children spend more time outdoors than adults and more often participate in activities likely to increase ventilation (breathing) rates. Both of these factors increase children's exposure to air pollution (Klepeis et al., 2001; Schwartz, 2004; Bateson and Schwartz, 2007). Among children, time spent outdoors is highest among children ages 6-11, suggesting heightened vulnerability of elementary school-age children relative to their older or younger peers (U.S. Environmental Protection Agency, 2008).

Existing research on the effects of exposure to air pollution on school absences has examined the question in variety of settings and using different measures of exposure, thus producing a wide range of estimates. Using changes in air quality resulting from a steel mill shutdown, Ransom and Pope (1992) estimated that a 100 microgram per cubic meter (μg/m^3) increase in monthly average PM_{10} was associated with a 2 percentage point (40 percent) increase in rates of school absences. They further found that effects on absences were larger for younger students relative to older students and that the effects persisted for several weeks. Building on this work, Currie et al. (2009) developed a framework to consider exposure to multiple pollutants including carbon monoxide (CO) and ozone (O_3) in addition to PM_{10}. Using data from elementary and middle schools in thirty-nine school districts in Texas, the authors found that for CO, one additional day of high exposure increased absences by between 5 and 9 percentage points.

In recent work, Heissel et al. (2019) leveraged student school transitions to "upwind" versus "downwind" schools near highways. They found that when students transitioned to a downwind school, their absence rate increased by 0.5 percentage points (a 10 percent increase relative to baseline), although this effect was only marginally statistically significant. Austin et al. (2019) exploited variation in school bus retrofitting, which dramatically reduces diesel emissions of nitrogen oxides (NO_x) and fine particulates ($PM_{2.5}$). They did not find any statistically significant effects of retrofitting on attendance rates.

Two additional recent papers investigate the effect of exposure to particulate matter on student absences in China, where air pollution levels are typically much higher than those observed in the U.S. Chen et al. (2018) used an instrumental variables framework to assess the effect of exposure to air pollution on absences in Guangzhou City. Using temperature inversions as an instrument for air quality, the authors found that a one standard deviation increase in daily Air Quality Index (AQI) levels lead to a 7 percent increase in absence rates. Using information on reasons for absences, they found that absences on days with poor air quality were mostly driven by increases in respiratory-related conditions, suggesting the importance of short-run health channels. Consistent with this work, Liu and Salvo (2018) found that increased exposure to $PM_{2.5}$ led to increases in absences among students enrolled in international schools in a major urban center in north China. They found that lagged daily average $PM_{2.5}$ levels in excess of 200 $\mu g/m^3$ increased the likelihood of student absenteeism by 0.9 percentage points (14 percent).

2.2 Coal-Fired Power Plant Closures and Changes in Air Quality

Between March and August of 2012, three large, coal-fired power plants located in (or on the border of) Chicago, Illinois were unexpectedly closed, leading to significant changes in local air quality. The Crawford and Fisk Street Generating Stations were located in Chicago – on the south branch of the Chicago River – while the State Line Generating Station was located in Hammond, Indiana, directly adjacent to the Illinois state (and Chicago city) line (Lydersen, 2012). The locations of the three coal-fired power plants are depicted in Figure 1.

In March 2012, the State Line Generating Station closed unexpectedly, in advance of a previously announced closure date of 2014 (Tweh, 2010; Saltanovitz, 2011; Schneider Kirk, 2012). Six months later, in August 2012, the Crawford and Fisk Street Generating Stations also closed unexpectedly and in advance of previously announced timelines. The parent company cited an inability to make the financial investments necessary to upgrade pollution control technologies and ongoing negotiations with environmental groups and state regulators regarding the company's portfolio of power plants across the state (Wernau, 2012b). In the months leading up to their unexpected closures, all three plants were operating regularly.[6] Further, at the time of the closures, the three coal-fired power plants collectively employed around 280 workers, a negligible share of total employment in the Chicago metropolitan area (Lydersen, 2012; Wernau, 2012c).

Prior to their closures, the Crawford, Fisk Street, and State Line Generating Stations were among some of the largest operational coal-fired power plants in the U.S. The plants were in the 70th (State Line), 69th (Crawford), and 59th (Fisk Street) percentiles of the coal-

[6]See Appendix Figure A2, in which we plot the time series of monthly capacity factors separately for each plant between 2008-2012.

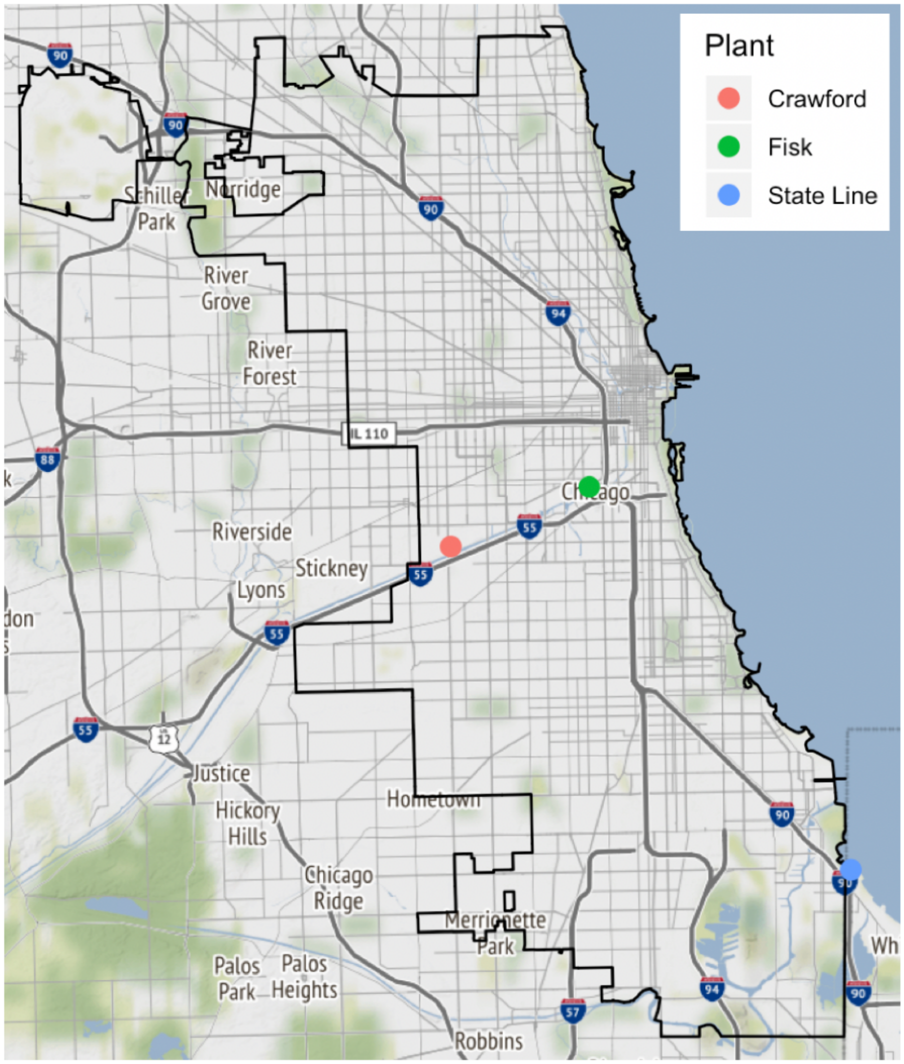


Figure 1: Locations of Three Coal-Fired Power Plants

Notes: Locations of the Crawford, Fisk Street, and State Line Generating Stations. The city limits of Chicago, Illinois are outlined in black.

fired power plant capacity distribution in 2009.[7] During their years in operation, the three plants underwent modifications to add pollution controls, particularly for nitrogen oxide (a precursor to ozone) and mercury (Laasby, 2010b; Wernau, 2012a; Hawthorne, 2012). Despite these efforts, however, there were limitations on what could be added – particularly in the cases of the Crawford and Fisk Street Generating Stations – due to the constrained sizes

[7]Authors' calculations using 2009 data from the U.S. Energy Information Association (EIA) Form EIA-860.

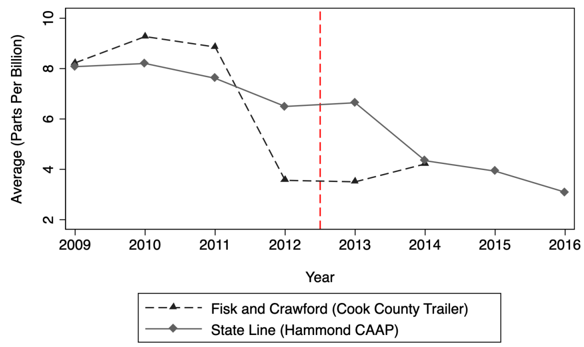
(and locations) of the plants' physical sites (Wernau, 2012a). This meant that prior to their closures, the three plants were among some of largest emitters of pollutants in the U.S. (Laasby, 2010a; Hawthorne, 2010a; Wernau, 2011).[8]

Comparisons of air quality data in Chicago from the years before and after the three coal-fired power plant closures reveal evidence of declines in concentrations of sulfur dioxide (SO_2), fine particulates ($PM_{2.5}$), and Nitrogen Dioxide (NO_2). In Figure 2 we plot annual concentrations of SO_2, $PM_{2.5}$, and NO_2 using averaged daily data from the air quality monitoring station closest to each of the three plants (note: all three coal-fired power plants operated for at least part of the year in 2012).[9] Averaging the annual data in the years before (2008-2011) and after the three coal-fired power plant closures (2013-2016) reveals that SO_2 declined by 4.09 parts per billion, $PM_{2.5}$ declined by 2.29 $\mu g/m^3$, and NO_2 declined by 5.64 parts per billion.

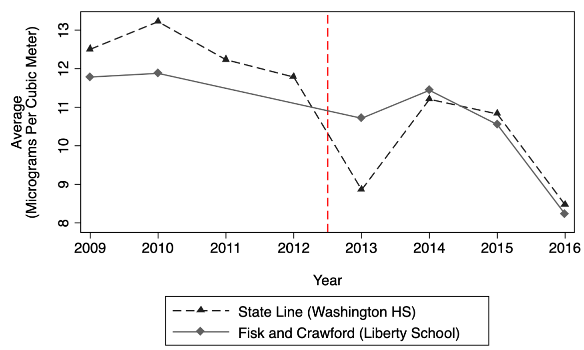
Although these changes cannot solely be attributed to the three coal-fired power plants, the descriptive evidence does suggest that average air quality improved during the period following their closures. The magnitudes of these estimates are in line with estimates reported in previous literature on the topic of coal-fired power plant closures. Using data from 12 air quality monitoring stations in the Pittsburgh area (2500 square miles), Russell et al. (2017) estimated $PM_{2.5}$ reductions between 0.94-1.00 $\mu g/m^3$. Jaffe and Reidmiller (2009) estimated that a coal-fired power plant in the Columbia River Gorge contributed to annual ambient concentrations of $PM_{2.5}$ on the order of 0.90 $\mu g/m^3$. Using a simple difference-in-differences approach and studying the same three coal-fired power plants in Chicago, Komisarow and Pakhtigian (2021) estimated that $PM_{2.5}$ concentrations decreased by between 0.21-0.34 $\mu g/m^3$ *more* in areas near the three coal-fired power plants relative to areas farther

[8] A federal lawsuit against Midwest Generation – the owner of the Crawford and Fisk Street Generating Stations – accused the company of unfairly avoiding the installation of additional pollution control technologies on their plants (Hawthorne, 2005, 2007, 2010b).

