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The Impact of Environmental Regulation on Fetal Health: Evidence from the Shutdown of a Coal-Fired Power Plant Located Upwind of New Jersey[1]

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Abstract

Our study examines a case where cross-border air pollution had not been effectively dealt with by a decentralized, state level policymaking, letting a coal-fired power plant located on the border between two states pollute the downwind state for years without being controlled. We find that the shutdown of the power plant, thanks to a landmark ruling by the federal government, reduces the likelihoods of having a low birth weight baby and having a preterm birth by 15 percent and 28 percent, respectively, in areas downwind of the power plant. The ruling marks the first-ever federal level regulation under the Clean Air Act that overrides state-level regulations and is directly imposed upon a single pollution source. Our empirical setting emphasizes the importance of such regulation in curbing environmental free riding induced by jurisdictional borders, where pollution cost-shifting can be aided by natural forces such as prevailing winds.

JEL codes: I18, Q53, Q58

Keywords: environmental free riding, power plants, downwind, fetal health

1 Introduction

While generating electricity, coal-fired power plants can put human health at risk. Nevertheless, coal is expected to remain in the U.S. energy portfolio in the foreseeable future, together with renewable energy sources such as solar, wind, and hydropower.[1] Because of the Earth's wind patterns and air pollutants' long-distance transportability through wind, some regions of the United States, such as the Northeast, are particularly affected by interstate air pollution due to transboundary emissions from upwind coal-fired power plants. While in nature there is no border for wind, jurisdictional borders do exist in our society. Under the U.S. system of federalism, enforcement of environmental regulations imposed by the federal government largely depends on individual states. Therefore, in theory a "free riding" problem can occur for a power plant located on the border between two states: the upwind state by having the plant creates jobs and tax revenue, and by locating the plant near the border the upwind state can shift the pollution cost to the downwind state, thanks to the wind.

Indeed, a study by Monogan III, Konisky and Woods (2017) provides empirical evidence showing that in the United States facilities that are major air polluters are more likely to be located near a state's downwind border than facilities whose hazardous wastes are mainly non-airborne. The presence of environmental free riding has also been detected in cases of water pollution disproportionately borne by downstream jurisdictions in the United States (Sigman, 2005) and in Brazil (Lipscomb and Mobarak, 2017), as well as in the case of elevated toxic emissions into the air and water near state borders relative to interior regions (Helland and Whitford, 2003).

The presence of negative interjurisdictional externalities induced by environmental free riding reveals a deficiency in environmental regulations that rely on decentralization.[2] In this

[1] For more information see: "Perry Says Coal-Fired Power Plants Important in US Future," *U.S. News*, July 6, 2017 (retrieved from https://www.usnews.com/news/best-states/west-virginia/articles/2017-07-06/perry-says-coal-fired-power-plants-important-in-us-future on August 27, 2017).

[2] In the United States the Environmental Protection Agency (a federal level government) promulgates the National Ambient Air Quality Standards (NAAQS), but the implementation and enforcement of NAAQS fall

regard, we examine the impact of a precedent-setting federal level environmental regulation imposed upon a single large air polluter located on the border between two states on fetal health in terms of births with low weight and preterm births. Avoidance of low birth weight and preterm births can have far-reaching implications on adult health,[3] but the benefit of this avoidance has not yet been included in the evaluation of public health benefits of regulating power plant emissions.[4]

Specifically, the air polluter examined by our study is the Portland Generating Station, a coal-fired power plant in Pennsylvania, located right on the border between Pennsylvania and New Jersey (Figure 1).[5] According to a report by the Environmental Integrity Project (EIP, 2007), this power plant was ranked fifth in the United States in 2006 by sulfur dioxide (SO_2) emission rate. In 2009 it emitted a total of 30,465 tons of SO_2, which is more than double the annual SO_2 emissions from all electricity-generating facilities in New Jersey *combined* (which was 12,810 tons), according to the New Jersey Department of Environmental Protection (NJDEP, 2010a, p. 30).

The federal level environmental regulation imposed upon this power plant is a landmark ruling by the U.S. Environmental Protection Agency (EPA) known as the Portland Rule, which led to the shutdown of the power plant in June 2014. This ruling involves multiple parties: the owner of the power plant, the NJDEP, the EPA, and the U.S. Court of Appeals for the Third Circuit. The EPA's Portland Rule is the *first-ever* federal level regulation under the U.S. Clean Air Act (CAA) that is directly imposed upon a *single* pollution source,

onto each individual state, who develops its own State Implementation Plan (SIP) with regard to pollution controls and emission limits for stationary pollution sources, such as power plants, and also for vehicles to meet and maintain the NAAQS. We gave detailed discussions on the EPA's regulations on interstate air pollution in Appendix A.

