The Impact of Prenatal Exposure to Power Plant Emissions on Birth Weight: Evidence from a Pennsylvania Power Plant Located Upwind of New Jersey[1]

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Abstract

To examine the infant health impact of prenatal exposure to power plant emissions, we draw scientific evidence on the impacted region downwind of a large polluter, a coal-fired power plant located on the border of two states and proven to be the sole contributor to the violation of air quality standards of the impact region. Our results show that among all live singleton births that occurred during 1990–2006, those born to mothers living as far as 20–30 miles away downwind from the power plant (which is also an affluent region) during pregnancy are at greater risks of low birth weight (LBW) and very low birth weight (VLBW): the likelihoods of LBW and VLBW could increase approximately by 6.50 percent and 17.12 percent, respectively. In light of the U.S. EPA's continual efforts in reducing cross-state air pollution caused by transboundary power plant emissions, our study is aimed at broadening the scope of cross-border pollution impact analysis by taking into account adverse infant health effects of upwind polluters, which can impose disproportionate burdens of health risks on downwind states due to air pollutants transported by wind.

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1 Introduction

Air pollution is a by-product of many essential activities of our society. A growing literature has examined adverse effects of *in utero* exposure to air pollution on later-life outcomes including educational attainment and earnings (Currie et al., 2014). However, the needed time frame and available data of such long-term analyses often restrict the period of early-life exposure to be mainly mid to late 20th century, when air pollution levels were substantially higher. In light of continual efforts in pollution abatement, more evidence drawn from lower level air pollution is needed and particularly important for justifying more stringent regulations on power plants, which in the process of electricity generation become a significant pollution source.[1]

In this study we aim to provide causal estimates of the impact of prenatal exposure to power plant emissions on birth weight for the period from 1990s to early 2000s, and in particular, for a wealthy region of the United States, which has been less the focus in previous work. Despite mounting evidence suggesting adverse impact of prenatal exposure to air pollution on birth weight (Currie et al., 2014), causal estimates of that impact are still lacking. Such estimates are not only needed for proposing regulatory policies on power plant emissions, but also useful for inferring long-term impacts of those policies, on the basis of a robust association found in the literature between birth weight and outcomes during adulthood such as health, educational attainment and earnings (Currie and Rossin-Slater, 2015). The main outcome variable of our study is low birth weight (LBW), which is defined as birth weight below 2,500 grams. This focus of our study is also aimed at broadening the scope of public health benefits from reducing power plant emissions examined by the U.S. Environmental Protection Agency (EPA). Those public health benefits already examined by the EPA include the avoidance of premature mortality, nonfatal heart attacks, hospital and

[1] Emissions from coal-fired power plants contain particles, mercury, and acid gases such as sulfur dioxide. The U.S. Environmental Protection Agency has been using multiple regulations on power plant emissions, including the Acid Rain Program, the Clean Power Plan, the Mercury and Air Toxics Standards, and the Cross-State Air Pollution Rule (a replacement for the Clean Air Interstate Rule).

emergency room visits, acute bronchitis, upper and lower respiratory symptoms, aggravated asthma, and lost work days or school absences.

The causal inference of our study is based on a unique empirical setting, in which a power plant located on the border between two states has polluted the downwind state for years with its pollution spillovers scientifically proven by the downwind state and also by the federal government.[2] Specifically, two petitions filed by the New Jersey Department of Environmental Protection (NJDEP) with the EPA against a Pennsylvania power plant—the Portland Generating Station (PGS)—show that sulfur dioxide (SO_2) emissions from the PGS have reached four New Jersey counties as far as 20–30 miles away, and the EPA's independent investigation confirms that the PGS is the *sole* pollution source causing the downwind state to violate air quality standards set by the EPA. These findings of the NJDEP and the EPA are based on atmospheric dispersion modeling analysis, which is the dominant analysis used for air quality policy making that often requires examining how air pollutants disperse in the ambient atmosphere as well as estimating downwind ambient concentrations of air pollutants emitted from power plants. Therefore, the findings from the NJDEP's and the EPA's atmospheric dispersion modeling analyses provide our study with a credible basis that there are indeed air pollutants (SO_2) emitted from the PGS and then traveling into a region as far as 20–30 miles away downwind from the power plant.

For each residential zip code-year-month pair, we construct a binary variable on downwind status. One unique feature of the construction of this variable is the calculation of azimuth, which gives the bearing of a zip code relative to the power plant (measured in 0–360 degrees). We compare this bearing with the direction towards which the wind near the power plant blows (also measured in 0–360 degrees). If the difference between the two directions is less than 45 degrees, the downwind variable will be equal to one, indicating that the zip code is downwind of the power plant during that year and month.

[2]Common approaches to causal inference on the health effect of exposure to air pollution in the economics literature include the use of maternal fixed effects (Currie, Neidell, and Schmieder, 2009), or utilization of exogenous variations in air pollution levels induced by economic recessions (Chay and Greenstone, 2003) or caused by traffic congestions (Currie and Walker, 2011; Schlenker and Walker, 2016).

For our causal inference on the effect of prenatal exposure to power plant emissions on birth weight, we extract the arguably exogenous variation in the downwind variable by using it in conjunction with the zip code-calendar month of birth fixed effects (i.e., zip code-month fixed effects), which also accommodate zip code fixed effects. In doing so, we control for the distance between each residential zip code and the power plant (by using zip code fixed effects), and this distance could reflect the residential preference for avoiding the power plant; furthermore, we also aim to remove the seasonal variation (throughout all calendar months) in the wind direction near the power plant for each zip code (by using zip code-month fixed effects), since that seasonal variation can be predictable and thus correlated with unobserved contributors to birth outcomes (e.g., pollution avoidance behaviors). As a result, the remaining variation in the downwind variable is likely to be *unusual* seasonal variation in the wind direction for that zip code, which is driven by nature and arguably exogenous to unobserved factors affecting birth outcomes. Those factors, if not controlled for, will cause omitted variables bias in estimating the effect of prenatal exposure to power plant emissions on birth weight.

Our study utilizes the findings reported in the NJDEP's petitions on the impact region (including four New Jersey counties), which is identified through atmospheric dispersion modeling analysis. In one of the petitions the NJDEP's Bureau of Technical Services further conducted a trajectory analysis showing how SO_2 emissions from the power plant were transported through the air and reached the impact region. Based on the evidence provided in the NJDEP's petitions, we focus on an area that is within about 20–30 miles downwind of the power plant. We drop the zip codes that are next to the power plant from our analysis for two important reasons. First, people living in those zip codes near the power plant may choose to leave there or stay put, according to their own preferences for air quality; this residence choice induced by the proximity to the power plant generates an endogeneity problem for the exposure to power plant emissions. Second, possible presence of protection behaviors of residents who live close to the power plant can confound our inference on the pollution impact, since effective protection behaviors could countervail the pollution impact.[3]

The focal region of our study is a wealthy region of New Jersey, which is a wealthy state of the United States. One implication of this focus is that our findings on adverse health effects of exposure to power plant emissions can be an underestimation for a general population, due to the possibility of one positive correlation and two negative correlations. First, the literature shows that income is positively correlated with preference for good air quality (Banzhaf and Walsh, 2008). Thus, high-income households in their chosen residential areas may invest more in improving indoor air quality, for example, through the use of high-quality (and costly) air cleaners to remove indoor fine particles and gaseous pollutants. Second, the preference for good air quality can be negatively correlated with exposure to power plant emissions, and this negative correlation can be reflected in the residential choice of living 20 to 30 miles away from the power plant. Third, health care that is affordable for high-income households in our focal region can correlate negatively with adverse birth outcomes. Although the focal region of our study can cause an underestimation problem, from a policy perspective, an underestimation of the adverse health impact may still be meaningful, especially when policy-makers need to assess a minimum of adverse health impact that requires policy interventions.

The main findings of our study suggest that among babies born during 1990–2006 and born to mothers who live as far as 20–30 miles away and downwind from the power plant during the final stage of pregnancy, the likelihood of LBW could increase by approximately 0.4 percentage points or 6.5 percent. Adjusting SO_2 emissions by a zip code's downwind status, we further find that in response to an increase of 1,000 tons of SO_2 monthly emissions (roughly 4% of the power plant's annual SO_2 emissions) that come from upwind directions during the final stage of pregnancy, the likelihood of LBW could increase by about 0.15 percentage points or 2.44 percent. Our study's findings add to the existing findings from the

[3]Indoor air quality and outdoor air quality can be highly correlated (Andersen, 1972; Phillips et al., 1993). For ways of improving indoor air quality, see https://www.epa.gov/indoor-air-quality-iaq/improving-indoor-air-quality (accessed September 4, 2016).

atmospheric dispersion modeling analyses conducted by the NJDEP and the EPA by showing that SO_2 emitted from the power plant and transported by wind into New Jersey can have adverse health impact on newborns. Furthermore, our finding contributes to the literature on the effects of air pollution on infant health, summarized in Currie, Neidell, and Schmieder (2009, chart 1, p. 690), by utilizing wind direction as a new source of exogenous variation in identifying the causal effect of air pollution. One biological mechanism underlying our findings could be reactive sulfur species (RSS)-induced intrauterine oxidative stress (Giles and Jacob 2002), which has not been emphasized in the continuation of proposing more stringent regulations on power plant SO_2 emissions: sulfur emitted from power plants can form RSS, and there is evidence in the medical field showing adverse effects of intrauterine oxidative stress on fetal growth, with LBW being an outcome of significant intrauterine growth restriction (Al-Gubory, Fowler and Garrel 2010; Kannan et al., 2006).

In the following we describe the background of our study and the identification strategy in Section 2. Section 3 explains our data and methods. Section 4 discusses our empirical findings, and Section 5 concludes.