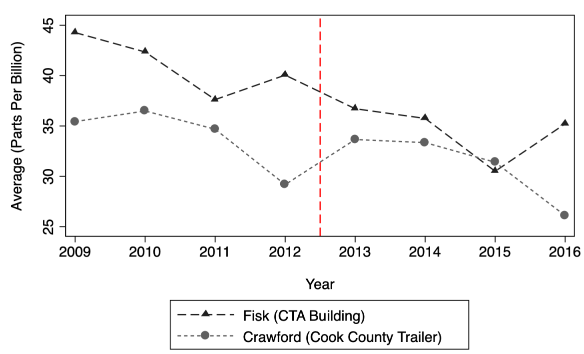
[9] In some cases, a single station was the closest for two plants and in other cases there was no air quality monitoring station that was within 15 kilometers with consistent data for the entire period. See Appendix B for more detail on the air quality monitoring stations used for these calculations and their respective distances to each of the three coal-fired power plants.



(a) Sulfur Dioxide (SO_2)



(b) Fine Particulates ($PM_{2.5}$)



(c) Nitrogen Dioxide (NO_2)

Figure 2: Average Annual Concentrations of Sulfur Dioxide, Fine Particulates, and Nitrogen Dioxide Based on Data from Air Quality Monitoring Stations Near the Crawford, Fisk Street, and State Line Generating Stations

Notes: The panels in this figure depict annual average concentrations of Sulfur Dioxide, Fine Particulates, and Nitrogen Dioxide using readings from the air quality monitoring stations closest to the Crawford, Fisk Street, and State Line Generating Stations. For more detail on the air quality monitoring stations and their distances to the coal-fired power plants, please see Appendix B.

away.

3 Data

3.1 School Data and Analytic Sample

We obtained information on school absences and other student characteristics aggregated at the school-level for all public elementary schools (covering grades K-8) in Illinois from the Illinois State Board of Education (ISBE) Report Card Data Library.[10] Our primary outcome in this paper is the annual aggregate absence rate at the school-level for students overall and for student subgroups. From the ISBE Report Card Data Library we also obtained the following time-varying school characteristics: total enrollment, percent black, percent Hispanic, and percent low-income. From district webpages, we obtained information on two time-varying policy controls relevant to public elementary schools in Chicago Public Schools (CPS) – the largest district in our sample – during this period: Safe Passage Program status (0/1) and Welcoming School status (0/1). These programs were introduced at a select number of public elementary schools in CPS following the mass closings in CPS at the end of the 2012/13 school year. For more information on the ISBE Report Card Data Library, see Appendix B.

To define our sample and partition schools into treatment and control groups, we obtained addresses for each traditional public elementary school in Illinois from annual published versions of the state's Directory of Educational Entities.[11] We geocoded all addresses and then merged these with school-level information from the ISBE Report Card Data Library. We then calculated the linear distance between each school's location and each of the three

[10] These data are publicly-available here: https://www.isbe.net/ilreportcarddata.

[11] The Illinois Directory of Educational Entities is available here: https://www.isbe.net/Pages/Data-Analysis-Directories.aspx. It contains information on all public entities that provide educational services to K-12 students in Illinois. The directory is updated continuously; snapshots are preserved each school year. The Illinois State Board of Education (ISBE) was unable to provide a snapshot for the 2015/16 school year, however, so we imputed school addresses for this school year based on the address listed in the previous school year.

power plants.

To define our analytic sample, we restricted our attention to the fifteen school districts in Illinois that had at least one traditional public elementary school located within 10 kilometers of at least one of the three coal-fired power plants. This resulted in a balanced panel of 457 traditional public elementary schools from fifteen school districts in Illinois (for a list of districts, please see Appendix B). We dropped traditional public elementary schools that changed locations at any point during the 2008/09-2015/16 school years, charter schools, and any schools that newly opened or closed during this time period. Approximately 85 percent of the schools in our sample came from one school district: Chicago Public Schools (CPS). CPS is the third largest school district in the U.S. and the single largest school district in Illinois. CPS schools account for roughly 18 percent of schools and 25 of student enrollment at the elementary school level in Illinois.[12]

3.2 Defining Treatment and Control Groups

In our main specifications, we defined schools as treated if they were located within 10 kilometers of at least one of the three coal-fired power plants; all other schools within the fifteen districts were then designated as controls. All districts contained at least one treated school and at least one control school. Although some papers in the air pollution literature have selected smaller (1-mile) distance thresholds to partition treatment and control groups (e.g., Currie et al. (2015) and Persico and Venator (2019)), these papers differ from ours both in terms of the types of industrial facilities examined and the pollutants studied. Their approaches to estimating the typical distance over which air pollution disperses relied on data from thousands of industrial sources and hundreds of air quality monitoring stations across much larger geographic areas (e.g., an entire state or multiple states). Given our context, which relies on three coal-fired power plants and occurs in a setting with fewer than 20 air quality monitoring stations, we were unable to implement a similar approach.

[12] Authors' calculations from the 2008/09 school year.

Instead, we chose a distance of 10 kilometers to divide treatment versus control schools in our sample because it is the median distance in our fifteen district sample of elementary schools. This distance likely *underestimates* the airborne distance that coal-fired power plant emissions can travel. For example, in a recent paper examining the effects of exposure to coal-fired power plants on birth outcomes, Yang and Chou (2018) find effects on birth outcomes up to 60 miles away. We therefore acknowledge the possibility that students attending schools in the control group were exposed to emissions from the three coal-fired power plants–and, thus, to air quality improvements following their closures–and believe that this potential control group contamination implies that our estimates should be interpreted as lower bounds. We demonstrate later in the paper that our results are not sensitive to the choice of 10 kilometers as the treatment group cutoff. For a visual depiction of our treatment and control schools, see Figure 3.

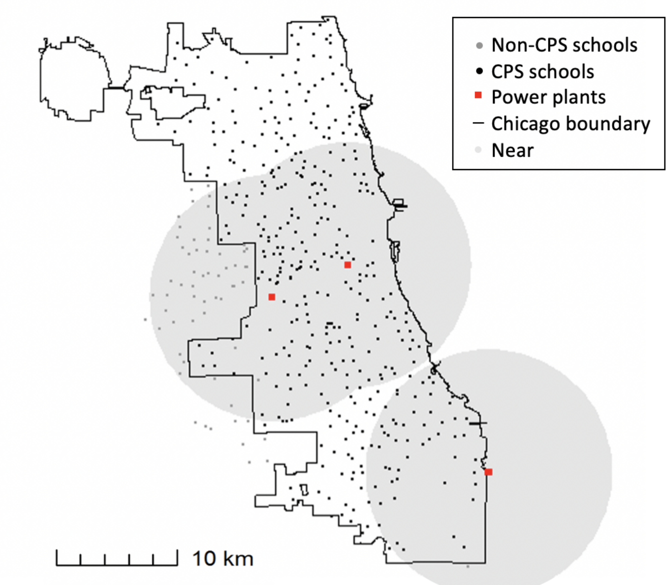


Figure 3: Analytic Sample, Elementary Schools in Fifteen Illinois School Districts

Notes: Schools within the gray shaded areas are within 10 kilometers of at least one of the coal-fired power plants. Schools in the Chicago Public School (CPS) district are indicated in black; non-CPS schools are indicated in dark gray.

Table 1 presents baseline school-level characteristics and absences for elementary schools in our sample. Columns (1) and (2) present mean estimates and standard errors for the 457 elementary schools during the 2008/09 school year. Columns (2) and (3) present the same descriptive information for our treatment (within 10 kilometers of at least one plant) and control (more than 10 kilometers from all three plants) groups. Column (4) presents the difference in means and associated standard errors, and Column (5) presents the p-value from a two-tailed t-test of the difference in means.

Table 1: Descriptive Statistics, Elementary Schools in Fifteen Illinois School Districts, 2008/09

	(1) Full Sample	(2) Treatment	(3) Control	(4) Diff.	(5) p-value
Panel A. School Characteristics					
Enrollment	608.16	593.19	645.81	-52.62	0.13
	(324.22)	(318.79)	(335.79)	(34.32)	
Percent Black	43.73	48.40	31.99	16.41***	0.00
	(42.75)	(43.39)	(38.86)	(4.17)	
Percent Hispanic	39.08	40.36	35.86	4.50	0.19
	(37.49)	(39.93)	(30.39)	(3.46)	
Percent Low-Income	78.02	81.53	69.20	12.33***	0.00
	(24.53)	(22.14)	(27.91)	(2.74)	
Panel B. Absence Rates					
	5.53	5.81	4.82	0.99***	0.00
All	(1.90)	(2.00)	(1.40)	(0.17)	
	5.71	6.00	4.99	1.02***	0.00
Male	(2.03)	(2.12)	(1.56)	(0.18)	
	5.34	5.61	4.65	0.96***	0.00
Female	(1.82)	(1.93)	(1.29)	(0.16)	
	6.64	6.95	5.88	1.07***	0.00
Black	(2.37)	(2.37)	(2.19)	(0.23)	
	5.55	5.94	4.60	1.34***	0.00
Hispanic	(4.75)	(5.37)	(2.47)	(0.38)	
	5.66	5.90	5.04	0.86***	0.00
Low-Income	(1.85)	(1.95)	(1.39)	(0.16)	
Observations (Schools)	457	327	130		

Notes: Column (1) reports means and standard deviations for the full sample of elementary schools from fifteen schools districts in Illinois. The fifteen districts included in the full sample are: Forest Park School District, Riverside School District, Oak Park Elementary School District, Berwyn North School District, Cicero School District, Berwyn South School District, Lyons School District, Summit School District, Central Stickney School District, Burbank School District, Oak Lawn-Hometown School District, Dolton School District, Burnham School District, Calumet City School District, and City of Chicago Public Schools. Column (2) reports means and standard deviations for schools within 10 kilometers (km) of at least one of of the following three coal-fired power plants: Crawford Generating Station, Fisk Street Generating Station, and State Line Generating Station. Column (3) reports means and standard deviations for schools located more than 10 kilometers (km) away from all three coal-fired power plants. Column (4) reports the difference in means (Near - Far) and the associated standard error. Column (5) reports the p-value from a two-tailed t-test of the difference in means. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, ***$p < 0.01$.