[3]See Currie and Rossin-Slater (2015) for a detailed summary about a robust association found in the literature between birth weight and outcomes during adulthood such as health, educational attainment and earnings.

[4]The public health benefits of power plant emission abatement have been examined in the avoidance of nonfatal heart attacks, hospital and emergency room visits, acute bronchitis, upper and lower respiratory symptoms, aggravated asthma, premature mortality, and lost work days or school absences (source: https://www3.epa.gov/crossstaterule/index.html, accessed on September 12, 2016).

[5]The address of the power plant is 40897 River Road, Portland, Pennsylvania 18351. We gave more details about this power plant in Appendix B.

overriding state-level regulations regarding the power plant.[6] In this ruling the power plant is confirmed by the EPA based on its own atmospheric dispersion modeling analyses[7] as the *sole* pollution source negatively impacting the air quality of the downwind state New Jersey, but the EPA did not examine the impact of the power plant's emissions on fetal health.

To the best of our knowledge, our study is the first to show fetal health improvement as a result of shutting down a large air polluter leading to a drastic reduction of SO_2 emission. Specifically, we find that shutting down the coal-fired power plant reduces the likelihood of having a low birth weight baby by 0.89 percentage points or by about 15 percent, and also reduces the likelihood of a preterm birth by 2.83 percentage points or by about 28 percent, in areas downwind of the power plant. Our study adds important evidence on improved birth outcomes from the shutdown of a large air polluter to the findings of Currie et al. (2015), since in their study "[t]he results are less conclusive on the question of whether a plant closing reverses the negative effects of a plant's operation on the incidence of low birthweight" (p. 701), although they find "[toxic] plant openings lead to 11 percent declines in housing values within 0.5 mile or a loss of about $4.25 million for these households; and a plant's operation is associated with a roughly 3 percent increase in the probability of low birthweight within 1 mile" (p. 678).

Our findings provide empirical evidence in support of federal level regulations imposed directly upon specific pollution sources. The empirical setting of our study is an important manifestation of negative interjurisdictional externalities in the case of cross-border air pollution that had not been effectively dealt with by the current state-by-state regulatory structure used by the CAA, letting a coal-fired power plant located on the border between two states pollute the downwind state for years without being controlled. In this regard,

[6] We gave more discussions about the implications of this precedent-setting federal level environmental regulation in Appendix B.

[7] Atmospheric dispersion modeling analysis is widely used for making air quality policies (e.g., the National Ambient Air Quality Standards, a.k.a. NAAQS) that require knowing the atmospheric process dispersing pollutants emitted from a source (e.g., a power plant) as well as predicting ambient concentrations of pollutants emitted from the source in downwind locations. For details, see https://www3.epa.gov/scram001/dispersionindex.htm (accessed on August 27, 2017).

Yang et al. (2017) focus on the same power plant examined by this study, and they provide evidence showing the adverse effect on fetal health during 1990–2006 in terms of low birth weight due to prenatal exposure to the power plant's emissions at the time when the emission levels were high.

Our study is a continuation of Yang et al. (2017), of which the sample period ends in 2006, long before the shutdown of the power plant. We add important evidence to Yang et al. (2017) by showing fetal health improvement in New Jersey as a result of the shutdown of the Pennsylvania coal-fired power plant in June 2014, using the most recent New Jersey birth data collected and released by the New Jersey Department of Health. One important piece of information that is available in these birth data, but not available in the data used by Yang et al. (2017), is the exact date of the mother's first day of her last menstrual period, which allows us to identify mothers whose pregnancies started after the shutdown of the power plant since a pregnancy cannot occur prior to the mother's first day of her last menstrual period.

The identification strategy used by our study derives from Yang et al. (2017). Specifically, both studies use the direction toward which the wind near the power plant blows (measured in zero to 360 degrees) and the direction toward which a pregnant woman's residential zip code is located relative to the power plant (also measured in zero to 360 degrees) to define the downwind status of maternal exposure to the power plant's emissions during pregnancy. The source of the exogenous variation in this *in utero* exposure measure, after controlling for the distance between the mother's residential zip code and the power plant, is the fact that nature determines where the wind blows. The explicit utilization of wind directions distinguishes both our study and Yang et al. (2017) from studies relying on comparing residents living almost next to (e.g., within one or two miles of) a pollution source with those living slightly farther away (e.g., outside of one or two miles of the pollution source) to ensure the similarity of the two groups except for their pollution exposure. Furthermore, by using the wind-driven exogenous variation in the *in utero* exposure measure, both our study and Yang et al. (2017) are able to examine the fetal health impact of air pollutants that can travel long distance in the air to a region that is far away but nonetheless downwind from the pollution source.