2 Research Design

2.1 Background

The Portland Generating Station (PGS, owned by GenOn REMA, LLC, then renamed to NRG REMA, LLC) is a coal-fired power plant, located on the west bank of the Delaware River in Upper Mount Bethel Township of Northampton County, Pennsylvania (shown in Figure 1). It is one of the only two large coal-fired power plants in Pennsylvania that immediately border New Jersey, and it is also the only coal-fired power plant without full controls of its emissions that immediately borders New Jersey.[4] According to the Environmental

[4] The other coal-fired power plant that immediately borders New Jersey, Eddystone Generating Station (located near Philadelphia, Pennsylvania), is a plant with controlled units.

Integrity Project (EIP)'s 2007 report, the PGS was ranked fifth among the top 50 dirtiest power plants for SO_2 by emission rate (with 28.30 lbs SO_2 per MWh).

On May 12, 2010, the NJDEP filed a petition with the EPA against the PGS, providing scientific evidence showing that the power plant *alone* has significantly hindered the National Ambient Air Quality Standards (NAAQS) attainment in Warren County, New Jersey. The petition also shows that in 2009, the power plant emitted 30,465 tons of SO_2, which was more than double the SO_2 emissions from all electricity-generating facilities in New Jersey *combined* (NJDEP, 2010a).

On June 2, 2010, the EPA promulgated a new primary standard of NAAQS for SO_2, under which the NJDEP filed a second petition with the EPA on September 13, 2010, providing scientific evidence further showing that the emissions from the PGS *alone* have caused violations of the one-hour SO_2 NAAQS in three additional New Jersey counties: Hunterdon, Morris, and Sussex (NJDEP, 2010b). In this petition the NJDEP's Bureau of Technical Services reported a trajectory analysis showing how SO_2 emissions from the power plant were transported through the air and reached the borough of Chester in Morris County, located about 21 miles east-southeast of the power plant.

On November 7, 2011, the EPA issued its ruling based on its independent assessment of the AERMOD[5] dispersion model and other technical analyses (EPA, 2011). The EPA concluded that the emissions from the PGS *alone* caused the violations of the SO_2 NAAQS in the downwind state, New Jersey; this ruling also marks the EPA's first-ever granting of a *sole-source* petition under the Section 126(b) of the Clean Air Act. In its ruling, the EPA also established specific emission limits for the power plant and required it to achieve and maintain these limits by 2015. On June 1, 2014, the coal-fired generating units of the power plant were shut down by its current owner, NRG REMA, LLC, and since then, the power plant has become a "peak plant," running only on days when the demand for electricity is high and using low-sulfur diesel fuel to generate electricity.

[5]AERMOD stands for the American Meteorological Society/Environmental Protection Agency Regulatory Model.

2.2 Identification Strategy

Our identification strategy relies on the scientific evidence provided in the NJDEP's petitions showing that SO_2 emissions from the PGS have reached four New Jersey counties by wind, as well as the scientific evidence provided in the EPA's independent investigation confirming the PGS to be the sole pollution source for the impacted region. It is possible that other air pollutants emitted from the PGS, such as nitrogen dioxide (NO_2) and carbon monoxide (CO), are also able to reach New Jersey through the prevailing wind in this region. However, both the NJDEP's petitions and the EPA's independent investigation have exclusively identified that it is SO_2 emitted from the PGS that has reached the four counties of New Jersey. One possible reason for this finding is that two processes—reaction with the hydroxyl radical (OH) and dry deposition, either of which can remove SO_2, NO_2 and CO from the atmosphere and therefore terminate their lifetime, are preventing less SO_2, but more NO_2 and CO, emitted from the PGS from affecting the downwind region. Longer lifetime of these gases will allow them to be transported in the atmosphere farther away from their origin. The lifetime of SO_2, based on the reaction with OH (at a typical atmospheric level of OH), is about one week; it is much longer than that of NO_2, which is about one day (Seinfeld and Pandis, 1998, p. 259 and p. 314). The average dry deposition velocities above land for SO_2 and NO_2 are about 0.8 and 0.02 centimeters per second, respectively (Möller, 2010, p. 448). When both processes are considered, the lifetime of SO_2 can be two days, but the lifetime of NO_2 can be one day only. Compared with SO_2, CO is a less stable gas. Unlike SO_2, whose reaction with OH requires oxygen (O_2, i.e., $SO_2 + OH + O_2 \rightarrow HO_2 + SO_3$), the reaction of CO with OH can occur either in the presence or in the absence of O_2 (i.e., $CO + OH \rightarrow H + CO_2$ or $CO + OH + O_2 \rightarrow CO_2 + HO_2$), which makes the lifetime of CO easier to be terminated than SO_2 in the presence of OH.

We use the difference between the direction towards which the wind near the power plant blows and the direction towards which a New Jersey zip code (where the mother lives) is located relative to the power plant (i.e., the azimuth) to construct a binary indicator of being downwind of the power plant for each residential zip code-year-month pair. If the difference between the two directions is less than 45 degrees, the downwind variable will be equal to one, and zero otherwise. Throughout our study we control for zip code-calendar month of birth fixed effects (henceforth referred to as zip code-month fixed effects), year-month of birth fixed effects (henceforth referred to as year-month or monthly fixed effects), and a large set of weather variables in conjunction with the variable on being downwind of the power plant. In doing so, we control for the distance between the power plant and a zip code, and this distance could reflect the residential preference for avoiding the power plant; the use of those fixed effects together with the weather variables also allows us to control for seasonality in birth outcomes and wind directions for each zip code, as well as unobserved determinants of birth outcomes that are common to each year-month birth cohort.

The use of zip code-month fixed effects also helps us remove the variation in the downwind variable that comes from seasonal changes in wind directions for a zip code, and thus, the resulting variation in the downwind variable is likely to come from *unusual* seasonal changes in wind directions for that zip code, which are driven by nature and arguably exogenous to unobserved factors affecting birth outcomes. Those factors, if not controlled for, will cause omitted variables bias in estimating the effect of prenatal exposure to power plant emissions on birth weight.

Among the four counties identified in the NJDEP's petitions Warren County is adjacent to the power plant (Figure 1). We drop the zip codes in Warren County that are next to the power plant[6] because residents in those zip codes could be aware of the potential impact of the power plant, and therefore they may have protection behaviors against the power plant's pollution, such as using air cleaners to improve indoor air quality that is affected by outdoor air pollution.[7] In our data there is no information on those behavioral responses. As a result, if those behavioral responses exist, the lack of controlling for them will confound our

[6]These zip codes are 07823, 07832, 07833 and 08865.

[7]For details about air cleaners for home use, see https://www.epa.gov/indoor-air-quality-iaq/guide-air-cleaners-home (accessed September 4, 2016).

causal inference. Another reason for excluding those zip codes from our analysis is the likely presence of sorting behaviors in choosing residential locations. People initially living close to the power plant may decide to migrate or stay put, according to their own preferences for air quality, which will generate an endogeneity problem for the exposure to power plant emissions.

Our study focuses on these four New Jersey counties identified in the NJDEP's petitions: Hunterdon, Morris, Sussex and Warren (except the zip codes that are next to the power plant), which is a wealthy region. All four counties except Warren belong to the New York-Northern New Jersey-Long Island Metropolitan Statistical Area (MSA). According to the U.S. Census Bureau, median annual household income (2008–2012) is $105,880 in Hunterdon, $97,979 in Morris, $85,507 in Sussex and $73,056 in Warren, all above the New Jersey average ($71,637) and the national average ($53,046).[8] The average general fertility rate (i.e., (total number of live births/total population women aged 15–44)$\times$1,000) of these four counties during 1995–2006 is 59.5, which is similar to the average general fertility rate (60.8) of the region including Bergen and Monmouth Counties, but lower than the New Jersey average (63.4), during the same period.[9] Like our study region, Bergen and Monmouth are wealthy New Jersey counties, both of which also belong to the New York-Northern New Jersey-Long Island MSA, but Bergen and Monmouth are located farther away from the Portland Generation Station. The similarity in general fertility rates of the two regions could be explained by the similar wealth level or similar labor market situation because of the shared MSA. Moreover, the similarity in general fertility rates of the two regions could suggest that women moving away from the Portland Generating Station after they made decisions to become pregnant, although plausible, is not prevalent in our study region. Furthermore, we examined the average general fertility rate of three counties in northern Virginia—Arlington County, Fairfax County, and City of Fairfax County—during 1995–2006, which is 59.6.[10]

[8]Source: http://quickfacts.census.gov/qfd/states/ (accessed June 2014).

[9]Source: https://www26.state.nj.us/doh-shad/query (accessed July 20, 2016).

[10]Source: https://www.vdh.virginia.gov/HealthStats/stats.htm (accessed July 20, 2016).

The median annual household income of these three northern Virginia counties is similar to our study region's, but the three northern Virginia counties are not exposed to significant emissions from nearby upwind power plants,[11] which could also suggest that the relative low general fertility rate of our study region (59.5) in comparison with the New Jersey average (63.4) could be associated closely with household income as opposed to exposure to emissions from the Portland Generating Station.

The focal region of our study is a wealthy part of the United States. This focus will limit the generalizability of our study's findings because what we find based on this wealthy region could be an underestimation of the actual impact of prenatal exposure to power plant emissions on birth outcomes for a general population. In addition to the reasons we give in the introduction section, the underestimation can be caused by our selected sample including newborns who are healthier than the general population because of better health care received by mothers of higher socioeconomic status who live in this wealthy region. Nonetheless, an underestimation of the adverse impact can still be meaningful for policy-makers when an assessment of a minimum "damage" is needed for considering policy interventions.

3 Data and Methods

3.1 Data

Our study uses six data sources: the State Inpatient Database (SID) of the New Jersey Healthcare Cost and Utilization Project (HCUP); the EPA's Air Markets Program Data (AMPD); Weather Source, LLC; the Global Historical Climatology Network Database (GHCND) of the National Climatic Data Center (NCDC); the EPA's Air Quality System (AQS); and the Zip Code Database.