At baseline, treatment group schools differed on numerous observable dimensions when compared to schools in the control group. Prior to the coal-fired power plant closures, treatment group elementary schools had higher percentages of black students (16 percentage points) and higher percentages of low-income students (12 percentage points). We did not find evidence of statistically significant differences in enrollment or the percentage of Hispanic students enrolled in the school. We also find that treatment group schools had worse absence outcomes at baseline (Panel (B)). This was true for students overall (0.60 percentage points higher) and for all subgroups examined: male (1.02 percentage points higher), female (0.96 percentage points higher), black (1.07 percentage points higher), Hispanic (1.34 percentage points higher), and low-income (0.86 percentage points higher).

4 Empirical Strategy

Due to the quasi-experimental nature of our context, we use difference-in-differences and event-study approaches to estimate the effect of coal-fired power plant closures on student absences. Both approaches exploit spatial variation in schools' proximity to the Crawford, Fisk Street, and State Line Generating Stations paired with temporal variation induced by the nearly-simultaneous closures of the three plants.

4.1 Difference-in-Differences Specification

Our difference-in-differences approach assumes parallel trends in observable and unobservable determinants of absences in our treatment and control groups in the years preceding the plant closures. This assumption is required in order for the control group schools to provide a valid counterfactual for how school-level absence outcomes in treated schools would have evolved in the absence of the three plant closures. Even though this assumption is not explicitly testable, we later provide evidence in support of the assumption and the validity of our identification strategy.

We obtained difference-in-differences estimates using an equation of the following form:

$$Y_{st} = \alpha + \beta \times (Near \times Post)_{st} + \delta_t + \phi_s + X_{st} \cdot \theta + \varepsilon_{st} \tag{1}$$

Y_{st} is a school-level absence outcome for school s in year t. $(Near \times Post)_{st}$ is a binary indicator that takes the value of one for all schools in the treatment group in school years $t = 2013, ..., 2016$. We included a vector of year fixed-effects, δ_t, to control for factors that are common across all elementary schools in the sample within specific school years, such as local economic conditions, state-level school policy changes, and weather. We included a vector of school fixed-effects, ϕ_s, to control for time-invariant school-level factors such as the local environment, curricular differences, school policies, and neighborhood characteristics. X_{st} is a vector of time-varying school characteristics and policy controls, including the natural logarithm of total enrollment, the share of black students, the share of Hispanic students, the share of low-income students, whether the school was designated as a Safe Passage school (0/1), and whether the school was designated as a Welcoming School (0/1). We report heteroskedasticity-robust standard errors clustered at the school level and weighted all regressions by total enrollment to increase precision.

4.2 Event-Study Specification

To further investigate the validity of the parallel trends assumption and to explore dynamic effects of the treatment, we modified our differences-in-differences specification by interacting the indicator variable for schools in the treatment group, $Near_s$, with event-time indicators. This flexible approach allows for more detailed investigation of changes in school-level absence outcomes around the year of the three plant closures. We present results based on estimating the following equation:

$$Y_{st} = \sum_{\substack{j=-3 \\ j \neq -1}}^{4} \left[\pi_j \cdot Near_s \cdot \mathbf{1} \cdot \Big(t - 2012 = j \Big) \right] + \phi_s + \delta_t + X_{st} \cdot \theta + \varepsilon_{st} \tag{2}$$

All components of Equation (2) are the same as the previous specification, although we interacted $Near_s$ with event-time dummies. The sequence of π_j coefficients for $j = -3, ..., 4$ ($j = -1$ omitted) traces out the evolution of relative differences in school-level absence rates in treatment and control schools. In the plots we produce based on this equation, we set $j = 0$ for the 2011/12 school year. Because the State Line Generating Station closed in March 2012 – three months prior to the end of the 2011/12 school year, we consider this school year to be "partially treated". Elementary schools in the vicinity of the State Line Generating Station experienced reduced exposure to coal-fired power plants for nearly one-quarter of that school year. We thus expect coefficient estimates from π_0 to be nonzero but smaller in magnitude than those in the following school years, since only one of the three plants had closed and for only part of the school year.

5 Main Results

5.1 Absences Overall and by Student Subgroup

Column (1) of Table 2 presents results for Equation (1) for absences among the full sample of elementary schools. The point estimate indicates that aggregate absence rates were 0.395 percentage points lower in treatment schools relative to control schools in the years following the three power plant closures. This reduction in absences represents a 7 percent decline (baseline mean is 5.809 percent). For the typical (median) treated elementary school with 525 enrolled students, this absence rate decline represents a reduction of around 372 student-absence days per year, or around 0.71 absences per student per year.[13]

Figure 4a depicts coefficients and associated ninety-five percent confidence intervals from estimating Equation (2). Coefficient estimates corresponding to $j = -3$ and $j = -2$ depict differences between the treatment and control groups in the years prior to the plant closures compared to $j = -1$ (note: $j = -1$ is omitted). We cannot reject the null hypothesis that

[13] To covert the percentage point reduction in the aggregate absence rate at the school-level into absences per student per year, we assume that all students were enrolled for the duration of the 180-day school year.

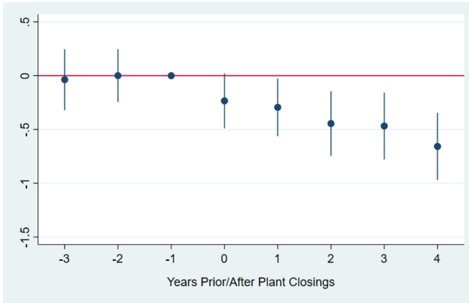
Table 2: Difference-in-Differences Estimates of the Effect of Power Plant Closures on Absences, Overall and by Subgroup

	All	Male	Female	Black	Hispanic	Low-Income
	(1)	(2)	(3)	(4)	(5)	(6)
Near X Post	-0.395***	-0.440***	-0.349***	-0.431**	-0.197**	-0.337***
	(0.085)	(0.088)	(0.087)	(0.183)	(0.096)	(0.094)
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3656	3654	3654	3635	3493	3652

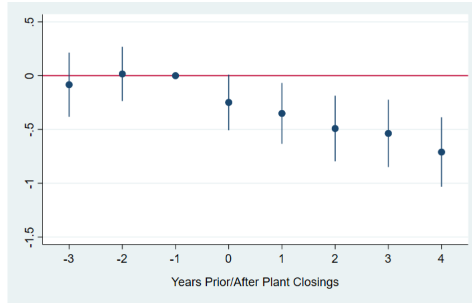
Notes: Each column reports results from a separate regression, where the dependent variable is a school-level absence rate calculated among the full sample or student subgroup indicated in the column heading. All regression specifications include school fixed-effects, year fixed-effects, total enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by enrollment in the full sample or relevant subgroup. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

both coefficients are jointly equal to zero ($p = 0.76$). This visual evidence suggests that annual absence outcomes were trending similarly in treatment versus control schools prior to the three coal-fired power plant closures. The coefficient estimate on $j = 0$ comes from the 2011/12 school year, which we consider to be partially treated, due to the closure of the State Line Generating Station prior to the end of the school year. The coefficient estimate is negative but statistically indistinguishable from zero and is then followed by a sequence of coefficients that become substantially more negative over time.

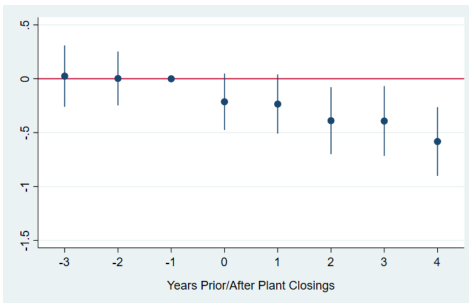
Columns (2)-(6) of Table 2 present results separately by student subgroup, including by gender, race/ethnicity, and for low-income students. While we find suggestive evidence of heterogeneous treatment effects by gender and by race/ethnicity, we we find that effects for low-income students are very similar to our main effects for the full sample. This is not surprising given that on average schools in our sample are comprised of 78 percent low-income students. Columns (2) and (3) present results separately for absence rates among male and female students. We consistently find that estimated effects on male students are larger than effects on female students (the bootstrapped p-value on this difference is $p = 0.038$).



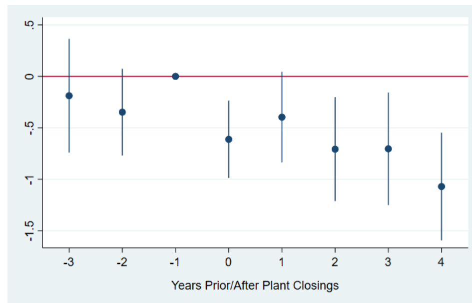
(a) All



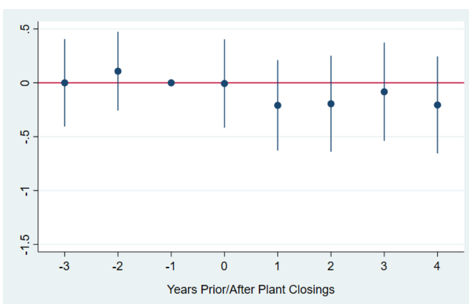
(b) Male



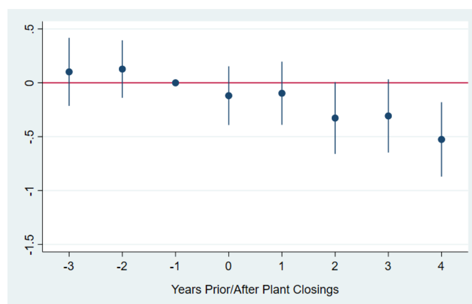
(c) Female



(d) Black



(e) Hispanic



(f) Low-Income

Figure 4: Event-Study Estimates, Absences

Notes: The panels in this figure depict event-study results for absences in fifteen Illinois school districts. Each plot depicts coefficient estimates from Equation (2) and their associated ninety-five percent confidence intervals. $t = 0$ is the 2011/12 school year (partially treated) and $t = -1$ is omitted. The event-study specification includes school fixed-effects, year fixed-effects, the natural logarithm of enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). The regression is weighted by student enrollment. Heteroskedasticity-robust standard errors are clustered at the school-level.