The rest of the paper proceeds as follows. Section 2 explains our empirical setting and identification strategy, followed by Section 3 describing the data and methods. Section 4 discusses our findings, and Section 5 concludes.

2 Research Design

2.1 The EPA's Portland Rule

In May and September 2010 the NJDEP filed two petitions (NJDEP, 2010a and 2010b) with the EPA against the Portland Generating Station, pursuant to the "Interstate Pollution Abatement" section (i.e., Section 126(b)) of the CAA. The NJDEP's petitions provided scientific evidence based on two atmospheric dispersion models (AERMOD and CALPUFF) showing that emissions from the power plant caused SO_2 concentrations in four counties of New Jersey—Warren, Sussex, Morris and Hunterdon (Figure 1)—to have exceeded the SO_2 NAAQS promulgated by the EPA. The trajectory analysis conducted by the NJDEP's Bureau of Technical Services, which was reported in the September 2010 petition, demonstrates how SO_2 emissions from the power plant were transported through the air and reached the borough of Chester in Morris County, located approximately 21 miles east-southeast of the power plant.

In response to the NJDEP's petitions, the EPA used the AERMOD atmospheric dispersion model to examine whether the power plant indeed caused the SO_2 NAAQS violations in New Jersey. On November 7, 2011, the EPA issued its final ruling—also known as the Portland Rule—concluding that the emissions from the Pennsylvania power plant *alone* caused the violations of the SO_2 NAAQS in the downwind state, New Jersey (EPA, 2011). In the Portland Rule the EPA required the power plant to reduce SO_2 emissions by 81 percent prior to January 2015 (i.e., within three years starting from January 6, 2012, on which the EPA's ruling took effect). The EPA's Portland Rule is the *first-ever* federal level regulation under the CAA that is directly imposed upon a *single* pollution source, overriding state-level regulations regarding the power plant.

On January 6, 2012 (the date when the Portland Rule took effect), the then owner of the power plant (GenOn REMA, LLC) filed a petition for review with the U.S. Court of Appeals for the Third Circuit, challenging the EPA's authority in imposing emission limits on the power plant without going through the State Implementation Plan (SIP) process (in this case the SIP process of Pennsylvania, where the power plant is located) used by the Good Neighbor Provision (i.e., Section 110(a)(2)(D)) of the CAA. On July 12, 2013, the Third Circuit issued its ruling, which upheld the Portland Rule (United States Court of Appeals for the Third Circuit, Opinion Filed July 12, 2013). The Third Circuit's ruling confirmed the EPA's authority under the CAA to impose direct federal regulations on the power plant. The EPA's use of AERMOD analysis withstood judicial scrutiny.

Prior to the Third Circuit's ruling, on February 29, 2012, the then owner of the power plant (GenOn REMA, LLC) announced that it planned to shut down the coal-fired generating units of the power plant by 2015. In August 2013 GenOn REMA, LLC was renamed to NRG REMA, LLC because of the merger between GenOn Energy Inc. and NRG Energy, Inc. completed in December 2012. Prior to 2015, on June 1, 2014, the coal-fired generating units were shut down by NRG REMA, LLC.[8] 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.[9] Figure 2 and Figure 3 show that the power plant emitted very little SO_2 and generated very little electricity after June 1, 2014. To be more precise, Panel A of Table 1 shows that after June 1, 2014, the power plant's SO_2 emission dropped by 99.9988 percent (0.031 tons in the post-shutdown period compared with 2,596.648 tons

[8]Source: http://www.lehighvalleylive.com/slate-belt/index.ssf/2014/05/portland_generating_station_st.html (accessed on August 7, 2017).

[9]Source: http://www.lehighvalleylive.com/slate-belt/index.ssf/2014/06/portland_generating_station_sw.html (accessed on August 7, 2017).

in the pre-shutdown period), and the electricity generated by the power plant dropped by 99.87 percent (254.871 MWh in the post-shutdown period compared with 201,049.600 MWh in the pre-shutdown period).