The New Jersey HCUP's SID data we obtained are repeated cross sections for the period

[11] For more details, see http://www.virginiaplaces.org/geology/coalfired.html (accessed September 4, 2016).

of January 1990 through December 2006. The data contain inpatient discharge records for nearly all general acute care hospitals in New Jersey, including the information on the year and month of a birth and the birth weight. Our study focuses on live singleton births that occurred in New Jersey from 1990 to 2006, which constitute about 96.58% of all live births in New Jersey during that period. We drop multiple-birth cases because LBW among those cases could be caused by factors that are related to carrying multiple fetuses with a single pregnancy, not related to prenatal exposure to power plant emissions. We use the birth weight information among live singleton births to create indicators for LBW with birth weight below 2,500 grams, and VLBW with birth weight below 1,500 grams.

In the SID data we also have demographic variables on the sex and race of an infant and the health insurance status of the mother, but we do not have information on the mother's age and educational attainment. The SID data also lack information on gestational length, which prevents us from investigating LBW cases caused by preterm or identifying critical windows of prenatal exposure to power plant emissions through, for example, by-trimester analysis. The SID data provide mothers' residential zip codes, allowing us to merge the SID data with the other datasets by zip codes. For example, our zip code database provides the latitude and longitude of each zip code centroid for all 723 New Jersey zip codes.[12] We merged these geographic coordinates into the SID data for each mother's residential zip code.

From the EPA's AMPD we extracted data on the PGS's daily and monthly SO_2 emissions from January 1, 1995 to December 31, 2006, as well as the latitude and longitude of the power plant's location. Although the PGS started operation in 1958, there are no SO_2 emission data prior to 1995 for the PGS in the AMPD. Nonetheless, the lack of data from 1990 to 1994, which is the period covered by our HCUP's SID data, will not affect our main analysis focused on the impact of being downwind of the power plant on birth weight. The reason is that the variable on being downwind of the power plant requires the information on the wind direction near the power plant and the direction of a New Jersey zip code towards which it

[12] For details about this database, see http://www.zip-codes.com/zip-code-statistics.asp (accessed August 10, 2016).

is located relative to the power plant, not on the power plant's emissions.

From Weather Source, LLC we purchased data on wind directions measured hourly at the Allentown Lehigh Valley International Airport weather station, which is located in Pennsylvania and used for the NJDEP's petition filed with the EPA in May 2010. This is the weather station that is closest to the power plant with a complete series of wind direction data every day since January 1, 1960. The wind direction in that database is a continuous variable measured hourly on a 0–360 degree scale: 0-degree (or 360-degree) for wind coming from due North, 90-degree for wind coming from due East, 180-degree for wind coming from due South, and 270-degree for wind coming from due West. We calculated the daily and monthly average wind directions by taking *vector means*, not arithmetic means, of the hourly wind direction data. Note that wind directions are measured on a 0–360 degree scale. Both a 1-degree wind and a 359-degree wind represent a northerly wind. In this case taking the vector means of the two directions will result in 360 degrees, which indicates a northerly wind and is a valid average. In contrast, taking the arithmetic mean will result in 180 degrees, which indicates a southerly wind instead.

From the EPA's AQS we extracted data on SO_2 and $PM_{2.5}$[13] concentrations measured by the EPA's monitors located in New Jersey and the adjacent states (i.e., Delaware, Maryland, New York and Pennsylvania). For SO_2 we extracted the one-hour daily maximum concentrations measured in parts per billion (ppb), and for $PM_{2.5}$, we extracted the 24-hour daily maximum concentrations measured in microgram per cubic meter ($\mu g/m^3$).[14] Using the AQS data, we construct zip code-level monthly pollution variables for SO_2 and $PM_{2.5}$. Note that the EPA's monitors are not located in every zip code. To solve this problem, we follow Currie and Neidell's (2005) study and use their inverse-distance weighting with a chosen radius of 20 miles method. This method includes four steps. First, we compute a

[13] $PM_{2.5}$ stands for particulate matter that is smaller than 2.5 micrometer in diameter.

[14] The NAAQS primary standard for SO_2 uses the one-hour interval (source: https://www.epa.gov/criteria-air-pollutants/naaqs-table, accessed August 10, 2016). The NAAQS primary and secondary standards for $PM_{2.5}$ use the 24-hour interval (source: https://www.epa.gov/criteria-air-pollutants/naaqs-table, accessed August 10, 2016).

monthly simple average of SO_2 (or $PM_{2.5}$) concentration for each SO_2 (or $PM_{2.5}$) monitor. Second, we combine each New Jersey zip code with all SO_2 (or $PM_{2.5}$) monitors. Using the latitudes and longitudes of each zip code centroid and the paired SO_2 (or $PM_{2.5}$) monitor, we calculate the *geodetic distance* between the zip code centroid and the paired SO_2 (or $PM_{2.5}$) monitor.[15] Third, using the calculated geodetic distance, for each zip code centroid we select SO_2 (or $PM_{2.5}$) monitors that are within 20 miles of that zip code centroid. Fourth, we obtain the zip code-level monthly SO_2 (or $PM_{2.5}$) concentration by taking a weighted average of the monthly SO_2 (or $PM_{2.5}$) concentrations obtained in the first step (i.e., the monitor-level monthly simple averages) and among the monitors selected in the third step; the weight is equal to the inverse of the geodetic distance between the zip code centroid and the paired SO_2 (or $PM_{2.5}$) monitor. In the end, the numbers of SO_2 monitors included in the 20-mile radius in Hunterdon, Morris, Sussex and Warren are 5, 7, 1 and 4, respectively; and the numbers of $PM_{2.5}$ monitors included in the 20-mile radius in Hunterdon, Morris, Sussex and Warren are 10, 19, 2 and 6, respectively. In these four counties the average numbers of monthly monitor readings included in the construction of zip code-level monthly pollution variables within the 20-mile radius are 2.11 and 2.43 for SO_2 and $PM_{2.5}$, respectively (reported in Table 3).

We obtained other weather variables from the NCDC's GHCND:[16] daily mean temperature, daily maximum temperature, daily minimum temperature, total monthly rainfall, total monthly snowfall, number of days in a month with minimum temperature less than or equal to 0.0 Fahrenheit, number of days in a month with minimum temperature less than or equal to 32.0 Fahrenheit, number of days in a month with maximum temperature greater than or equal to 90.0 Fahrenheit, number of days in a month with maximum temperature less than or equal to 32.0 Fahrenheit, number of days in a month with greater than or equal to

[15] Throughout our study we use the geodetic distance (a.k.a. geodesic distance) for the distance between two places on the earth.

[16] The start year of these weather data is 1989, one year prior to the start year of our HCUP data (i.e., 1990), to accommodate lagged weather variables used in the regression analysis of births that occurred in 1990.

1.0 inches of precipitation, and extreme maximum daily precipitation total within a month (measured in inches). We also construct zip code-level monthly weather variables, using the variables obtained from the NCDC's GHCND with the following three steps. First, we combine each New Jersey zip code with all weather stations included in our NCDC's GHCND data. Using the latitudes and longitudes of each zip code centroid and the paired weather station, we calculate the geodetic distance between the zip code centroid and the paired weather station. Next, using the calculated geodetic distance, for each zip code centroid we select weather stations that are within 20 miles of that zip code centroid. Lastly, we obtain the zip code-level monthly varied weather variables by taking weighted averages of the variables we obtained from the NCDC's GHCND and among the weather stations selected in the previous step, with the weight given by the inverse of the geodetic distance between the zip code centroid and the paired weather station.

3.2 Construction of the Downwind Variable

We construct a binary variable indicating whether a zip code is downwind of the power plant for each year-month of the sample period, using a three-step procedure. First, we measure the direction in which each New Jersey zip code centroid (point B, the "destination") is located relative to the power plant (point A, the "origin") by using an angle called "azimuth" ranging from 0 to 360 degrees. The azimuth of B relative to A is the angle between the vector $\overrightarrow{\text{AB}}$ projected onto a horizontal plane and the reference vector, which is due North, on that plane. By definition, the reference vector on that plane has an azimuth of zero degree, and accordingly, moving clockwise on a 360-degree circle, an azimuth of 90 degrees, 180 degrees, or 270 degrees means that B is due East, due South, or due West of A, respectively. The calculation of an azimuth uses the latitudes and longitudes of A and B, and it is direction specific: the azimuth of B relative to A and the azimuth of A relative to B are different by 180 degrees.

In the second step, we convert the wind direction recorded in the Weather Source database as where the wind *comes from* into the direction measured as where the wind *blows*, which henceforth is referred to as the wind vector azimuth. For example, a wind coming from due West is recorded as a wind with a direction of 270 degrees in the Weather Source database. We subtract 180 from the 270 degrees and convert that record into a 90-degree wind direction; we will add 360 degrees if the subtraction used by the conversion results in a negative value. In our analysis that 90-degree wind direction means a wind blowing towards due East and the 90-degree is referred to as the wind vector azimuth.

In the third step, we generate the indicator of being downwind of the power plant based on the difference between the direction towards which a New Jersey zip code is located relative to the power plant (henceforth referred to as the zip code azimuth, θ_{zip}) and the monthly average direction towards which the wind near the power plant blows (i.e., the monthly average wind vector azimuth, $\theta_{\text{wind}}^{\text{monthly}}$): this indicator is equal to one if the absolute value of the difference is less than 45 degrees (i.e., $\left|\theta_{\text{zip}} - \theta_{\text{wind}}^{\text{monthly}}\right| < 45$), and zero otherwise (i.e., $\left|\theta_{\text{zip}} - \theta_{\text{wind}}^{\text{monthly}}\right| \geqslant 45$).