Aggregate absence rates were around 0.440 percentage points lower for males in treatment schools versus control schools and 0.349 percentage points lower for female students in the school years following the plant closures. In relative terms, these translate into 7 percent and 6 percent reductions. For the typical (median) treated elementary school with enrollment split evenly between males and females, these declines represent reductions of 207 and 165 student-absence days per year, or around 0.79 and 0.63 fewer absences per student per year among males and females, respectively. The visual evidence in Figures 4b and 4c are similar to the results for the full sample, although once again effects are larger for males than for females. This pattern of results is consistent with well-documented differences in asthma prevalence and time use. Asthma prevalence is higher in boys than girls in this age range (Akinbami et al., 2009), which suggests that boys are potentially more vulnerable to the negative effects of exposure to coal-fired power plants compared to girls. This result is also consistent with time-use patterns by gender in this age group: specifically, boys spend more time outside than girls and more time engaged in moderate and vigorous physical activities, which raises breathing rates (Nader et al., 2008; U.S. Environmental Protection Agency, 2008). These descriptive patterns also underscore boys' heightened vulnerability relative to girls'.

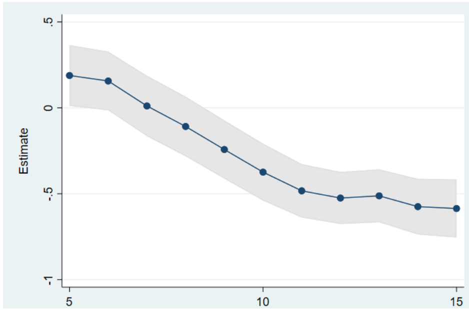
Columns (4) and (5) of Table 2 present results separately for black and Hispanic students.[14] These results reveal suggestive – albeit weaker – evidence of larger effects on black students relative to Hispanic students. Aggregate absence rates were around 0.431 percentage points lower for black students in treatment schools versus control schools and 0.197 percentage points lower for Hispanic students in the years following the plant closures (the bootstrapped p-value on this difference is $p = 0.209$). In relative terms, these translate into 7 percent and 3 percent reductions, respectively. The visual evidence in Figure 4d reveals a pattern of effects on black students that are similar to the pattern observed in the full sample, but the pattern of results for Hispanic students in Figure 4e is quite different. The effects on Hispanic students are relatively constant in all of the years following the plant closures, unlike the pattern of increasingly negative effects observed for all other groups. Column (6) of Table 2 presents results for students from low-income families; Figure 4f depicts the event study results. We find that the results are very similar to our results for the full sample

[14] We are unable to obtain results for other racial/ethnic groups due to high levels of non-reporting of other subgroup absence rates at the school-level in our panel.

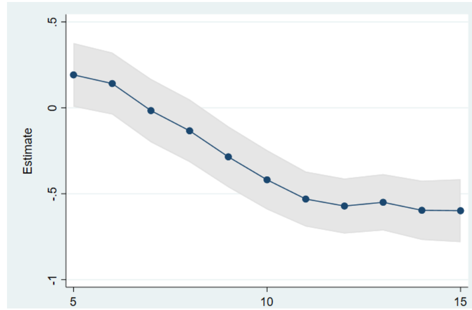
and believe that this is likely explained by the high percentage (78 percent) of low-income students enrolled in the schools in our sample.

To assess the sensitivity of our estimates to the use of a 10-kilometer distance to define the treatment group, we re-estimated our main model and allowed this distance to vary. We plot the resulting coefficients and their associated ninety-five percent confidence intervals for 1-kilometer increments ranging from 5 to 15 kilometers in Figure 5. In this figure, each coefficient estimate comes from a separate regression in which we re-assigned schools to treatment and control groups based on the distance indicated on the horizontal axis.

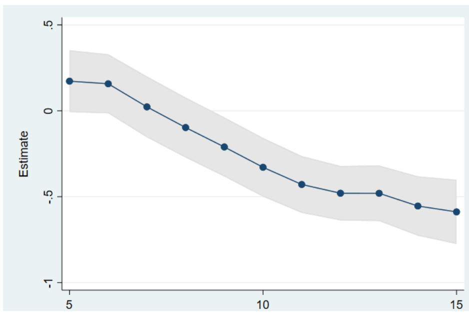
Our treatment effect estimate is slightly positive, though statistically insignificant, for a distance of 5 kilometers, likely due to substantial control group contamination. The sequence of estimates then crosses zero around 7 kilometers and becomes increasingly negative as we allow the distance to increase. We note a "leveling-off" (i.e., flattening slope) between 10 and 11 kilometers, although in all cases the estimated effect continues to become more negative past 10 kilometers – albeit only slightly. We interpret this as evidence that our choice of 10 kilometers is conservative (i.e., that some schools in our control group were affected by the coal-fired power plant closures) and that our main results should be interpreted as lower bounds on the treatment effect.



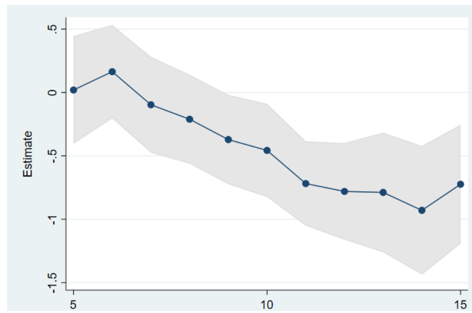
(a) All



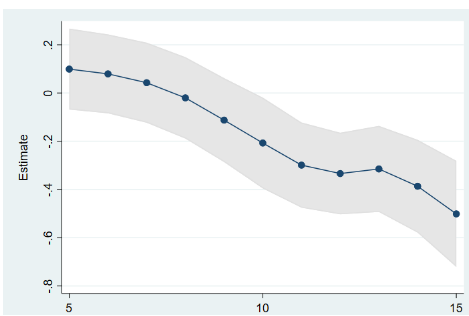
(b) Male



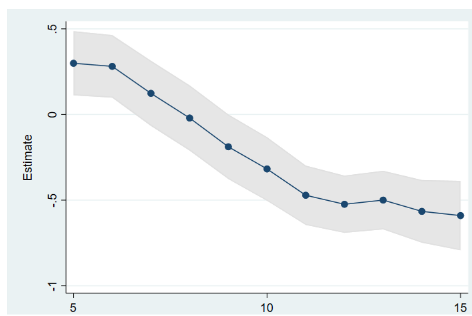
(c) Female



(d) Black



(e) Hispanic



(f) Low-Income

Figure 5: Estimated Treatment Effects Using Alternate Treatment Group Definitions (Distance), Absences Overall and by Subgroup

Notes: This figure depicts estimated treatment effects for varying treatment group definitions (distance in kilometers). Each coefficient estimate comes from a separate regression in which the treatment group of schools is defined based on the distance indicated on the horizontal axis; the control group of schools is then comprised of all schools located farther than the specified distance (on the horizontal axis) from all three coal-fired power plants.

In addition to our estimating equation outlined in Equation (1), we report estimates using Equation (1) augmented with district-specific trends (Appendix Table A1) and from unweighted regressions (Appendix Table A2), both of which are very similar to our main results. We also report results from several falsification tests (Appendix Table A3) – using outcomes related to school resources and instructional time that we expect to be unaffected by coal-fired power plant closures. Our point estimates from these falsification tests are small and statistically insignificant, and the associated ninety-five percent confidence intervals are quite narrow. These results strengthen the causal interpretation of our absence results by demonstrating that our estimates are not picking up the effects of unobserved improvements in school resources or changes in teachers' behavior that were correlated with the timing of the closures or our choice of distance. Finally, we present two alternative approaches to statistical inference, including standard errors clustered at the zip code-level (Appendix Table A4) and non-parametric permutation tests (Appendix Table A5), which characterize uncertainty in our estimates that arises from the assignment of schools to treatment and control groups, rather than sampling. Our conclusions about the statistical significance of our estimates remain unchanged.

5.2 Heterogeneous Effects by Pre-Closure Exposure Intensity

To provide evidence supporting the internal validity of our estimates, we investigated treatment heterogeneity on the basis of the intensity of pre-closure exposure to coal-fired power plants and their operations. We expected, *ex ante*, that the effects of the three coal-fired power plant closures would be larger in treated schools where pre-closure exposure was more intense. By partitioning schools within our treatment group on the basis of pre-closure exposure intensity and by showing that exposure intensity is uncorrelated with distance, we provide evidence that pre-closure exposure – and not unobservables correlated with distance – is the main driver of our results. To investigate treatment heterogeneity along this dimension, we partitioned treated schools into two groups (i.e., "high" and "low" exposure) using three characteristics: wind direction, air conditioning, and magnet status. We repeated this exercise three times and report the results in Table 3.

As a first approach, we used daily wind data from the 2008/09 school year (baseline) to split treatment group schools into two groups: "High Wind" and "Low Wind." We created

Table 3: Heterogeneous Effects of Coal-Fired Power Plant Closures by Wind Intensity, Air Conditioning, and School Magnet Status

	All	Male	Female	Black	Hispanic	Low-Income
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Days in Wind Path						
High Wind X Post	-0.452***	-0.506***	-0.399***	-0.370*	-0.370***	-0.385***
	(0.095)	(0.098)	(0.098)	(0.213)	(0.100)	(0.106)
Low Wind X Post	-0.316***	-0.351***	-0.278***	-0.550**	-0.037	-0.271**
	(0.105)	(0.111)	(0.106)	(0.217)	(0.105)	(0.115)
p-value: Low vs. High Wind	0.221	0.184	0.282	0.392	0.000	0.343
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3,656	3,654	3,654	3,635	3,493	3,652
Panel B. Air Conditioning						
Low AC X Post	-0.518***	-0.604***	-0.439***	-0.466**	-0.250*	-0.501***
	(0.134)	(0.143)	(0.132)	(0.227)	(0.137)	(0.145)
High AC X Post	-0.414***	-0.437***	-0.387***	-0.491**	-0.187*	-0.331***
	(0.102)	(0.105)	(0.105)	(0.207)	(0.105)	(0.109)
p-value: Low vs. High AC	0.474	0.272	0.715	0.909	0.621	0.269
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3,128	3,126	3,126	3,111	2,966	3,125
Panel C. School Magnet Status						
Not Magnet X Post	-0.427***	-0.463***	-0.380***	-0.652***	-0.217**	-0.357***
	(0.099)	(0.104)	(0.102)	(0.221)	(0.105)	(0.110)
Magnet X Post	-0.341***	-0.395***	-0.296***	-0.313	-0.186*	-0.297***
	(0.103)	(0.107)	(0.105)	(0.211)	(0.107)	(0.113)
p-value: Not Magnet vs. Magnet	0.449	0.566	0.462	0.112	0.736	0.626
Baseline Mean	5.799	5.990	5.606	6.934	5.934	5.887
Observations	3,624	3,622	3,622	3,604	3,462	3,620

Notes: Columns within panels report results from separate regressions, where the dependent variable is the aggregate absence rate calculated among the full sample or student subgroup indicated in the column heading. All regression specifications include school fixed-effects, year fixed-effects, enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by student enrollment in the full sample or relevant subgroup. The control group is comprised of schools located more than 10 kilometers away from all three coal-fired power plants. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

these two groups based the median number of days (45 days) during the school year on which the school was directly in the wind path of the nearest plant (for a visual depiction, see Appendix Figure A3).[15] We then re-estimated Equation (1) with an interaction that allowed

[15] For more information on Wind Data sources, see Appendix B.

the treatment effect to vary between these two groups. We report results in Panel (A) of Table 3. Our absence results in Columns (1)-(6) demonstrate that reductions in absence rates were larger in High Wind compared to Low Wind schools, with the lone exception appearing for black students in Column (4). Although we cannot reject the null hypothesis of equal effects, the pattern is highly suggestive of larger effects in schools were pre-closure exposure on the basis of wind was more intense.