2.2 Identification Strategy

We use a difference-in-differences (DID) method to examine the impact on birth outcomes from the shutdown of the power plant. In the New Jersey birth data we have, there is information on the exact date of a birth and the exact date of the first day of the mother's last menstrual period (hereafter referred to as LMP). The LMP date tells us the earliest possible date when a pregnancy starts,[10] and the birth date is the ending date of a pregnancy. In our DID setup, we use both the LMP date and the birth date to define the pre- and post-shutdown periods.

Specifically, the post-shutdown period goes from June 1, 2014, which is the shutdown date of the power plant, to December 31, 2015, which is the last day of the New Jersey birth data we have. We include into this period pregnancies that started on or after June 1, 2014 (i.e., LMP dates on or after June 1, 2014) and pregnancies that ended on or before December 31, 2015 (i.e., birth dates on or before December 31, 2015). The pre-shutdown period is matched to the post-shutdown period with the same length of 19 months, going from June 1 to the following year's December 31. The years of 2008 and 2009 were included in the pre-shutdown period. During those years the power plant had very high levels of emissions (Figure 2) and electricity generations (Figure 3). Specifically, the pre-shutdown period goes from June 1, 2008 to December 31, 2009. It includes pregnancies that occurred on or after June 1, 2008 (i.e., LMP dates on or after June 1, 2008) and pregnancies that ended on or before December 31, 2009 (i.e., birth dates on or before December 31, 2009). During this pre-shutdown period

[10] Biologically, a pregnancy starts at the moment of conception, that is, when a sperm cell breaches the ovum. This breach occurs after ovulation and during the luteal phase. Neither the start time nor the end time of the breach is observable given current technology. As a result, the mother's first day of her last menstrual period (i.e., LMP) is commonly used as a proxy for the start date of her pregnancy, when in fact the LMP date can only be the earliest possible start date of a pregnancy, since a pregnancy begins at the moment of conception and the conception cannot happen before the LMP date.

and at the yearly level, there were no significant reductions in the power plant's emissions (Panel A of Figure 2), nor in the power plant's electricity generations (Panel A of Figure 3). In fact, during this period the power plant's yearly electricity generations were peaked (Panel A of Figure 3), and the power plant's yearly SO_2 emissions were very high, above 30,000 tons (Panel A of Figure 2). In comparison, the *total* SO_2 emissions in 2009 from *all* electricity-generating facilities in New Jersey was only 12,810 tons (NJDEP 2010a, p. 30).

In our analysis we exclude the period of January 1, 2010 through May 31, 2014. During this period the yearly emissions were trending down (Panel A of Figure 2), while the monthly emissions were bouncing up and down (Panel B of Figure 2). Those large swings in monthly emissions could occur at specific time points of a mother's pregnancy (e.g., the first month or the last week of her pregnancy), which may have significant effects on birth outcomes. Our study does not focus on the impact on birth outcomes from prenatal exposure to short-lived changes in power plant emissions. Instead, our study focuses on comparing the birth outcomes of fetuses conceived after the power plant's shutdown with the birth outcomes of fetuses conceived before the shutdown, to infer the health impact of closing the power plant. This focus of our study has policy implications since in reality the power plant was required by the EPA to reduce SO_2 emissions by 81 percent (a semi-closing of the power plant) within a three-year time limit.

The treatment and control groups in our DID setup are defined by the downwind status of each New Jersey zip code where the mother lives relative to the power plant, using the multiple-step procedure developed by Yang et al. (2017) and reiterated here. First, we calculate the direction in which each New Jersey zip code centroid is located relative to the power plant. This calculation uses the latitudes and longitudes of two points—the power plant[11] and each New Jersey zip code centroid. Throughout our study we use *azimuth* as the measure for that direction, which is an angle (ranging from 0 to 360 degrees) between the power plant (point A) and the zip code centroid (point B) with the curvature of the earth

[11]We obtained latitude (i.e., +40.91) and longitude (i.e., −75.0789) of the Portland Generating Station from the EPA's AMPD.

taken into account. Henceforth, we call this the *zip code azimuth* (θ_{zip}). To calculate the azimuth of point B relative to point A, we project the vector $\overrightarrow{\text{AB}}$ onto a horizontal plane. On that horizontal plane, the reference vector is due North, which is used for point A and has an azimuth of 0 or 360 degrees; moving clockwise on a 360-degree circle, a point due East has an azimuth of 90 degrees, and accordingly, 180 degrees for due South and 270 degrees for due West. The azimuth of point B relative to point A is given by the angle between the projected vector of $\overrightarrow{\text{AB}}$ and the reference vector on that horizontal plane.[12]