3.3 Regression Model

We use the following regression model for our main analysis:

$$\begin{aligned} y_{i,jt} &= \alpha_0 D_{jt} + \alpha_1 D_{j,t-1} + \alpha_2 D_{j,t-2} + \mathbf{x}_i'\beta + \mathbf{w}_{jt}'\gamma_0 + \mathbf{w}_{j,t-1}'\gamma_1 + \mathbf{w}_{j,t-2}'\gamma_2 \\ &\quad + \text{zip code-month fixed effects} + \text{year-month fixed effects} + \text{error term}_{i,jt}. \quad (1) \end{aligned}$$

Here, $y_{i,jt}$ denotes the birth outcome (e.g., LBW or VLBW) of infant i whose mother living in zip code j gives the birth at time t, where t indexes the year and month of the birth (ranging from January 1990 to December 2006). We use a comma between the subscripts i and jt to emphasize that our data are repeated cross sections: there is no identifier for infant i's mother in our data, and therefore we are unable to use mother fixed effects for infants who were born to the same mother.

The binary indicator for zip code j's downwind status at time t is denoted by D_{jt} in equation (1). In our data we have information on the year and month of a birth, but we do not have information on gestational length. As a result, we do not know when the pregnancy starts. Nonetheless, we include the downwind indicator for the birth month (D_{jt}) and also for the two months prior to the birth month ($D_{j,t-1}$ and $D_{j,t-2}$) into our regression model, to capture the impact of maternal exposure to power plant emissions during the final stage of the pregnancy; for a normal pregnancy, this three-month period is largely the third (and last) trimester.

In equation (1) $\mathbf{x}_i$ includes sex and race (White, Black, Hispanic or Asian) of infant i, and the health insurance status (Medicare, Medicaid, private insurance or self-pay) of i's mother; $\mathbf{w}_{jt}$ includes weather variables for zip code j at time t (whose constructions were explained in the previous section): daily mean temperature, daily maximum temperature, daily minimum temperature, total monthly rainfall, total monthly snowfall, number of days in a month with minimum temperature less than or equal to 0.0 Fahrenheit, number of days in a month with minimum temperature less than or equal to 32.0 Fahrenheit, number of days in a month with maximum temperature greater than or equal to 90.0 Fahrenheit, number of days in a month with maximum temperature less than or equal to 32.0 Fahrenheit, number of days in a month with greater than or equal to 1.0 inches of precipitation, and extreme maximum daily precipitation total within a month. We estimate the regression model (equation 1) by ordinary least squares (OLS). The standard errors of our OLS estimations are clustered at the zip code level.

3.4 Descriptive Statistics

Table 1 reports summary statistics related to power plant emissions, wind directions, downwind status, and weather. Specifically, it shows that on a monthly basis the wind near the power plant on average blows southeastwards (about 139 degrees shown in Panel A). Figure 2 further demonstrates the variations in the wind directions over the entire sample period

(Panel A) and for each calendar month of the sample period (Panel B): on average, the wind near the power plant blows southeastwards in every calendar month, with the range of the wind directions between 116.1 degrees (in June) and 155.1 degrees (in September).

In Table 1 we see that among the four counties identified in the NJDEP's petitions, Hunterdon is most aligned with the wind direction (indicated by the average value of the downwind variable, 0.7461, shown in Panel B), followed by Warren (with the average value equal to 0.5724) and Morris (with the average value equal to 0.5450); Sussex is least aligned with the wind direction (with the average value equal to 0.1383), although its distance to the power plant (about 25.08 miles) is similar to Hunterdon's (about 25.21 miles). Figure 3 demonstrates the power plant's monthly SO_2 emissions for the four New Jersey counties adjusted by the downwind status. The direction-adjusted monthly SO_2 emission is calculated by the product of the actual monthly SO_2 emission and the downwind variable defined in Section 3.2 that varies monthly and by zip code. The lowered levels in the direction-adjusted SO_2 emissions (shown in Figure 3) come from the fact that none of the four counties are perfectly downwind of the power plant. In addition, Figure 3 highlights the presence of seasonal changes in SO_2 levels. To take these seasonal changes into account, we control for several important weather variables (together with the zip code-month fixed effects and the year-month fixed effects) described in Section 3.3.

Table 2 reports the summary statistics obtained from the HCUP data. Among all live singleton births in New Jersey during our sample period, the LBW and VLBW rates are 6.10% and 1.11%, respectively, which are on par with the national rates (6.15% for LBW and 1.11% for VLBW).[17] For the four New Jersey counties (Hunterdon, Morris, Sussex and Warren), the LBW rates among live singleton births are all much lower than the New Jersey average, suggesting that the sample of our main analysis includes newborns who are healthier on average than the general population.

[17] The national LBW and VLBW rates among all live singleton births are obtained from the CDC WONDER Online Database (http://wonder.cdc.gov/natality.html, accessed on August 9, 2016) averaged over the period of 1995–2006. The earliest year in this database is 1995.

4 Results

4.1 First-Stage Analysis

To check the quality of our wind direction data, which is key to the construction of our downwind variable, we conduct a first-stage analysis on the impact of the power plant's SO_2 emissions on SO_2 levels measured at the New Jersey zip code level, using the EPA's AQS data.[18] If our findings are consistent with the findings from the atmospheric dispersion modeling analyses independently conducted by the NJDEP (reported in its two petitions) and by the EPA (reported in its ruling), we would have the assurance that our use of data on wind directions measured near (not precisely at) the power plant is valid, even though we do not have the exact data used by the NJDEP and the EPA for their atmospheric dispersion modeling analyses. Furthermore, we examine the effects of the power plant's SO_2 emissions on $PM_{2.5}$ levels at the New Jersey zip code level, to check whether our results are consistent with the literature about SO_2 being a major precursor to ambient $PM_{2.5}$ concentrations.

Table 3 reports the results on this first-stage analysis. Our results are consistent with the findings of the NJDEP's and the EPA's atmospheric dispersion modeling analyses, and our results also suggest that SO_2 could be a precursor to ambient $PM_{2.5}$ concentrations in our study region. Specifically, Panel A (or B) shows that on a monthly basis, SO_2 (or $PM_{2.5}$) levels measured at zip codes of the four counties identified in the NJDEP's petitions could increase by about 8.4153 ppb (or 0.3383, shown in column 2) as a result of increasing 1,000 tons of SO_2 emissions from the power plant that are in a perfectly upwind direction, that is, when the direction towards which a zip code is located relative to the power plant is the same as the direction towards which the wind blows near the power plant.[19] The magnitude

[18] The EPA's AQS data used for this air pollution analysis are from 2004 to 2006 (the last three years of our study's sample period). The number of observations on $PM_{2.5}$ in the EPA's AQS for the early years of our study's sample period is very small.

[19] The monthly SO_2 emissions from the power plant that are in a perfectly upwind direction is calculated by the power plant's daily SO_2 emissions multiplied by Z, and then aggregated to the zip code-monthly level, where Z is equal to $(1/2)\times$[cosine(daily average wind vector azimuth - New Jersey zip code azimuth) + 1]; Z is set to be one for the power plant's emissions that are in a perfectly upwind direction.

of the estimated effect becomes smaller when we drop Warren County from the estimation sample (column 1). This can be explained by the fact that among the four counties Warren is closest to the power plant (Figure 1). Furthermore, we do not find any local pollution effects in the cases of SO_2 and $PM_{2.5}$ from the power plant's SO_2 emissions in zip codes that are at least 100 miles away from the power plant (column 3).

In Table 4 we report the results on our examination of the difference in the observable characteristics that are available in our data by the downwind status of the mother's residential zip code. The observable characteristics examined here are the infant's race and ethnicity and the mother's health insurance status. We find that infants born to mothers living in downwind zip codes are slightly more likely be White (with an increase of 0.54 percentage points, column 1), and their mothers are slightly more likely to have private health insurance (with an increase of 1.03 percentage points, column 6) and slightly less likely to have to self pay for the childbirth (with a decrease of 0.55 percentage points, column 7). Although these results are not conclusive because of the limited set of observable characteristics that are available in our data, they at least suggest that large-scale moving away from the power plant among high-income mothers who typically have private insurance is unlikely in our study's empirical setting. Nonetheless, we control for those aforementioned observable characteristics throughout our regression analyses.

4.2 Main Results

Table 5 reports the estimates of the effects of being downwind of the power plant on LBW and VLBW. Overall, we find that among mothers living in the four counties (except the zip codes that are next to the power plant) with their residential zip codes lying within 45 degrees of the wind direction during the last month of pregnancy, the LBW likelihood increases by about 0.4 percentage points or 6.50% (i.e., 0.004/0.0615), and the VLBW likelihood increases by about 0.19 percentage points or 17.12% (i.e., 0.0019/0.0111). Our estimates are robust to alternative specifications with the preferred specifications listed in columns

(3) and (6). Specifically, the robustness of the estimates between columns (1) and (3) (and between columns 4 and 6) suggests that the variations in the downwind variables are plausibly exogenous to the individual level demographic variables controlled for in our regression analysis. One reason for those variations being plausibly exogenous is that the variations used in the downwind variables, after we control for zip code-month fixed effects and year-month fixed effects, are driven by unusual seasonal changes in wind directions, which are not foreseeable by individuals and therefore independent of the individuals' demographic characteristics. To check the validity of our regression model specifications, we include the term for being downwind of the power plant during the month after birth. In columns (2) and (5), we find no statistically significant coefficients for that term, which is consistent with the fact that there is no impact from maternal exposure to power plant emissions after birth on infant health outcomes measured at birth.

The results in Table 5 suggest that the effect on LBW (or VLBW) could be driven mainly by the exposure during the last month (or last two months) of pregnancy. However, these results are inconclusive, especially for the early stage of pregnancy, because we are unable to control for maternal exposure to the power plant for the entire length of the pregnancy due to the lack of information on gestational length. Nonetheless, our results are consistent with the medical literature, where most epidemiological studies find adverse effects on birth outcomes of prenatal exposure to air pollution to be concentrated in the first or the third trimester of a pregnancy. For example, four articles reviewed in Maisonet et al. (2004) examined the relationship between air pollution exposure and LBW among full-term births. Three out of the four show that the exposure in the third trimester has positive effects on full-term LBW, and one study shows that the exposure in first trimester has positive effects on full-term LBW.