As a second approach, we divided treated schools in our sample based on the percent of the school building that was air-conditioned.[16] The presence of air conditioning within schools is likely to affect students' exposure to coal-fired power plants in two ways: First, schools with more air conditioning would be less likely to have open windows on hot days, thus limiting the potential for outdoor air to circulate inside. Second, air conditioners (and HVAC systems more generally) have basic air filtration capacities and thus provide some filtering of outdoor air that circulates inside the school building (Parker et al., 2008). We find evidence of the same pattern of exposure-based effect in Panel (B) of Table 3, where the point estimates for schools with low levels of air conditioning are consistently larger in magnitude than those for high levels of air conditioning. The lone exception is, once again, for black students in Column (4).

As a final approach, we divided treated schools in our sample based on their magnet status. We expect larger effects in non-magnet schools (i.e., schools with designated attendance boundaries) since those schools draw from local neighborhoods and thus are more likely to have students living nearby. If students' residences were also more likely to be near the plants, they would be exposed to coal-fired power plants not only at school but also at home. Consistent with our previous findings, the estimates we report in Panel (C) of Table 3 once again demonstrate a pattern of larger effects in high exposure (i.e., non-magnet) schools.

Our three approaches yielded results that were remarkably consistent with one another, despite the fact that these school-level characteristics are essentially uncorrelated with one

[16]We obtained data on air conditioning in CPS schools from an Energy Star Audit in 2012. We were unable to find data measuring this school-level characteristic from an earlier school year.

another, unrelated to the share of low-income students in the school, and uncorrelated with school's average distance from the three coal-fired power plants.[17]

5.3 Heterogeneous Effects by Dosage

Table 4 presents results from exercises designed to investigate the presence of heterogeneous treatment effects by "dosage". We measure dosage in three ways: close proximity to one versus two coal-fired power plants, coal-fired power plant capacity, and distance.

Panel (A) reports results from the first exercise, in which we partitioned schools in the treatment group into two groups: those located within 10 kilometers of one plant and those located within 10 kilometers of two plants (there are no schools located within 10 kilometers of all three coal-fired power plants). We find a pattern of results that is suggestive – albeit somewhat weak – of a dose-response relationship. In all cases except one, the effect is larger in magnitude for the group of schools located within 10 kilometers of two plants relative to those located within 10 kilometers of just one. Although in most cases we cannot reject the null hypothesis of equal effects, there one exception appears in Column (4), where we find significant evidence of a stronger effect on absences for black students who attend schools within 10 kilometers of two plants versus one.

As a second means to explore dosage effects, we assign treated schools to one of three groups based on the nearest coal-fired power plant: Crawford, Fisk Street, or State Line. Because the three coal-fired power plants had different capacities, we view this exercise as a way to investigate whether the size of the plant influenced the magnitude of the treatment effect.[18] We do not find evidence of a monotonic relationship between plant size and the magnitude of the treatment effect. Instead, we find a fairly consistent pattern of effects that are largest at State Line, followed by Fisk, followed by Crawford, although this does not hold for all subgroups and in most cases we cannot reject the null hypothesis that the effects

[17] For cross-sectional correlations between school-level air conditioning (percent), number of wind days, magnet status (0/1), and the percentage of low-income students in the school, see Appendix Table A6.

[18] State Line Generating Station was the largest (614 MWh), followed by Crawford (597 MWh), and Fisk (374 MWh).

Table 4: Heterogeneous Effects of Coal-Fired Power Plant Closures by Number of Plants, Capacity, and Distance

	All (1)	Male (2)	Female (3)	Black (4)	Hispanic (5)	Low-Income (6)
Panel A. Number of Plants						
Near 1 Plant X Post	-0.366***	-0.418***	-0.316***	-0.235	-0.197*	-0.366***
	(0.104)	(0.109)	(0.107)	(0.211)	(0.102)	(0.120)
Near 2 Plants X Post	-0.419***	-0.458***	-0.377***	-0.702***	-0.198*	-0.316***
	(0.098)	(0.103)	(0.100)	(0.213)	(0.104)	(0.106)
p-value: 1 vs. 2 Plants	0.632	0.738	0.580	0.031	0.992	0.684
Panel B. Nearest Plant						
State Line (614 MWh) X Post	-0.549***	-0.606***	-0.498***	-0.306	-0.149	-0.535***
	(0.182)	(0.191)	(0.183)	(0.258)	(0.148)	(0.189)
Crawford (597 MWh) X Post	-0.271***	-0.319***	-0.222**	-0.482**	-0.118	-0.184*
	(0.095)	(0.100)	(0.098)	(0.230)	(0.099)	(0.105)
Fisk (374 MWh) X Post	-0.526***	-0.559***	-0.489***	-0.505**	-0.405***	-0.505***
	(0.117)	(0.124)	(0.117)	(0.232)	(0.129)	(0.129)
p-value: State Line vs. Crawford	0.125	0.131	0.128	0.520	0.812	0.061
p-value: Crawford vs. Fisk	0.040	0.071	0.029	0.926	0.011	0.017
p-value: Fisk vs. State Line	0.908	0.822	0.962	0.489	0.100	0.884
Panel C. Partition Treatment Group by Distance						
Within 5k X Post	-0.143	-0.171*	-0.123	-0.287	-0.083	-0.044
	(0.092)	(0.097)	(0.096)	(0.244)	(0.103)	(0.099)
Between 5k-10k X Post	-0.573***	-0.630***	-0.509***	-0.466**	-0.363***	-0.573***
	(0.102)	(0.106)	(0.105)	(0.193)	(0.109)	(0.114)
p-value: Under 5k vs. 5k-10k	0.000	0.000	0.000	0.431	0.003	0.000
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3656	3654	3654	3635	3493	3652

Notes: Columns within panels report results from separate regressions, where the dependent variable is the aggregate absence rate calculated among the full sample or student subgroup indicated in the column heading. All regression specifications include school fixed-effects, year fixed-effects, enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by student enrollment in the full sample or relevant subgroup. The control group is comprised of schools located more than 10 kilometers away from all three coal-fired power plants. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * $p < 0.10$, ** $p < 0.05$, ***$p < 0.01$.

are equal across plants.

As a final exercise, we partition treated schools into two groups based on distance to the nearest of the three plants: the first group is comprised of schools located within 5 kilometers of the nearest plant, while the second group is comprised of schools located between 5 and 10 kilometers of the nearest plant. We do not find any evidence of dosage effects based on proximity; instead, we find robust evidence of larger effects on absences in schools located between 5 and 10 kilometers from the nearest plant. We believe this is likely explained by dispersion patterns that result from a combination of tall stacks and wind.[19]

6 Mechanisms

To examine the mechanisms underlying the reduced-form effects on absences presented in the previous section, we consider two possibilities suggested by previous literature: endogenous migration of higher-income families to neighborhoods near the plants following their closures (mediated through housing price responses) and improvements in children's respiratory health. We first explore the possibility that the coal-fired power plant closures led to endogenous migration; specifically, the sorting of higher-income or otherwise more socioeconomically advantaged families into neighborhoods near the coal-fired power plants following their closures. We do this by examining the effects of the closures on housing prices directly and on the demographic composition of students enrolled in schools near the plants. We then investigate the effects of the coal-fired power plant closures on children's respiratory health by examining whether emergency department visits for asthma-related conditions among school-age children responded to the closures.

In Table 5 we present results from two sets of difference-in-differences regressions in which we use housing values and rates of emergency department visits on the left-hand side. For more detail about the housing value and emergency room visit data used in these analyses, see Appendix B. In both cases, these data are aggregated up to the 5-digit zip code-level. Our analysis follows Equation (1) as closely as possible; we consider zip codes to be treated if their centroids fall within 10 kilometers of at least one of the three coal-fired power plants, and control otherwise. Appendix Figure A4 depicts treatment and and control zip codes in

[19]Stack heights: Crawford (378 feet), Fisk Street (450 feet), and State Line (400 feet).

Chicago.

Previous empirical evidence on the responsiveness of housing values (prices) to toxic plant operations comes from Currie et al. (2015), who find considerable asymmetry in price responses to plant openings versus closures. Although Currie et al. (2015) find that toxic plant openings lead to sizable declines in housing prices, their estimates indicate that plant closures result in only small price increases (that are statistically insignificant) at best.[20] Our findings, although somewhat less precise and covering a larger geographic area, are consistent with the existing evidence. Our point estimates in Columns (1)-(3) of Panel (A) suggest that – if anything – housing values in zip codes near the three coal-fired power plants may have *decreased* slightly following the closures, although only one of the three estimates is statistically significant. Consistent with previous work, we find no convincing evidence that closures led to housing price increases. The upper bounds of the ninety-five percent confidence intervals associated with our estimates are small enough to rule out housing value increases larger than 3 percent. We present supporting event-study results for the same dependent variable in Figure 6a. The lack of strong positive responses along this dimension makes a story about the endogenous migration of higher-income families (mediated through housing prices) unlikely. This evidence helps us rule out the story that our absence results are driven by compositional changes of students (and families) within neighborhoods near the coal-fired power plants.

To further investigate the issue of endogenous migration and compositional change, we investigate the responses of enrollment levels and the demographic composition of students who attended schools near the coal-fired power plants. Even in the absence of increases in housing prices, it is still possible that high-income (or otherwise more socioeconomically advantaged) families moved to the neighborhoods feeding into treatment group schools following the coal-fired power plant closures. If this were the case, this could help to explain

[20] "[P]lant closings appear to modestly increase housing prices, but this effect is small economically (less than 2 percent, even less than 0.5 miles from a plant) and statistically indistinguishable from zero" (Currie et al., 2015, p. 696).