In the second step we convert the wind direction from being measured as where the wind comes from in the weather database we obtained to being measured as where the wind blows, which henceforth is referred to as the *wind vector azimuth* (θ_{wind}): we subtract 180 degrees from the direction from which the wind comes, and we will add 360 degrees if the subtraction results in a negative value. So in the end, for example, a 90-degree wind direction in our study 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 an indicator (D_t) of being downwind of the power plant during year-month t for each New Jersey zip code where the mother lives, based on the difference between the zip code azimuth and the wind vector azimuth averaged over year-month t: D_t equals one if the absolute value of the difference is less than 45 degrees (i.e., when $\left|\theta_{\text{zip}} - \theta_{\text{wind}}^{\text{year-month } t}\right| < 45$), and D_t equals zero otherwise (i.e., when $\left|\theta_{\text{zip}} - \theta_{\text{wind}}^{\text{year-month } t}\right| \geqslant 45$). So, D_t is a binary variable (1/0) indicating whether the zip code during year-month t is downwind of the power plant (1) or not (0). Here, we choose the same cutoff point, the 45-degree, which is also used by Yang et al. (2017). So, the empirical findings of these two studies can be easily compared.

In the fourth step we take the average of D_t, D_{t-1} through D_{t-11}, where t indicates the year and month of a birth. So, this is an average of the downwind indicators for each zip code over a 12-month period ($\overline{D}$) (i.e., a full year) covering the birth month and the

[12]For example, the direction in which New York City is located relative to Chicago can be expressed by an azimuth of 91.95 degrees, indicating that New York City is located east of Chicago.

11 months prior to the birth month. Based on this average we generate a dummy variable called "downwind" for each zip code over a 12-month period: it is equal to one if $\overline{D}$ is greater than or equal to 0.5, and equal to zero if $\overline{D}$ is less than 0.5. So when this downwind variable equals one, it means that the wind near the power plant blows toward the zip code (i.e., $\left|\theta_{\text{zip}} - \theta_{\text{wind}}^{\text{year-month } t}\right| < 45$) for at least six months during a year. We assign a birth to the treatment (or control) group if the downwind variable is equal to one (or zero). In our DID setup the treatment group is downwind of the power plant, which is expected to benefit from the shutdown of the power plant in terms of improved birth outcomes due to prenatal exposure to reduced power plant emissions.

Throughout our DID analysis we control for New Jersey zip code fixed effects, and those zip code fixed effects incorporate the effect of the distance between each New Jersey zip code and the power plant. Note that the downwind variable we use for assigning each birth to the treatment group or the control group varies by zip code over a 12-month period with the time variation coming from the time-varying wind directions. As a result, once we control for the New Jersey zip code fixed effect, the source of the remaining variation in the downwind variable should be the wind direction. Thus, the use of the New Jersey zip code fixed effects is not only necessary for controlling for the distance between each New Jersey zip code and the power plant, but also necessary for extracting the arguably exogenous variation in the downwind variable, with the plausible exogeneity being determined by the wind directions that are governed by nature.

Note that based on the global wind patterns, both New Jersey and Pennsylvania lie in the "prevailing westerlies" zone, meaning that prevailing winds go from west to east. The "prevailing westerlies" zone is in sharp contrast with the "monsoon" zone (e.g., in Asia), where there is seasonal reversal in the wind direction. In Figure 4 we show that the winds near the power plant (which is located on the border between Pennsylvania and New Jersey) are indeed westerly winds, blowing consistently southeastward from January to December with little seasonal difference in the wind directions. This also means that after we control for New Jersey zip code fixed effects, the remaining variation in the downwind variable (that comes from the time variation in wind directions) is not driven by wind direction changes that are systematic and therefore predictable (e.g., seasonal changes), but driven by wind directions that deviate randomly from the exact 135-degree (indicating a wind blowing exactly southeastward) and therefore unpredictable. Those unpredictable changes in the wind directions are arguably exogenous. It is this plausible exogeneity that could rationalize the common trend assumption needed for our DID analysis: the treatment (i.e., being downwind of the power plant), after controlling for the zip code fixed effects, is assigned almost randomly to each New Jersey zip code, and therefore, it can be reasonable to assume that in the absence of the shutdown of the power plant, factors determining the birth outcomes in the treatment and control groups have on average the same changes between the pre- and post-shutdown periods.