In our data we have information on the year and month of a birth, but we do not have the information on the exact date of that birth. As a result, we are unable to distinguish births that occurred during the first half of a month from births that occurred during the second half of that month. In Table 5 we find that the effect on LBW of being downwind of the power plant is statistically significant in the month of a birth, but the effect in the month prior to the birth is statistically insignificant and the magnitude is close to zero. One explanation for these results could come from the study by Huynh et al. (2006), who find that greater exposure to $PM_{2.5}$ (particles that are contained in emissions from coal-fired power plants) during the *last two weeks* of a pregnancy is associated with a higher likelihood of LBW. Thus, the month of a birth used by our study as an exposure period, although not ideal, is still meaningful not only for those born in the second half a month, who have a nearly full month of exposure, but also for those born in the first half of that month, who without a full month of exposure nonetheless have the exposure period that falls within the critically important exposure period of the last two weeks of a pregnancy. As a robustness check, we code the month of a birth and the month prior to the birth as a single variable, and then we repeat our estimations conducted in Table 5. The results, which are reported in Appendix Table 1, are consistent with the results in Table 5: the coefficients of the merged exposure period (in Appendix Table 1) are all statistically significant, and the estimates of those coefficients (in Appendix Table 1) are approximately the sums of the estimates for the birth month and the estimates for the prior month.

4.3 Potential Mechanism

We further examine the effect of being downwind of the power plant on LBW by sex, given that the literature on the impact of prenatal exposure to air pollution on LBW finds that male and female fetuses can respond differently to a compromised intrauterine environment, thus making the effect differ by sex. Our findings are reported in Table 6. Because we are unable to control for maternal exposure to the power plant during the early stage of a pregnancy, our results are not conclusive on how exactly the effect of being downwind of the power plant on LBW differs by sex. Nonetheless, results in Table 6 suggest that the adverse effect of prenatal exposure to power plant emissions on LBW could be most salient during the last month of pregnancy for males (column 2), while the adverse impact could occur earlier for females (column 3).

In Table 6 we also examine the effect on LBW of prenatal exposure to the power plant's SO_2 emissions that are adjusted by a zip code's downwind status on a year-month basis. Specifically, we multiply the power plant's monthly SO_2 emissions by the downwind variable we constructed, to get direction-adjusted SO_2 emissions that vary not only monthly but also by zip code. We find that in response to an increase of 1,000 tons of the power plant's SO_2 monthly emissions[20] that come from upwind directions during the last month of pregnancy, the likelihood of LBW increases by about 0.15 percentage points (Panel B, column 1) or 2.44% (i.e., 0.0015/0.0615).

One potential biological mechanism explaining the results in Panel B of Table 6 is reactive sulfur species (RSS)-induced intrauterine oxidative stress. Intrauterine oxidative stress usually is induced by an imbalance between antioxidants and cellular reactive oxygen species (ROS) production *in utero*, whose adverse effects on fetal growth have been confirmed (Al-Gubory, Fowler and Garrel 2010; Kannan et al., 2006). Nonetheless, Giles and Jacob's (2002) study further points out that oxidative stress can also be induced by RSS. This RSS-induced oxidative stress could potentially explain, to some extent, about the results in Panel B of Table 6 showing the linkage between LBW and the power plant's SO_2 emissions.

Another explanation for the linkage between SO_2 emissions and LBW is the inhaled particulate matter that comes from SO_2. When emitted into the atmosphere, SO_2 can react with other substances to form sulfates, which are components of $PM_{2.5}$. In the United States, sulfates have been found to be the major ingredient of particulate matter pollution east of Mississippi (Schneider and Bank, 2010) and for areas downwind of coal-fired power plants (EIP, 2007). Kannan et al. (2006) also show that exposure to particulate matter pollution could lead to adverse birth outcomes, such as LBW, through several channels including oxidative stress.

[20] The increase considered here is approximately 4% of the average annual SO_2 emissions from the PGS during 1995–2006, which is 25432.41 tons (not shown in Table 1).

4.4 Additional Robustness Checks

For our main results reported in Table 5 we conduct two additional robustness checks on the results. One robustness check uses a zip code-monthly level analysis, given that the downwind variables used in Table 5 vary monthly and only by zip code. The results of this robustness check are reported in Appendix Table 2, and they are very similar to the results in Table 5, despite the fact that the sample size of the zip code-monthly level analysis (i.e., 18,261) is only 12.4 percent of the sample size used in the main analysis reported in Table 5 (i.e., 147,382). In the second robustness check we add back the zip codes dropped from our main analysis because of their proximity to the power plant. The results of this robustness check are reported in Appendix Table 3: the estimates of the adverse effects on LBW and VLBW become smaller than those reported in Table 5, which is consistent with the previously given explanation that people living close to the power plant may have protection behaviors against the power plant's pollution (e.g., using air cleaners to improve indoor air quality that is affected by outdoor air pollution) and these protection behaviors could mitigate the adverse effects from exposure to the power plant's emissions.[21]

Furthermore, we conduct a falsification check and report the results in Appendix Table 4. For this check, we select two counties that are downwind but far away from the power plant: neither county is supposed to be affected by the emissions from the power plant because of the long distance and also the fact that neither county is in the impacted region identified in the NJDEP's petitions. One is Hudson County, which is far east of the power plant and also one of the most populous counties in New Jersey, and the other is Cape May County, which is farthest away from the power plant. If we find any adverse effects on birth outcomes of being downwind of the power plant in these two counties when in fact the two counties are not exposed to the power plant's emissions, it will indicate the presence of zip

[21] In addition, we also construct a continuous measure for how downwind of the power plant a zip code is by using a cosine function of the difference between the monthly direction towards which the wind near the power plant blows and the New Jersey zip code azimuth. The results of using this continuous measure are qualitatively similar to those reported in Table 5 and they are available upon request.

code-level monthly varied factors omitted from our regression model that are correlated with both the downwind variable we constructed and birth outcomes. Not controlling for those zip code-level monthly varied factors will incur an omitted variables bias in estimating the effects of being downwind on birth outcomes. In Appendix Table 4 we find no effects on birth weight and LBW of being downwind of the power plant in these two counties, which suggests that our findings (reported in Table 5) on the adverse health effects of being downwind of the power plant are unlikely to be driven by zip code-level monthly varied factors that are uncontrolled by our regression analysis.

5 Conclusion

Our study examines the impact of prenatal exposure to power plant emissions on birth weight. We draw scientific evidence independently provided by the NJDEP and by the EPA on the impact region downwind of a large polluter, a coal-fired power plant ascertained to be the sole pollution source causing the air quality standards violations of the impact region. We find that among all live singleton births that occurred during 1990–2006, those born to mothers who live as far as 20 to 30 miles away downwind from the power plant during the final stage of pregnancy are at greater risks of LBW and VLBW: the likelihoods of LBW and VLBW could increase approximately by 6.50 percent and 17.12 percent, respectively. Furthermore, using SO_2 emissions adjusted by a zip code's downwind status, we find suggestive evidence that an increase of 1,000 tons of SO_2 monthly emissions (roughly 4% of the power plant's annual SO_2 emissions) that come from upwind directions during the final stage of pregnancy could increase the likelihood of LBW by about 0.15 percentage points or 2.44 percent.

These results extend the scope of the existing findings from the atmospheric dispersion modeling analyses conducted by the NJDEP and the EPA by showing that SO_2 emissions from the power plant can have adverse health effects on newborns, in addition to the pollution impact on air quality. Our findings could also shed light on a biological mechanism that can be important for justifying more stringent regulations on power plant SO_2 emissions: sulfur emitted from power plants can form reactive sulfur species, which can induce intrauterine oxidative stress (Giles and Jacob 2002); intrauterine oxidative stress can have adverse effects on fetal growth (Al-Gubory, Fowler and Garrel 2010; Kannan et al., 2006), and LBW results from significant intrauterine growth restriction.

The empirical setting of our study highlights a case of cross-state air pollution caused by transboundary power plant emissions. In fact, in the United States the East Coast states have been pitted in a constant battle against the Midwestern states over the westerly wind that can transport air pollutants from coal-fired power plants in the Midwest to the East Coast states. Despite continual efforts by the state and the federal governments in reducing power plant emissions that cross state lines,[22] the empirical setting of our study demonstrates a realized possibility that a coal-fired power plant located on the border between two states pollutes the downwind state for years without being controlled. In the absence of direct regulations on power plants by the federal government (e.g., the EPA), transboundary power plant emission problems will be dealt with mainly by individual states. However, incentives for regulating a power plant located on the border between two states can be significantly different between the downwind state and the upwind state: the former receives the immediate cross-border air pollution, while the latter in regulating power plants within its border can have different priorities, especially when comparing areas with different levels of pollution damage. For example, as Henry, Muller and Mendelsohn (2011) point out, the current cap-and-trade program used for regulating SO_2 emissions could potentially result in emissions being relocated from low damage area to high damage area, given that pollution abatement costs are usually higher in high damage area (e.g., urban area) than in low damage area (e.g., rural area). One practice of avoiding pollution abatement costs is postponement

[22] These efforts include, for example, the State Implementation Plan on the basis of the Clean Air Act's "Good Neighbor" Provision (i.e., Section 110(a)(2)(D)), and the EPA's Clean Air Interstate Rule promulgated in 2005, which was replaced by the EPA's Cross-State Air Pollution Rule in July 2011 (source: https://www3.epa.gov/airtransport/CSAPR/index.html, accessed September 3, 2016).

of installing emission controls, such as the flue gas desulfurization (FGD, a.k.a. "scrubbers") for SO_2 emissions, by some of the oldest and dirtiest coal-fired power plants: "Unfortunately, not all power companies are committed to cleaning up their dirtiest plants, choosing instead to buy their way out of emissions caps." (EIP, 2007, p. 1). According to an EPA's report, as of March 2015, there is still 18 percent of electricity generation (measured by MWh) coming from coal-fired power plants without SO_2 emission controls.[23] The empirical setting examined by our study highlights a case where federal regulations imposed directly upon pollution sources are needed, and such regulations are also examples of currently debated spatial regulations of air pollution "hot spots" (Turaga, Noonan, and Bostrom, 2015).