Table 5: The Effect of Coal-Fired Power Plant Closures on Housing Prices and Rates of Emergency Department Visits for Asthma-Related Conditions

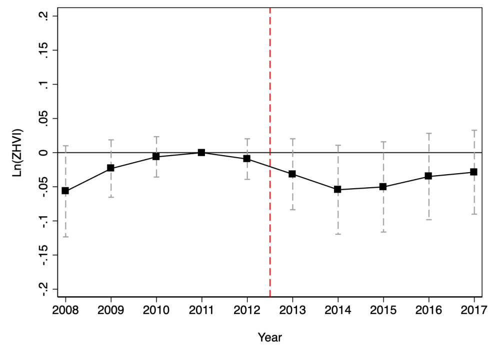
	(1)	(2)	(3)	(4)
Panel A. Log ZHVI				
Near X Post	-0.042	-0.032	-0.058**	X
	(0.037)	(0.030)	(0.028)	X
Baseline Mean	12.615			
Obs.	528	528	528	
Panel B. Crude Rate of ED Visits				
Near X Post	-1.637**	-1.676**	-1.954*	-2.145**
	(0.691)	(0.691)	(1.103)	(0.844)
Baseline Mean	21.241			
Obs.	384	384	384	288
Year and Zip FE	X	X	X	X
Covariates		X	X	X
Zip Code Trends			X	
Truncated Sample				X

Notes: Each cells reports results from a separate regression, where the dependent variable is the natural logarithm of zip code-level housing values (Panel A) or the crude rate of emergency department visits for asthma-related conditions among school-age children (Panel B). All regressions are weighted by zip code population. Heteroskedasticity-robust standard errors are clustered at the zip code-level. Asterisks denote statistical significance: * p <0.10, ** $p < 0.05$, ***$p < 0.01$.

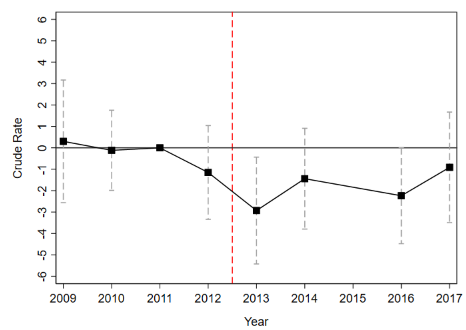
our absence-related findings because high-income students are less likely to be absent – on average – than low-income students (Gershenson et al., 2016). We do not find any statistically significant effects of the coal-fired power plant closures on the natural logarithm of enrollment nor on the percentages of black, Hispanic, or low-income students enrolled in the school. All of the point estimates are small, and the associated ninety-five percent confidence intervals are narrow. We report these results in Appendix Table A7.

To probe whether decreases in absences were generated through improvements in children's respiratory health, we present results from a series of regressions that investigate the effects of the three coal-fired power plant closures on rates of emergency department visits for asthma-related conditions among school-age children.[21] This outcome measure captures more extreme health-driven responses to the coal-fired power plant closures than school absences themselves. Columns (1)-(4) of Panel (B) present our results for the crude rate of

[21] We define school-age children as those between the ages of 5 and 18. For more information on the diagnoses included in the definition of asthma-related conditions, please see Appendix B.



(a) Housing Values (Natural Log of ZHVI)



(b) Rate of ED Visits for Asthma-Related Conditions Among 5-18 Year-Olds

Figure 6: Event-Study Estimates for Housing Prices and Rates of Emergency Department Visits for Asthma-Related Conditions

Notes: This figure depicts event-study results for housing values and rates of emergency department (ED) visits for asthma-related conditions among 5-18 year olds. The plots depict coefficient estimates and their associated ninety-five percent confidence intervals (note: 2011 is omitted). The event-study specification includes zip code fixed-effects, year fixed-effects, and all regressions are weighted by zip code population. Emergency department visit rate data are missing for 2015. Heteroskedasticity-robust standard errors are clustered at the zip-code level.

emergency department visits for asthma-related conditions among school-age children.[22] We find that emergency department visits decreased in treatment group zip codes by around 1.64 visits per ten thousand residents per year (7 percent) following the three coal-fired power plant closures. This result is robust to the inclusion of time-varying covariates (Column (2)), zip-code specific linear trends (Column (3)), and truncation of the sample after 2014 (Column (4)), which is a check to ensure that our results are not driven by a change in the

[22]The crude rate measures the number of emergency department visits for asthma-related conditions among school-age children per ten thousand residents in the zip code.

coding of asthma-related conditions that occurred in 2015 (for more information, see Appendix B). We present supporting event-study results in Figure 6b. As a robustness check, we present the same regression and event-study results for age-specific rates of emergency department visits in Appendix Table A8 and Appendix Figure A5. These results are very similar to our main results using the crude rate and provide reassurance that our findings are not driven by changes in population (the denominator of our outcome variable) in other age ranges. Interpreted in light of existing medical evidence on children's vulnerability to air pollution exposure (Schwartz, 2004; Bateson and Schwartz, 2007), we believe that this evidence supports improvements in children's respiratory health as a primary channel through which coal-fired power plant closures improved school attendance.

7 Conclusion

In this paper we estimate the causal effect of three, nearly-simultaneous coal-fired power plant closures on school absences. We exploit quasi-experimental variation in exposure to coal-fired power plants induced by the closures to estimate the effect of exposure on children's health. This unique context – in which large industrial sources abruptly closed after decades of operation – allows us to sharply identify short-run and medium-run effects. We find that school-level absence rates decreased by around 0.395 percentage points (7 percent) in schools located near the plants following their closures. This translates into 372 fewer student absence-days per year for the typical elementary school, or around 0.71 fewer absence-days per student per year. In addition to our results overall, we also investigate effects on absences for student subgroups. We consistently find evidence to suggest that absence reductions were larger for boys than for girls. We also find evidence – albeit much weaker – to suggest that absence reductions were larger for black students than for Hispanic students.

We investigate the possibility of heterogeneous treatment effects on the basis of exposure intensity as a means to assess the internal validity of our main results. By examining heterogeneity within our treatment group, we rule out the possibility that our results are driven by unobserved shocks correlated with distance and the timing of the three coal-fired power plant closures. Our three approaches – using data on windy days, air conditioning, and magnet schools – yield a consistent pattern of results: reductions in absences were larger in schools with higher baseline exposure to emissions from coal-fired power plants.

Finally, we gain insight into the mechanisms underlying our estimated effects on school absences by exploring the effects of coal-fired power plant closures on housing prices (and the composition of schools near the plants) and children's respiratory health. We do not find consistent statistical evidence to suggest that the three coal-fired power plant closures affected housing prices – if anything, we find some weak evidence to suggest that housing prices actually declined slightly in zip codes near the three plants following their closures. We do not find any statistically significant effects of the three coal-fired power plant closures on school enrollments nor on the demographic composition of students in schools near the plants. We do, however, find evidence to suggest that children's respiratory health improved following the three coal-fired power plant closures. Specifically, we find that rates of emergency department visits for asthma-related conditions declined among school-age children in zip codes near the plants compared to zip codes farther away. When considered together, these results from these exercises strongly suggest improved respiratory health as a primary absence-reducing channel.

This paper contributes to the emerging literature on the effects of exposure to coal-fired power plants on human health and to the larger literature on the effects of air pollution exposure on children's outcomes more broadly. The results from this work contribute to understanding how current trends in energy generation in the U.S. – away from coal – may have broad and far-reaching impacts. In so doing, we provide insight into how the ongoing energy transition in the U.S. and in other countries experiencing such changes could benefit (or harm, in the case of increased coal use) children who live and attend school near coal-fired power plants. Given the geographical distribution of operational coal-fired power plants – and other large, industrial pollution emitters – our findings suggest that current trends in energy generation and transitions toward alternative sources of energy could also be influential in reducing inequality.

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Appendix A: Supplemental Results

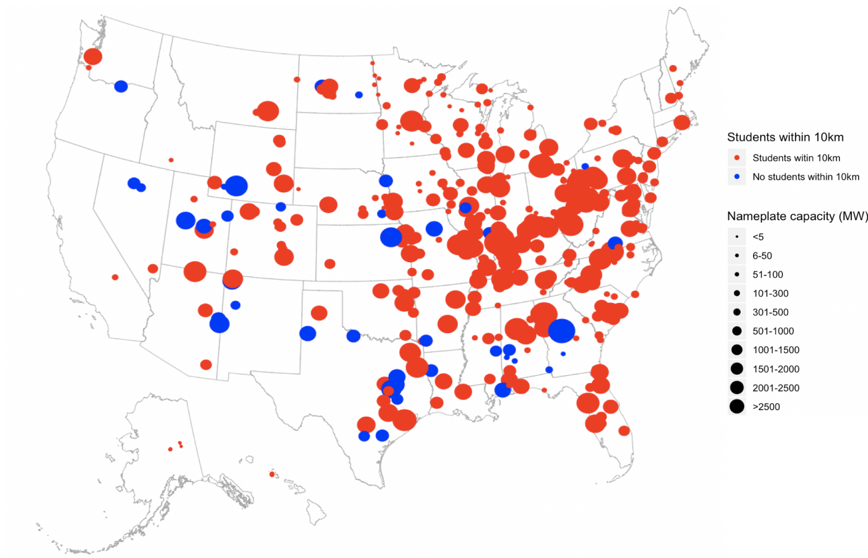


Figure A1: Coal-Fired Power Plant Locations and K-8 Public School Enrollment in the United States, 2016

Notes: This figure depicts the locations of operational coal-fired power plants in the United States in 2016. Dot sizes represent the number of K-8 students enrolled in a public school located within 10 kilometers (km) of the plant. Power plants depicted in red have public schools (K-8) within 10 km of their operation; power plants depicted in blue do not. Power plant locations, energy sources, and operational status come from the United States Energy Information Administration (EIA) Form EIA-860. Public school locations and enrollments come from the Elementary and Secondary Information System (ElSi) of the National Center for Education Statistics (NCES) of the United States Department of Education.