3 Data and Methods

3.1 Data

Our study uses data from five sources: birth records collected by the New Jersey Department of Health (NJDOH); the EPA's Air Markets Program Data (AMPD); Weather Source, LLC; the National Climatic Data Center (NCDC); and the zip code database.

The birth data we obtained from the NJDOH are the data on live births that occurred in New Jersey. These birth data contain information on the exact birth date, birth weight, gestational age (a.k.a., gestational length, which is measured in weeks), and the sex of a newborn; as well as information on the newborn's mother's LMP date, age, race and ethnicity, education, marital status, the number of prenatal visits, and smoking status. In addition, the birth data include information on the mother's residential zip code. We use the LMP date of a mother and the birth date of her baby to assign each birth record to the pre- or the post-shutdown period based on our DID setup explained in Section 2.2. We use the mothers' residential zip codes to link the birth data with the datasets obtained from the other data sources that include the zip code variable. One limitation of the birth data we obtained from the NJDOH is the lack of a unique identifier for each mother. As a result, we are unable to use mother fixed effects for infants who were born to the same mother.

We use the birth weight and gestational length information in the birth data to generate indicators for low birth weight (LBW), very low birth weight (VLBW), and preterm, based on the commonly used and accepted definitions: birth weight below 2,500 grams (or 1,500 grams) defines LBW (or VLBW), and gestational length less than 37 weeks defines preterm. We exclude from our analysis the newborns whose mothers did not live in New Jersey, which is a drop of approximately three percent of the original sample including all live births that occurred in New Jersey. When analyzing birth outcomes, we focus on singleton births, which constitute approximately 96 percent of all live births in the data we obtained from the NJDOH. Yang et al. (2017) also focus on singleton births. Both studies drop the cases of multiple births (e.g., twins) because LBW in those cases (e.g., one newborn with LBW of a twin birth) could be the result of the mother carrying multiple fetuses during one single pregnancy, not the result of prenatal exposure to power plant emissions.

From the EPA's AMPD we extract the Portland Generating Station's emission data, as well as the latitude and longitude of the power plant's location.[13] In AMPD the following three categories of power plant emissions are reported: sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2). We do not extract from AMPD the emission data on CO_2, mainly because CO_2 is one of the greenhouse gases and CO_2 is not among the six common air pollutants (i.e., carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide), for which the Clean Air Act requires the EPA to set NAAQS.

To obtain the information on the direction of the wind near the power plant, we purchased a database from Weather Source, LLC, which includes data on wind directions measured hourly at the Allentown Lehigh Valley International Airport weather station. This weather

[13]The AMPD's power plant emission data are available at https://ampd.epa.gov/ampd/.

station was used by the NJDEP in its petition filed with the EPA in May 2010, and this weather station was also used in Yang et al. (2017). It is the weather station that is closest to the power plant with a complete series of records on hourly wind directions every day since January 1, 1960. The wind direction recorded at this weather station is a continuous variable measured on a 0–360 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 compute the monthly average wind directions by taking *vector means* of the hourly wind direction data. The reason for taking vector means, not arithmetic means, is that wind direction data are examples of "circular" data, where both the start value (0 degree) and end value (360 degree) indicate exactly the same direction.[14]

We obtain other weather variables for New Jersey from the NCDC: 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 (measured in inches). This is the same set of weather variables used by Yang et al. (2017), and in this study we follow their procedure (Yang et al. 2017, pp. 565–566) to obtain zip code-level monthly weather variables.

Lastly, we purchase a zip code database that includes all 723 New Jersey zip codes as well as the exact latitudinal and longitudinal coordinates of each New Jersey zip code centroid.

[14]Ignoring this fact and using arithmetic means can result in serious mistakes when averaging wind directions. For example, both a 5-degree wind and a 355-degree wind are winds coming from the north, and so should be the average of the two. But, the arithmetic mean of 5 degrees and 355 degrees is 180 degrees, which indicates a wind coming from due South. In contrast, the vector mean of 5 degrees and 355 degrees is 360 degrees, which indicates a wind coming from due North.

These geographic coordinates, together with the latitude and longitude of the power plant (obtained from the EPA's AMPD), allow us to calculate the *geodetic distance* (a.k.a. geodesic distance) between a New Jersey zip code centroid and the power plant. Geodetic distance represents the length of the shortest curve between two points on the earth's surface.