Our study's findings can be meaningful for broadening the scope of public health benefits from reducing power plant emissions by taking infant health into account in light of a large literature showing adverse effects of infant LBW. Furthermore, our results can also be useful for inferring the long-term impact of reducing power plant emissions, given that there is a robust association found in the literature between improved birth weight and improved outcomes during adulthood such as health, educational attainment and earnings (Currie and Rossin-Slater, 2015), with the following caveats.

First, our findings may not be generalizable to other states, noting that in terms of median annual household income New Jersey is now the second wealthiest state in the United States (behind the state of Maryland) and the region focused by our study is a wealthy part of New Jersey.

Second, based on our data we are able to identify infant weights of live births only, which will incur a bias from "survival of the fittest." Our findings are only valid for a population of survivors who experience an adverse event *in utero*. Thus, using the sample of survivors to estimate the health effect of the adverse event *in utero* is likely to be biased downward. As a result, our study could understate the true health impact of prenatal exposure to power plant emissions for all fetuses.

[23] Source: https://www3.epa.gov/airmarkets/progress/reports/emission_controls_and_monitoring.html (accessed September 3, 2016).

Third, we lack the data on certain key information, such as gestational age (i.e., the length of a pregnancy), which may help to pinpoint a critical period of fetal development that makes a fetus most vulnerable to power plant emissions. In this study, we are unable to examine by each trimester of a pregnancy the effects of prenatal exposure to power plant emissions on infant birth outcomes. We are also unable to investigate the impact of prenatal exposure to power plant emissions on preterm birth (i.e., birth of a baby before the 37th week of a pregnancy), one cause of LBW. Hence, our results indicate an indirect health effect, at best, of prenatal exposure to power plant emissions, or evidence for the rejection of a null hypothesis that there is no effect of maternal exposure to power plant emissions during pregnancy on LBW for our study region.

Fourth, although both the NJDEP's petitions and the EPA's independent investigation have exclusively identified that it is SO_2 emitted from the Portland Generating Station that has reached New Jersey, it is possible that other air pollutants emitted from the power plant (e.g., NO_2 and CO) are also able to reach New Jersey through the prevailing wind in our study region. As a result, we are unable to decompose the adverse health effects found in our study into components that are attributable to specific air pollutants emitted from the power plant.

For the proposal and design of environmental policies that seek to protect public health and improve social welfare, overcoming the aforementioned limitations is needed, possibly through the acquisition of more comprehensive and detailed data. The findings of our study should be viewed with caution in light of those limitations. Nonetheless, our identification strategy based on wind directions could be useful for studies that consider the impact of emissions from power plants located in upwind states, which have been the targets of a series of environmental regulations, such as the EPA's Cross-State Air Pollution Rule.

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Figure 1: The Portland Generating Station and the New Jersey Counties

Note: The solid dot on the map represents the location of the Portland Generating Station (PGS), which is in Northampton County of Pennsylvania.

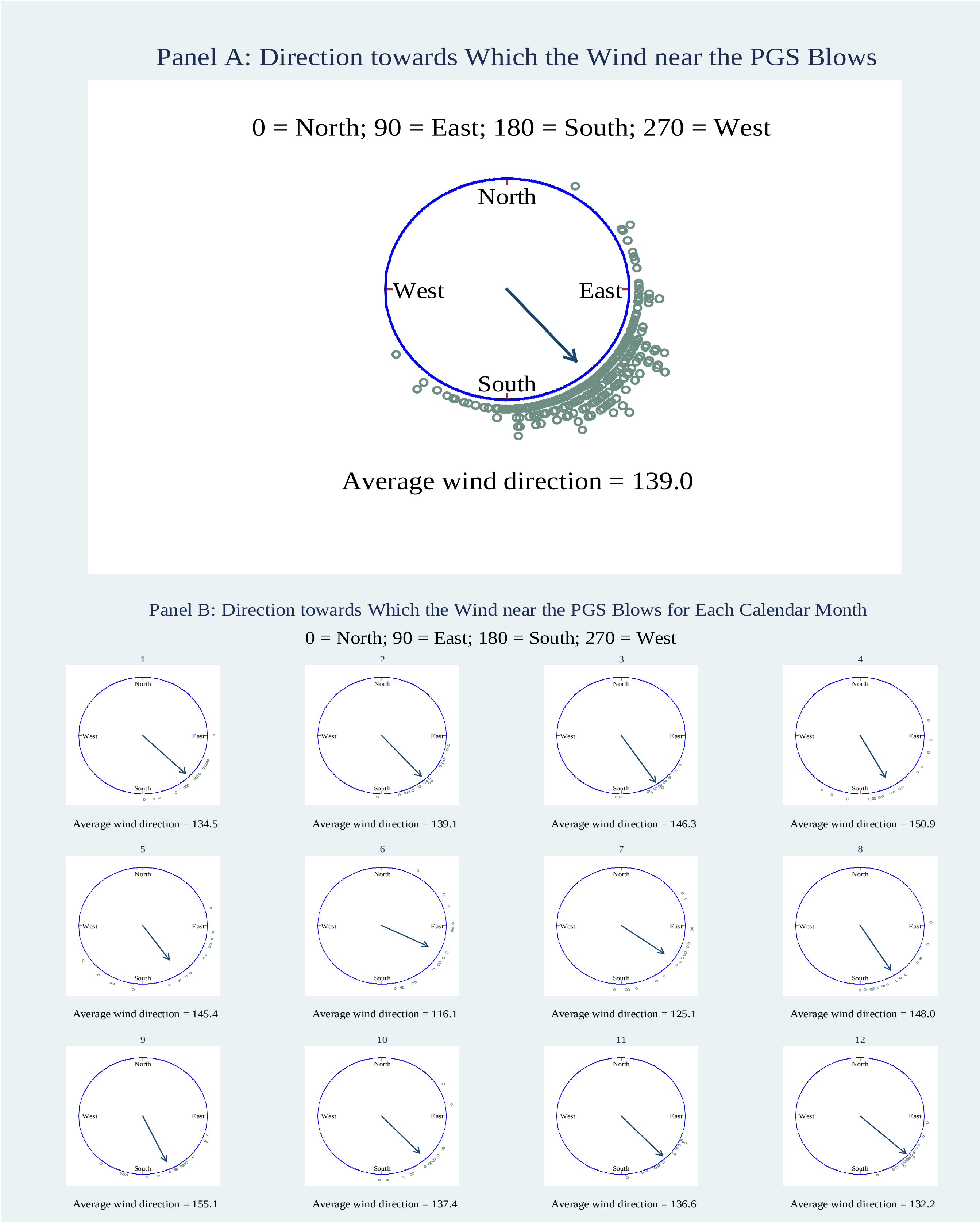

Figure 2: Wind Directions near the Portland Generating Station

Note: In Panel A, the average wind direction is the monthly average over the period of 1990–2006. In Panel B, the average wind directions are the monthly averages by calendar month (January through December) over the period of 1990–2006. In each plot point symbols (hollow circles) represent observations of wind directions that are measured on a 0–360 degree scale, and the arrow from the center of a circle indicates the resultant average wind direction.