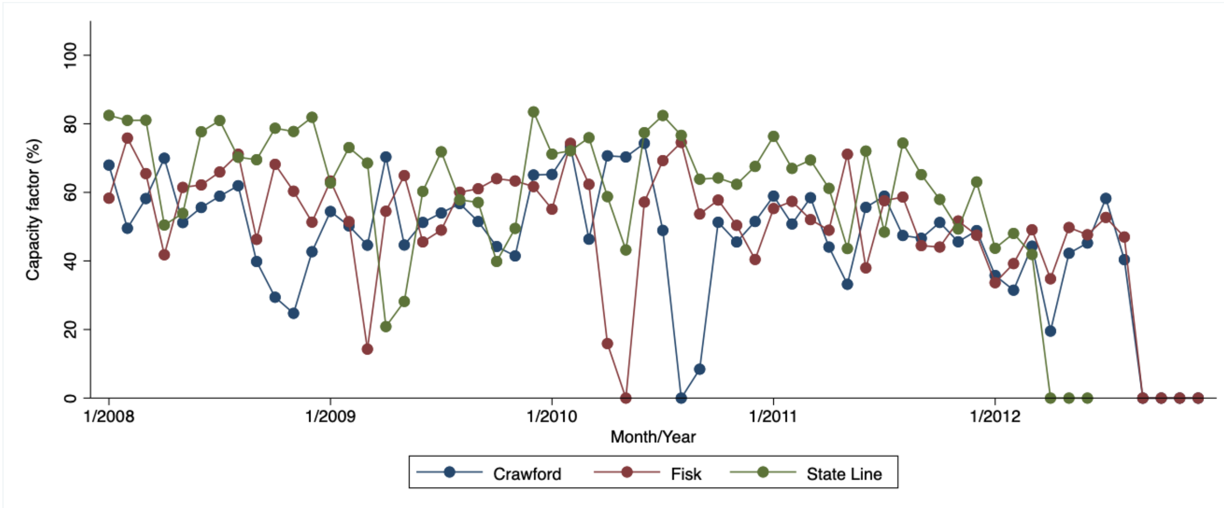
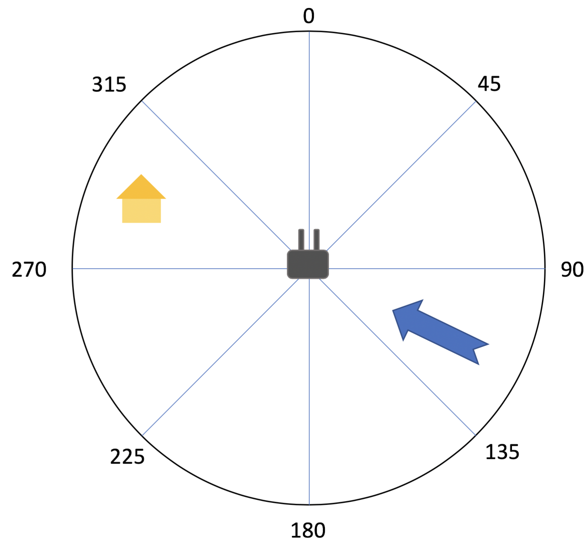
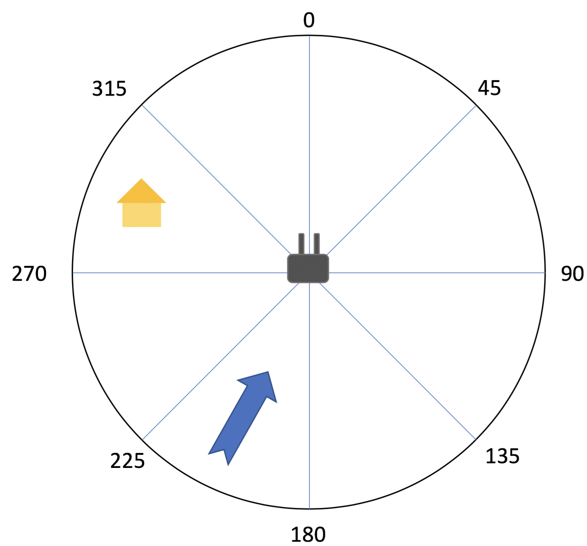


Figure A2: Monthly Capacity Factors for the Crawford, Fisk Street, and State Line Generating Stations, 2008-2012

Notes: Monthly capacity factors were calculated as the ratio of actual energy generation (MWh) to potential energy generation (MWh) in each month. Data were obtained from the the Air Markets Program Data of the United States Environmental Protection Agency.



(a) School in Wind Path



(b) School Not in Wind Path

Figure A3: School in Wind Path versus Not in Wind Path

Notes: This figure illustrates how we classified High versus Low Wind school days. The blue arrow depicts the direction from which the day's wind originated.

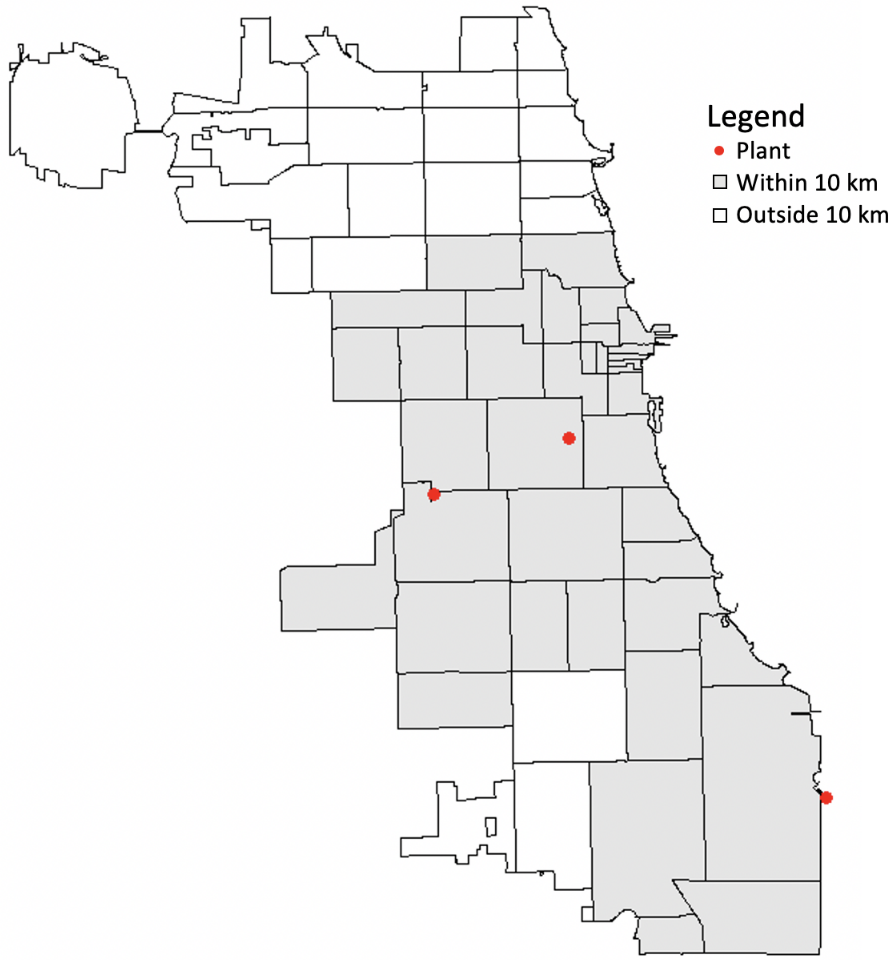


Figure A4: Map of Treatment and Control Zip Codes

Notes: This figure shows the zip codes designated as treatment (shaded in gray) and control (in white) in the analysis of housing values and emergency department visits for asthma-related conditions among school-age children.

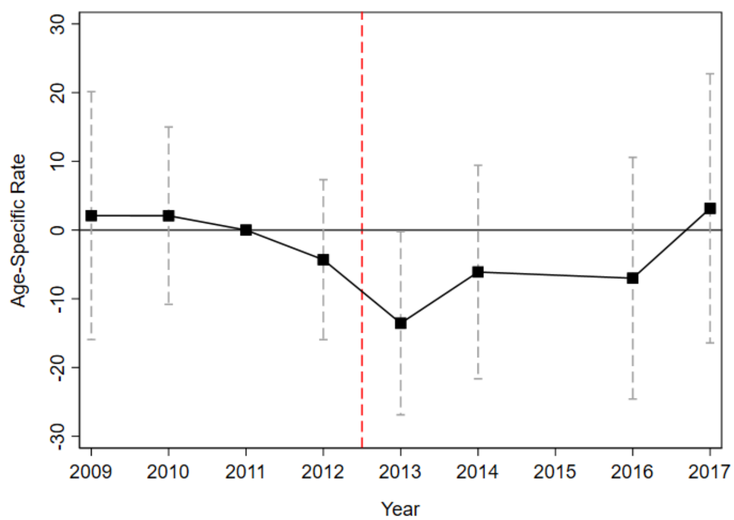


Figure A5: Event-Study Estimates for Emergency Department Visits for Asthma-Related Conditions (Age-Specific Rate)

Notes: This figure depicts event-study results for age-specific rates of emergency department (ED) visits for asthma-related conditions among 5-18 year olds. The plot depicts coefficient estimates and their associated ninety-five percent confidence intervals (note: 2011 is omitted and data from 2015 are missing). The event-study specification includes zip code fixed-effects, year fixed-effects, and all regressions are weighted by zip code population in the age group. Heteroskedasticity-robust standard errors are clustered at the zip-code level.

Table A1: (District-Specific Trends) Difference-in-Differences Estimates of the Effect of Coal-Fired Power Plant Closures on Absences, Overall and by Subgroup

	All	Male	Female	Black	Hispanic	Low-Income
	(1)	(2)	(3)	(4)	(5)	(6)
Near X Post	-0.419***	-0.464***	-0.374***	-0.342*	-0.209**	-0.356***
	(0.088)	(0.092)	(0.090)	(0.175)	(0.098)	(0.098)
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3656	3654	3654	3635	3493	3652

Notes: Each column reports results from a separate regression, where the dependent variable is a school-level absence rate calculated among the full sample or student subgroup indicated in the column heading. All regression specifications include school fixed-effects, year fixed-effects, total enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by enrollment in the full sample or relevant subgroup. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * p <0.10, ** $p < 0.05$, ***$p < 0.01$.

Table A2: (Unweighted) Difference-in-Differences Estimates of the Effect of Coal-Fired Power Plant Closures on Absences, Overall and by Subgroup

	All (1)	Male (2)	Female (3)	Black (4)	Hispanic (5)	Low-Income (6)
Near X Post	-0.398***	-0.427***	-0.367***	-0.161	-0.483*	-0.357***
	(0.094)	(0.099)	(0.095)	(0.188)	(0.262)	(0.097)
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3656	3654	3654	3638	3541	3652

Notes: Each column reports results from a separate regression, where the dependent variable is a school-level absence rate calculated among the full sample or student subgroup indicated in the column heading. All regression specifications include school fixed-effects, year fixed-effects, total enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by enrollment in the full sample or relevant subgroup. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * p <0.10, ** $p < 0.05$, ***$p < 0.01$.

Table A3: Difference-in-Differences Estimates of the Effect of Coal-Fired Power Plant Closures on Other School-Level Outcomes

	Class Size	Math Minutes	English Minutes
	(1)	(2)	(3)
Near X Post	0.183	-0.841	0.466
	(0.192)	(0.913)	(1.100)
Baseline Mean	24.324	53.069	123.858
Observations	3656	3610	3610

Notes: Each column reports results from a separate regression, where the dependent variable is a school-level measure of class size or the average number of minutes per day spent on Math or English instruction. All regression specifications include school fixed-effects, year fixed-effects, total enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by enrollment in the full sample or relevant subgroup. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A4: (SEs Clustered at Zip Code Level) Difference-in-Differences Estimates of the Effect of Coal-Fired Power Plant Closures on Absences, Overall and by Subgroup

	All	Male	Female	Black	Hispanic	Low-Income
	(1)	(2)	(3)	(4)	(5)	(6)
Near X Post	-0.395***	-0.440***	-0.349***	-0.431**	-0.197*	-0.337**
	(0.121)	(0.118)	(0.125)	(0.216)	(0.116)	(0.140)
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3656	3654	3654	3635	3493	3652

Notes: Each column reports results from a separate regression, where the dependent variable is a school-level absence rate calculated among the full sample or student subgroup indicated in the column heading. All regression specifications include school fixed-effects, year fixed-effects, total enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by enrollment in the full sample or relevant subgroup. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * p <0.10, ** $p < 0.05$, ***$p < 0.01$.