3.2 Regression Model

The regression model is specified as follows based on the DID setup explained in Section 2.2:

$$y_{ij} = \alpha_0 \text{downwind}_{ij} + \alpha_1 \text{downwind}_{ij} \times T_i + \mathbf{x}_i'\beta + \text{zip code fixed effects}$$
$$+ \text{year-month of conception fixed effects} + \text{error term}_{ij}. \quad (1)$$

Here, y denotes the birth outcome (e.g., LBW) of infant i whose mother lives in zip code j. The vector $\mathbf{x}$ includes variables on infant i's sex; infant i's mother's age, race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), having completed a four-year college education or higher (1/0), being married (1/0), number of prenatal visits, and smoking status (1/0).

The construction of the binary variable "downwind" in equation (1) is explained in Section 2.2. This variable "downwind" varies by infant i's zip code j over a period that consists of 12 consecutive months (i.e., a full year) and ends in infant i's birth month. The construction of the binary variable T in equation (1) is also explained in Section 2.2. This binary variable is equal to one if infant i's mother's LMP date is on or after June 1, 2014 and infant i is born on or before December 31, 2015; it is equal to zero if infant i's mother's LMP date is on or after June 1, 2008 and infant i is born on or before December 31, 2009. In other words, if infant i is conceived on or after June 1, 2014 (or June 1, 2008) and then born before the end of 2015 (or 2009), the binary indicator T will equal one (or zero). In this regression model we include zip code fixed effects, and we also add year-month of conception fixed effects, which are applied to each year-month of conception that is determined by the mother's LMP date. Note that once the regression model includes the year-month of conception fixed effects, it cannot simultaneously include T as a separate regressor because T is a linear combination of the dummy variables used for the year-month conception fixed effects. The year-month conception fixed effects are used for controlling for common shocks (e.g., weather shocks) that are experienced by mothers whose pregnancies start at the same year and month. In other words, these fixed effects are conception cohort effects.

In this regression model α_1 is the DID coefficient, indicating the impact on birth outcomes from shutting down the power plant. We estimate this regression model (equation 1) by ordinary least squares with standard errors clustered at the zip code level. Yang et al.'s (2017) study also clusters the standard error at the zip code level.

3.3 Descriptive Statistics

Panel A of Table 1 reports the summary statistics on the power plant's emissions and electricity generations, as well as on the wind directions near the power plant. Between the pre- and post-shutdown periods, the power plant's SO_2 emission dropped by 99.9988 percent (from 2,596.648 tons in the pre-shutdown period to 0.031 tons in the post-shutdown period), and the electricity generation dropped by 99.87 percent (from 201,049.600 MWh in the pre-shutdown period to 254.871 MWh in the post-shutdown period). The reason why these reductions did not reach 100 percent is that the shutdown has only been close to 100 percent: since June 1, 2014, the power plant still has been running, but running only on days when the demand for electricity is high and using low-sulfur diesel fuel to generate electricity.[15]

In Panel A of Table 1 we also see that on a monthly average the wind blows southeastward in both the pre-shutdown period (160.235 degrees) and the post-shutdown period (153.932 degrees). This is consistent with Figure 4, which shows that the wind near the power plant blows consistently southeastward in all 12 calendar months (from January to December).

[15]Source: http://www.lehighvalleylive.com/slate-belt/index.ssf/2014/06/portland_generating_station_sw.html (accessed on August 7, 2017).

Panel C reports the summary statistics on the weather variables we obtained from the NCDC, and these summary statistics are consistent with the fact that the entire state of New Jersey is influenced mainly by the humid continental climate, with the southmost and southeastmost parts of the state influenced by the humid subtropical climate.

Panel B of Table 1 shows that among the four impacted New Jersey counties identified in the NJDEP petitions filed with the EPA, Warren County is located closest to (in fact, immediately next to) the power plant, followed in order by Sussex, Hunterdon, and Morris. When comparing with the wind direction near the power plant the azimuth averaged over all zip codes for each of the four counties, we see that Hunterdon County is most downwind of the power plant (because the average azimuth of Hunterdon, which is 157.514, is closest to the wind vector azimuth of 160.235 or 153.932), followed in order by Warren, Morris, and Sussex.