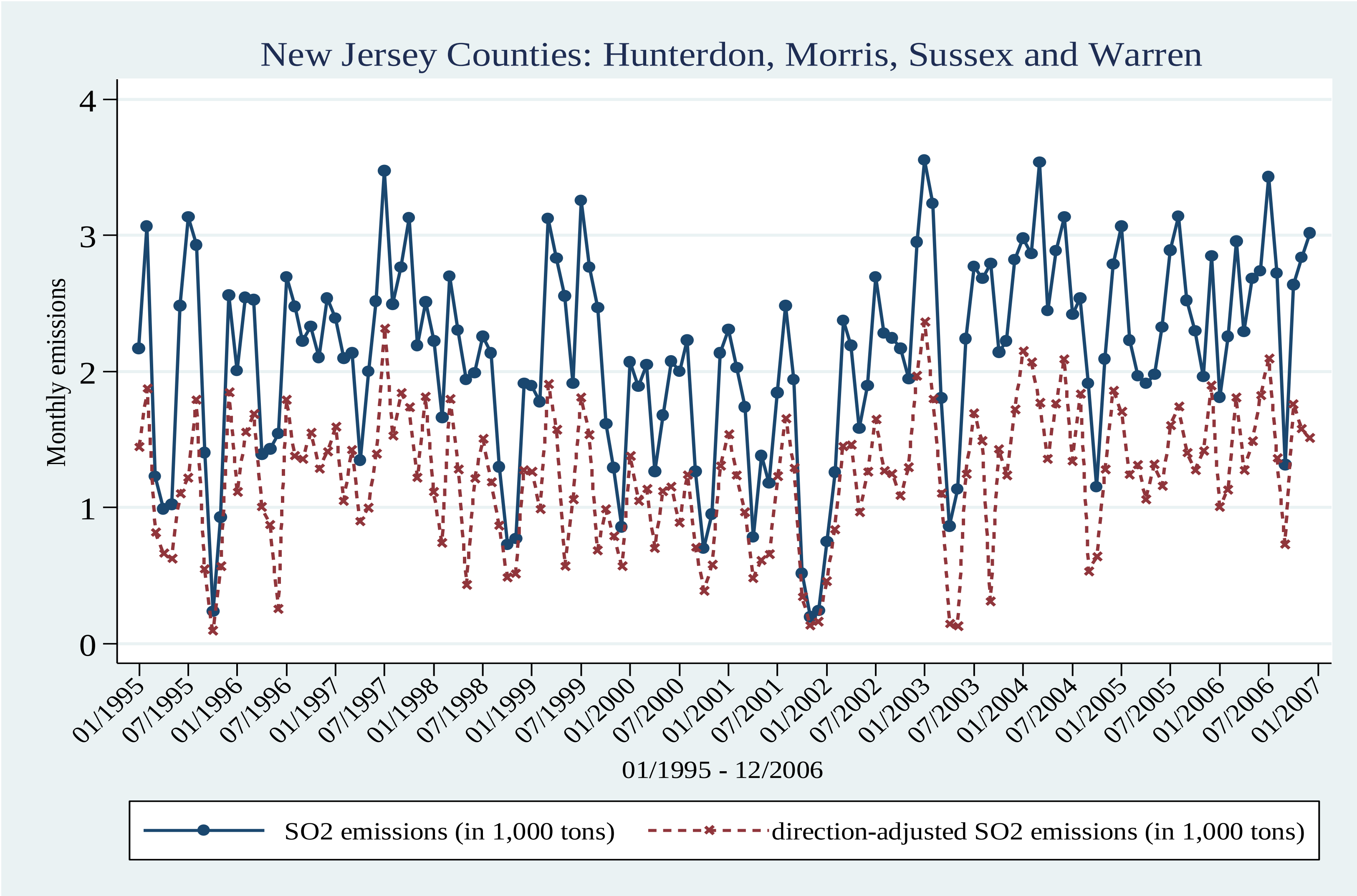

Figure 3: Sulfur Dioxide Emissions from the Portland Generating Station

Note: The direction-adjusted monthly sulfur dioxide emissions from the power plant are calculated by the power plant's monthly sulfur dioxide emissions × D, where D = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise. Azimuth is used for the direction towards which the wind near the power plant blows and also for the direction towards which a zip code is located relative to the power plant.

Table 1: Summary Statistics, Part I

Panel A: Portland Generating Station (PGS), a coal-fired power plant located in Pennsylvania	
PGS SO_2 monthly emissions (in 1,000 tons)	2.1193
	(0.7299)
Number of observations (monthly from 01/1995 to 12/2006)	144
Monthly average direction (in degrees) towards which the wind near the PGS is blowing (i.e., wind vector azimuth): 0 = North, 90 = East, 180 = South, 270 = West	138.9642
	(31.9769)
Number of observations (monthly from 01/1990 to 12/2006)	204

Panel B: New Jersey counties	Hunterdon	Morris	Sussex	Warren
Distance (in miles) between a New Jersey zip code centroid and the PGS	25.2071	30.6386	25.0767	10.1585
	(5.8932)	(6.7149)	(7.6035)	(3.7397)
Direction (in degrees) towards which a New Jersey zip code is located from the PGS (i.e., New Jersey zip code azimuth): 0 = North, 90 = East, 180 = South, 270 = West	157.5134	98.2254	57.4196	125.7527
	(15.4119)	(10.4471)	(14.9601)	(44.5407)
Downwind (1/0): equal to one if the difference between monthly average wind vector azimuth and New Jersey zip code azimuth is less than 45 degrees, and zero otherwise	0.7461	0.5450	0.1383	0.5724
	(0.4353)	(0.4980)	(0.3453)	(0.4948)
Number of zip codes	28	55	27	18
Number of observations (zip code-monthly from 01/1990 to 12/2006)	5,712	11,220	5,508	3,672

Panel C: Weather variables at the zip code-monthly level		
New Jersey Counties:	Hunterdon, Morris, Sussex and Warren	All counties
Daily mean temperature (Fahrenheit)	51.1231	53.3828
	(15.6698)	(15.3790)
Daily maximum temperature (Fahrenheit)	61.7408	63.5217
	(16.4493)	(16.0536)
Daily minimum temperature (Fahrenheit)	40.5107	43.2458
	(14.9866)	(14.8189)
Total monthly rainfall (inches)	4.0249	3.8874
	(2.0821)	(1.9942)
Total monthly snowfall (inches)	2.5585	1.6528
	(5.2932)	(4.0797)
Number of days in a month with minimum temperature less than or equal to 0.0 Fahrenheit	0.1858	0.0751
	(0.7957)	(0.4615)
Number of days in a month with minimum temperature less than or equal to 32.0 Fahrenheit	10.5768	8.8836
	(10.9365)	(9.9847)
Number of days in a month with maximum temperature greater than or equal to 90.0 Fahrenheit	1.2210	1.7361
	(2.7357)	(3.3913)
Number of days in a month with maximum temperature less than or equal to 32.0 Fahrenheit	1.7365	1.2494
	(3.7183)	(3.0325)
Number of days in a month with greater than or equal to 1.0 inches of precipitation	1.1007	1.0668
	(0.9280)	(0.9064)
Extreme maximum daily precipitation total within a month (inches)	1.4198	1.3975
	(0.8231)	(0.7949)
Number of zip codes	128	723
Number of observations (zip code-monthly from 01/1990 to 12/2006)	26,106	147,055

Note: Means and standard deviations (in parentheses) are reported in this table.

Table 2: Summary Statistics, Part II

New Jersey Counties:	Hunterdon		Morris		Sussex		Warren		All counties	
Sample period: January 1990 to December 2006	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Birth weight (grams)	3,463.5170	538.9600	3,421.6460	575.4184	3,448.2480	588.5038	3,438.8820	563.1989	3,348.3930	586.9483
Low birth weight (1/0): birth weight < 2,500 grams	0.0380	0.1912	0.0454	0.2083	0.0470	0.2117	0.0448	0.2069	0.0610	0.2394
Very low birth weight (1/0): birth weight < 1,500 grams	0.0053	0.0725	0.0113	0.1058	0.0131	0.1139	0.0080	0.0892	0.0111	0.1047
Female (1/0)	0.4877	0.4999	0.4848	0.4998	0.4907	0.4999	0.4908	0.4999	0.4873	0.4998
White (1/0)	0.9059	0.2919	0.8169	0.3867	0.9479	0.2222	0.9195	0.2721	0.5836	0.4930
Black (1/0)	0.0194	0.1378	0.0292	0.1684	0.0120	0.1089	0.0181	0.1332	0.1602	0.3668
Hispanic (1/0)	0.0367	0.1880	0.0621	0.2414	0.0135	0.1153	0.0271	0.1623	0.1531	0.3601
Asian (1/0)	0.0190	0.1365	0.0512	0.2204	0.0110	0.1043	0.0136	0.1160	0.0426	0.2020
Medicare (1/0)	0.0003	0.0166	0.0008	0.0282	0.0009	0.0304	0.0004	0.0204	0.0005	0.0212
Medicaid (1/0)	0.0439	0.2049	0.0671	0.2502	0.0663	0.2488	0.1106	0.3137	0.1730	0.3782
Private insurance (1/0)	0.8919	0.3105	0.8569	0.3502	0.8822	0.3224	0.8222	0.3823	0.7241	0.4470
Self-pay (1/0)	0.0494	0.2167	0.0532	0.2245	0.0312	0.1739	0.0364	0.1874	0.0826	0.2752
Number of observations	21,752		89,029		23,810		19,210		1,676,798	

Note: The summary statistics are based on the sample including live and singleton births.

Table 3: Effects of the Power Plant's Sulfur Dioxide Emissions on Local Pollution Computed at New Jersey Zip Code Level

New Jersey regions included:	Hunterdon, Morris and Sussex	Hunterdon, Morris, Sussex and Warren	Zip codes that are at least 100 miles away from the power plant
	(1)	(2)	(3)
Panel A: Dependent variable—SO_2 (ppb), zip code level, inverse-distance weighted, monthly average of the one-hour daily maximum levels			
PGS SO_2 monthly emissions (in 1,000 tons), direction-adjusted	7.1318***	8.4153***	-3.4948
	(1.3124)	(1.2142)	(2.4302)
Number of observations (zip code-monthly level)	3,096	3,707	1,620
Mean of the dependent variable	11.209	11.772	6.749
Average distance (in miles) between a New Jersey zip code centroid and a monitor	13.331	13.685	11.110
Average number of monthly monitor readings within the 20-mile radius	2.186	2.107	1.288
Panel B: Dependent variable—$PM_{2.5}$ ($\mu g/m^3$), zip code level, inverse-distance weighted, monthly average of the 24-hour daily maximum levels			
PGS SO_2 monthly emissions (in 1,000 tons), direction-adjusted	0.3185**	0.3383***	-1.6365
	(0.1396)	(0.1250)	(3.6173)
Number of observations (zip code-monthly level)	3,348	3,959	1,272
Mean of the dependent variable	11.857	11.813	12.086
Average distance (in miles) between a New Jersey zip code centroid and a monitor	13.385	13.708	11.132
Average number of monthly monitor readings within the 20-mile radius	2.592	2.426	1.094
Control variables used in both Panel A and Panel B			
Weather variables	Yes	Yes	Yes
Zip code-month fixed effects	Yes	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes	Yes

Note: The sample period is monthly from January 2004 to December 2006. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table 4: Maternal and Newborns' Characteristics

New Jersey counties included: Hunterdon, Morris, Sussex and Warren (except the zip codes in Warren County that are next to the power plant)

Being downwind of the power plant (1/0) = D = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Year and month of birth = t = 01/1990, 02/1990, …, 12/2006 (monthly)

Dependent variables measured at the zip code-monthly level:	Proportion of Newborns Who Are White	Proportion of Newborns Who Are Black	Proportion of Newborns Who Are Hispanic	Proportion of Newborns Who Are Asian	Proportion of Mothers Whose Insurance Status is Medicaid	Proportion of Mothers Whose Insurance Status is Private Insurance	Proportion of Mothers Whose Insurance Status is Self-Pay
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
D_t	0.0054**	0.0005	-0.0016	-0.0015	-0.0054	0.0103***	-0.0055*
	(0.0026)	(0.0009)	(0.0020)	(0.0014)	(0.0034)	(0.0035)	(0.0031)
Other control variables							
Zip code-month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	18,261	18,261	18,261	18,261	18,261	18,261	18,261