Table A5: (Randomization-Based Inference) Difference-in-Differences Estimates of the Effect of Coal-Fired Power Plant Closures on Absences, Overall and by Subgroup

	All (1)	Male (2)	Female (3)	Black (4)	Hispanic (5)	Low-Income (6)
Near X Post	-0.395***	-0.440***	-0.349***	-0.431**	-0.197**	-0.337***
	[0.000]	[0.000]	[0.000]	[0.012]	[0.021]	[0.000]
Baseline Mean	5.809	6.004	5.611	6.948	5.939	5.899
Observations	3656	3654	3654	3635	3493	3652

Notes: Each column reports results from a separate regression, where the dependent variable is a school-level absence rate calculated among the full sample or student subgroup indicated in the column heading. All regression specifications include school fixed-effects, year fixed-effects, total enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). All regressions are weighted by enrollment in the full sample or relevant subgroup. Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A6: Correlation Matrix, School Characteristics Related to Exposure and Percentage of Low-Income Students

	Percent AC	Wind Days	Magnet (0/1)	Percent Low-Income
	(1)	(2)	(3)	(4)
Percent AC	1.0000			
Wind Days	-0.0741	1.0000		
Magnet (0/1)	-0.0737	0.0030	1.0000	
Percent Low-Income	0.0121	-0.1887	-0.0306	1.0000

Notes: Each cell reports a correlation coefficient calculated in the baseline school year (2008/09) among all schools in the sample. Correlation coefficients involving school-level air conditioning are only calculated among the subsample of schools from Chicago Public Schools (CPS).

Table A7: Difference-in-Differences Estimates of the Effect of Coal-Fired Power Plant Closures on Enrollment the Demographic Composition of Students

	Log Enrollment (1)	Percent Black (2)	Percent Hispanic (3)	Percent Low-Income (4)
Near X Post	-0.037*	0.219	0.196	-0.195
	(0.021)	(0.263)	(0.352)	(0.465)
Baseline Mean	6.253	48.403	40.360	81.531
Observations	3656	3656	3656	3656

Notes: Each column reports results from a separate regression, where the dependent variable is a school-level measure of enrollment, student characteristics, or the shared of tested students. All regression specifications include school fixed-effects, year fixed-effects, total enrollment, percent black, percent Hispanic, percent low-income, Safe Passage (0/1), and Welcoming School (0/1). Heteroskedasticity-robust standard errors are clustered at the school-level. Asterisks denote statistical significance: * p <0.10, ** $p < 0.05$, ***$p < 0.01$.

Table A8: The Effect of Coal-Fired Power Plant Closures on Emergency Department Visits for Asthma-Related Conditions Among school-age Children (Age-Specific Rate)

	(1)	(2)	(3)	(4)
Near X Post	-5.967	-8.491**	-12.809**	-9.840**
	(4.060)	(3.807)	(5.717)	(4.255)
Baseline Mean	101.764			
Observations	384	384	384	288
Year and Zip FE	X	X	X	X
Covariates		X	X	X
Zip Code Trends			X	

Notes: Each cell reports results from a separate regression, where the dependent variable is the crude rate of asthma-related emergency department (ED) visits for the age group listed in the column heading. All regressions are weighted by population. Heteroskedasticity-robust standard errors are clustered at the zip code-level. Asterisks denote statistical significance: * p <0.10, ** $p < 0.05$, ***$p < 0.01$.

Appendix B: Data Sources

K-8 Public School Enrollment Data

Public school locations and enrollments were obtained from the Elementary and Secondary Information System (ElSi) of the National Center for Education Statistics (NCES) of the United States Department of Education (2015/16 school year). These data are public-use and are available here: https://nces.ed.gov/ccd/elsi/.

Data on Operational Coal-Fired Power Plants

Coal-fired power plant locations, energy sources, and operational statuses were obtained from the United States Energy Information Administration (EIA) Form EIA-860 for 2016. These data are public-use and are available here: https://www.eia.gov/electricity/data/eia860/.

Illinois State Board of Education (ISBE) Report Card Data Library

Illinois State Board of Education Report Card Data are public-use and are available here: https://www.isbe.net/ilreportcarddata.

The annual aggregate absence rate is a ratio of the sum of all student absence days (summed across all students enrolled in the school) to the sum of all student enrollment days (summed across all students in the school). Let a_{ist} be the number of absence days for student i enrolled in school s in year t and let e_{ist} be the number of enrollment days for student i enrolled in school s in year t. Note that $e_{ist} \leq 180$, since some students may enroll (transfer in) after the first day or disenroll (transfer out) prior to the end of the school year. The annual aggregate absence rate is then given by: $A_{st} = \Sigma_{i=1}^{N_g} a_{ist}/e_{ist}$, where g denotes student group (either all students in the school, male students, female students, or low-income students).

Air Quality Monitoring Station Data

We obtained daily data from Air Quality Monitoring Stations in Cook County, Illinois and Lake County, Indiana for the years 2008-2016. These data are public-use and are available here: https://www.epa.gov/outdoor-air-quality-data/download-daily-data.

To produce time-series figures documenting annual average concentrations of sulfur dioxide, fine particulates, and nitrogen dioxide, we used data from the following air quality monitoring stations located in Cook County, Illinois and Lake County, Indiana. We selected the stations below because they were the closest (distance listed below) to the Crawford, Fisk Street, and State Line Generating Stations:

- Sulfur Dioxide (SO_2)
  - Crawford: Cook County Trailer (3.86 kilometers)
  - Fisk Street: Cook County Trailer (8.25 kilometers)

- State Line: Hammond CAAP (7.89 kilometers)

- Fine Particulates ($PM_{2.5}$)
  - Crawford: Liberty School (4.54 kilometers)
  - Fisk Street: Liberty School (8.08 kilometers)
  - State Line: Washington High School (2.66 kilometers)
- Nitrogen Dioxide (NO_2)
  - Crawford: Cook County Trailer (3.86 kilometers)
  - Fisk Street: CTA Building (3.35 kilometers)

School Districts in Study

We included school-level data from the following fifteen school districts in Illinois in our sample:

1. Forest Park School District
2. Riverside School District
3. Oak Park Elementary School District
4. Berwyn North School District
5. Cicero School District
6. Berwyn South School District
7. Lyons School District, Summit School District
8. Central Stickney School District
9. Burbank School District
10. Oak Lawn-Hometown School District
11. Dolton School District
12. Burnham School District
13. Calumet City School District
14. City of Chicago Public Schools

Coal-Fired Power Plant Emissions Data

We obtained monthly emissions data from the EPA's Air Markets Program Data.[23] These monthly generation data provide information about the current and historical patterns of operation of industrial sites. For this paper, monthly generation data were used for the period of 2008-2012 to calculate monthly capacity factors for the Crawford, Fisk Street, and State Line Generating Stations.

Wind Data

We obtained daily wind data from the Global Historical Climatology Network (GHCN) of the National Centers for Environmental Information (NCEI) of the National Oceanic and Atmospheric Administration (NOAA).[24] These daily wind readings came from the land surface station located at Midway Airport (MDW) in Chicago, Illinois (station number: USW00014819). We used daily readings on the direction (in degrees) of the fastest 2-minute wind ($wdf2$).

Air Conditioning Data in Chicago Public Schools (CPS)

We obtained information on air conditioning (AC) in CPS school buildings from a published report of the Chicago Public Schools (CPS). This report was generated using the United States Environmental Protection Agency (US EPA) Energy Star Portfolio Manager. The report contained building level information on the percent of the school with air conditioning from April 2011.

Magnet School Status

We obtained information on schools' magnet status from the Elementary/Secondary Information System (ElSi), a web application of the National Center for Education Statistics (NCES).[25] These data came from the 2008/09 school year. Magnet schools typically do not have attendance boundaries, and spaces in magnet schools are allocated on the basis of random lottery (following an application process).

Zillow Housing Value Data

We obtained zip code-level housing values from https://www.zillow.com/research/data/. According to Zillow, the Zillow Housing Value Index (ZHVI) is "[a] smoothed, seasonally adjusted measure of the typical home value and market changes across a given region and housing type. It reflects the typical value for homes in the 35th to 65th percentile range." We used the smoothed, seasonally adjusted time series for all homes and converted levels of nominal dollars to the natural logarithm of 2017 dollars.

[23] Air Markets Program data are available here https://ampd.epa.gov/ampd/.

[24] These data are public-use and can be downloaded here: https://www.ncdc.noaa.gov/ghcn-daily-description.

[25] ElSi data are available here https://nces.ed.gov/ccd/elsi/.

Data on Emergency Department (ED) Visits for Asthma-Related Conditions

We obtained annual counts of emergency department visits for children ages 0-4 and 0-18 for asthma-related conditions at the zip code-level from the Chicago Health Atlas. These data are public-use and are available here: https://www.chicagohealthatlas.org/. These annual counts were available for 48 zip codes (or zip code aggregates) for the years 2009-2017 (excluding 2015, when no data were available). These data were derived from microdata from the Discharge Data, Division of Patient Safety and Quality, Illinois Department of Public Health. We subtracted these measures from one another to create our measure of the number of visits among 5-18 year-old children, since this age group was closest to the population of elementary school (K-8) students.

We calculated crude and age-specific emergency department (ED) visit rates (per 10,000 inhabitants) for asthma-related conditions using zip-code level data from American Factfinder.[26] Crude rates were calculated for by adjusting annual counts of ED visits for asthma-related conditions by total population, and age-specific rates were calculated using population counts for age groups (5-18). We used population estimates for the age group 5-19 to calculate the age-specific rate for children ages 5-18 because more granular data were not available. Population estimates (overall) and by age group came from the Decennial Census (2010) and the American Community Survey (ACS) 5-Year Estimates (2011-2017). Data for 2009 were linearly interpolated using the Decennial Censuses from 2000 and 2010.

Diagnoses included in the definition of asthma-related conditions can be found here: https://www.cdc.gov/asthma/data-analysis-guidance/ICD-9-CM-ICD-10-CM.htm. We note that the coding of this measure changed in 2015 (omitted from our data) due to transition from the Ninth to the Tenth version of the International Classification of Disease (i.e., ICD-9 to ICD-10).

[26]There data are public-use and are available here: https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.