Note: The estimation sample includes live and singleton births. Each column (1–7) uses a weighted least squares regression, with the weight being the number of births of each mother’s residential zip code-year and month of a birth pair. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table 5: Effects of Being Downwind of the Power Plant during Pregnancy on Infant Birth Outcomes

New Jersey counties included: Hunterdon, Morris, Sussex and Warren (except the zip codes in Warren County that are next to the power plant)

Being downwind of the power plant (1/0) = D = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Year and month of birth = t = 01/1990, 02/1990, ..., 12/2006 (monthly)

Dependent variables:	Low birth weight (1/0) (birth weight < 2,500 grams)			Very low birth weight (1/0) (birth weight < 1,500 grams)		
	(1)	(2)	(3)	(4)	(5)	(6)
D_t	0.0039***	0.0039***	0.0040***	0.0019***	0.0019***	0.0019***
	(0.0012)	(0.0012)	(0.0012)	(0.0007)	(0.0007)	(0.0007)
D_{t-1}	-0.0004	-0.0004	-0.0003	0.0022**	0.0022**	0.0022**
	(0.0016)	(0.0016)	(0.0016)	(0.0010)	(0.0010)	(0.0010)
D_{t-2}	0.0022	0.0023*	0.0024*	-0.0003	-0.0004	-0.0002
	(0.0014)	(0.0014)	(0.0014)	(0.0007)	(0.0007)	(0.0007)
D_{t+1}		0.0011			0.0009	
		(0.0017)			(0.0009)	
Other control variables						
Individual level demographic variables	No	Yes	Yes	No	Yes	Yes
Zip code-month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	147,382	147,382	147,382	147,382	147,382	147,382

Note: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are sex and race (White, Black, Hispanic or Asian) of an infant and the health insurance status (Medicare, Medicaid, private insurance or self-pay) of the mother. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table 6: Effects of Being Exposed to the Power Plant's Sulfur Dioxide Emissions during Pregnancy on Infant Birth Outcomes

New Jersey counties included: Hunterdon, Morris, Sussex and Warren (except the zip codes in Warren County that are next to the power plant)

Panel A: Being downwind of the power plant (1/0) = D = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Year and month of birth = *t* = 01/1990, 02/1990, …, 12/2006 (monthly)

Dependent variable:	Low birth weight (birth weight < 2.500 grams)		
	Full sample	Male	Female
	(1)	(2)	(3)
D_t	0.0040***	0.0059***	0.0023
	(0.0012)	(0.0017)	(0.0024)
D_{t-1}	-0.0003	0.0016	-0.0026
	(0.0016)	(0.0020)	(0.0022)
D_{t-2}	0.0024*	0.0006	0.0045*
	(0.0014)	(0.0022)	(0.0023)
Number of observations	147,382	75,578	71,804

Panel B: Direction-adjusted PGS SO_2 monthly emissions (in 1,000 tons) = W = PGS monthly SO2 emissions × D, where D = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Year and month of birth = *t* = 01/1995, 02/1995, …, 12/2006 (monthly)

Dependent variable:	Low birth weight (birth weight < 2.500 grams)		
	Full sample	Male	Female
	(1)	(2)	(3)
W_t	0.0015**	0.0017*	0.0016
	(0.0007)	(0.0010)	(0.0014)
W_{t-1}	-0.0003	0.0003	-0.0010
	(0.0008)	(0.0011)	(0.0012)
W_{t-2}	0.0008	-0.0005	0.0022**
	(0.0009)	(0.0013)	(0.0011)
Number of observations	105,337	53,965	51,372
Other control variables used in both Panel A and Panel B			
Individual level demographic variables	Yes	Yes	Yes
Zip code-month fixed effects	Yes	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes

Note: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are sex and race (White, Black, Hispanic or Asian) of an infant and the health insurance status (Medicare, Medicaid, private insurance or self-pay) of the mother. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Appendix Table 1: Effects of Being Downwind of the Power Plant during Pregnancy on Infant Birth Outcomes

New Jersey counties included: Hunterdon, Morris, Sussex and Warren (except the zip codes in Warren County that are next to the power plant)

Being downwind of the power plant (1/0) = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Year and month of birth = *t* = 01/1990, 02/1990, ..., 12/2006 (monthly)

Dependent variables:	Low birth weight (1/0) (birth weight < 2,500 grams)			Very low birth weight (1/0) (birth weight < 1,500 grams)		
	(1)	(2)	(3)	(4)	(5)	(6)
Being downwind of the power plant during the month of birth or the month before birth	0.0036**	0.0035**	0.0036**	0.0041***	0.0040***	0.0041***
	(0.0017)	(0.0017)	(0.0017)	(0.0009)	(0.0010)	(0.0009)
Being downwind of the power plant during the second month before birth	0.0022	0.0023*	0.0024*	-0.0002	-0.0003	-0.0001
	(0.0014)	(0.0013)	(0.0014)	(0.0007)	(0.0007)	(0.0007)
Being downwind of the power plant during the month after birth		0.0012			0.0009	
		(0.0017)			(0.0009)	
Other control variables						
Individual level demographic variables	No	Yes	Yes	No	Yes	Yes
Zip code-month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	147,382	147,382	147,382	147,382	147,382	147,382

Note: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are sex and race (White, Black, Hispanic or Asian) of an infant and the health insurance status (Medicare, Medicaid, private insurance or self-pay) of the mother. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Appendix Table 2: Effects of Being Downwind of the Power Plant during Pregnancy on Infant Birth Outcomes, Zip Code-Monthly Level Analysis

New Jersey counties included: Hunterdon, Morris, Sussex and Warren (except the zip codes in Warren County that are next to the power plant)

Being downwind of the power plant (1/0) = D = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Year and month of birth = t = 01/1990, 02/1990, ..., 12/2006 (monthly)

Dependent variables:	Low birth weight (1/0) (birth weight < 2,500 grams)			Very low birth weight (1/0) (birth weight < 1,500 grams)		
	(1)	(2)	(3)	(4)	(5)	(6)
D_t	0.0037***	0.0037***	0.0038***	0.0019***	0.0018**	0.0019**
	(0.0013)	(0.0013)	(0.0013)	(0.0007)	(0.0007)	(0.0007)
D_{t-1}	-0.0004	-0.0004	-0.0003	0.0022**	0.0022**	0.0022**
	(0.0017)	(0.0016)	(0.0016)	(0.0011)	(0.0010)	(0.0010)
D_{t-2}	0.0020	0.0020	0.0022*	-0.0003	-0.0004	-0.0003
	(0.0014)	(0.0013)	(0.0013)	(0.0007)	(0.0007)	(0.0007)
D_{t+1}		0.0014			0.0008	
		(0.0017)			(0.0009)	
Other control variables						
Individual level demographic variables averaged at the zip code-monthly level	No	Yes	Yes	No	Yes	Yes
Zip code-month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	18,261	18,261	18,261	18,261	18,261	18,261

Note: The estimation sample includes live and singleton births. Individual level demographic variables averaged at the zip code-monthly level and controlled for are sex and race (White, Black, Hispanic or Asian) of an infant and the health insurance status (Medicare, Medicaid, private insurance or self-pay) of the mother. Each regression is weighted by the number of births of a zip code-year-month pair. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Appendix Table 3: Effects of Being Downwind of the Power Plant during Pregnancy on Infant Birth Outcomes

New Jersey counties included: Hunterdon, Morris, Sussex and Warren

Being downwind of the power plant (1/0) = D = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Year and month of birth = t = 01/1990, 02/1990, ..., 12/2006 (monthly)

Dependent variables:	Low birth weight (1/0) (birth weight < 2,500 grams)			Very low birth weight (1/0) (birth weight < 1,500 grams)		
	(1)	(2)	(3)	(4)	(5)	(6)
D_t	0.0037***	0.0038***	0.0039***	0.0018***	0.0017***	0.0018***
	(0.0011)	(0.0011)	(0.0011)	(0.0006)	(0.0006)	(0.0006)
D_{t-1}	-0.0003	-0.0001	-0.0001	0.0018*	0.0018*	0.0018*
	(0.0015)	(0.0015)	(0.0014)	(0.0010)	(0.0010)	(0.0010)
D_{t-2}	0.0021	0.0023*	0.0024*	0.0001	-0.0000	0.0001
	(0.0013)	(0.0012)	(0.0012)	(0.0007)	(0.0006)	(0.0007)
D_{t+1}		0.0009			0.0010	
		(0.0014)			(0.0008)	
Other control variables						
Individual level demographic variables	No	Yes	Yes	No	Yes	Yes
Zip code-month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	153,801	153,801	153,801	153,801	153,801	153,801

Note: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are sex and race (White, Black, Hispanic or Asian) of an infant and the health insurance status (Medicare, Medicaid, private insurance or self-pay) of the mother. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Appendix Table 4: Falsification Checks on the Effects of Being Downwind of the Power Plant during Pregnancy on Infant Birth Outcomes

New Jersey counties included: Hudson and Cape May

Year and month of birth = t = 01/1990, 02/1990, ..., 12/2006 (monthly)

D = Being downwind of the power plant (1/0) = 1 if -45 degrees < monthly average wind vector azimuth - New Jersey zip code azimuth < 45 degrees, and 0 otherwise

Dependent variables:	Low birth weight (1/0) (birth weight < 2,500 grams)	Birth weight (grams)
	(1)	(2)
D_t	0.0001	-6.5656
	(0.0018)	(6.0665)
D_{t-1}	0.0012	-2.3260
	(0.0017)	(4.2721)
D_{t-2}	0.0021	-4.1745
	(0.0023)	(6.9334)
Other control variables		
Individual level demographic variables	Yes	Yes
Zip code-month fixed effects	Yes	Yes
Year-month (monthly) fixed effects	Yes	Yes
Weather variables	Yes	Yes
Number of observations	139,108	139,108

Note: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are sex and race (White, Black, Hispanic or Asian) of an infant and the health insurance status (Medicare, Medicaid, private insurance or self-pay) of the mother. Standard errors (reported in parentheses) are clustered at the zip code level. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.