Panel A of Table 2 reports the summary statistics on New Jersey's live singleton birth outcomes and mothers' characteristics. We notice that among live singleton births the LBW rate (5.88%) and the VLBW rate (0.70%) are both lower than the national rates (6.34% for LBW and 1.08% for VLBW, both among live singleton births in 2015).[16] This is consistent with the fact that New Jersey is the second wealthiest state in the United States (ranked only below the state of Maryland), and birth outcomes tend to improve with wealth, possibly through improved access to health care.

According to the DID setup explained in Section 2.2, almost all births in the pre-shutdown period ($T = 0$) were born in 2009, and almost all births in the post-shutdown period ($T = 1$) were born in 2015. One important trend we noticed in Panel A of Table 2 is that the LBW rate increased in New Jersey from 2009 to 2015. This, perhaps surprising, trend detected in the birth data we obtained from the NJDOH is indeed consistent with the national trend: the LBW rate and also the preterm rate in the United States started to increase in 2015 and then increased again in 2016, after both rates had declined between 2007 and 2014 (Tanne,

[16] The national LBW and VLBW rates among all live singleton births are obtained from the CDC WONDER Online Database (https://wonder.cdc.gov/natality.html, accessed on August 13, 2017).

2017).[17] These increases in the LBW rate and the preterm rate in 2015 and 2016 have also been reported by the U.S. news media.[18]

Panel B of Table 2 further shows that in the control group both the LBW rate and the preterm rate increased between the pre- and the post-shutdown periods. In comparison with the control group, the treatment group experienced an increase in the LBW rate as well, but a slight decrease in the preterm rate. Simple DID calculations conducted in this panel suggest that shutting down the power plant could have potentially improved the birth outcomes by reducing the LBW rate and the preterm rate in areas downwind of the power plant. We next use the regression model explained in Section 3.2 to pinpoint the magnitude of the effects of shutting down the power plant.

4 Results

4.1 Main Results

Table 3 reports the estimates of the effects of shutting down the power plant on LBW (Panel A), VLBW (Panel B), and birth weight (Panel C), based on the regression model explained in Section 3.2. When all New Jersey zip codes are included in the estimation sample (column 1), we find that shutting down the power plant could reduce the likelihood of LBW by 0.89 percentage points (Panel A) or by about 15 percent (i.e., 0.89/5.88, shown in Table 2) in areas downwind of the power plant, which is also shown in Figure 5 constructed based on our DID setup explained in Section 2.2. In Table 3 we also find that the shutdown of the power plant could increase the birth weight on average by about 26.4 grams (Panel C) in areas downwind of the power plant.

[17]Specifically, Tanne (2017) reports that "US preterm birth rates rose from 9.63% in 2015 to 9.84% in 2016. The low birth weight rate increased from 8.07% in 2015 to 8.16% in 2016. Both rates had declined between 2007 and 2014" (doi: https://doi.org/10.1136/bmj.j3311).

[18]For example, *NBC News* reported on June 30, 2017 (in the article "Preterm Birth Rates Have Increased in the U.S."): "Nearly 10 percent of babies born in the U.S. are born prematurely and the rates of preterm birth are going up, a new government report shows" (http://www.nbcnews.com/health/health-news/preterm-birth-rates-have-increased-u-s-n778576).

These fetal health effects appear to be driven mainly by the sample including New Jersey zip codes that are within 50 miles (column 2) and within 60 miles (column 3) of the power plant, but not driven by the sample including New Jersey zip codes that are more than 60 miles away from the power plant. This pattern is consistent with the fact that all four New Jersey counties (Hunterdon, Morris, Sussex, and Warren) identified in the NJDEP petitions as the impacted counties lie within 60 miles of the power plant. It is this area affected by the power plant's emissions that is expected to benefit from the shutdown of the power plant. Panel A of Figure 6 further demonstrates that the magnitude of the effect of shutting down the power plant on LBW becomes smaller when the sample includes New Jersey zip codes that are farther away from the power plant. In addition, Panel C of Figure 6 shows that the impact of being downwind of the power plant on LBW among fetuses conceived prior to the shutdown of the power plant becomes greater when the sample excludes New Jersey zip codes that are farther away from the power plant.

We next conduct a robustness check by dropping from the estimation sample the zip codes in Warren County (the county closest to the power plant) that are next to the power plant,[19] to see whether there will be significant changes in the results in Table 3 (columns 2 and 3). Those significant changes could suggest that residents in those zip codes may have taken effective actions against the power plant's pollution to offset the adverse impact (e.g., using air cleaners at home to improve indoor air quality that is affected by outdoor air pollution). We report the results of this robustness check in Appendix Table A1, where we find that the estimates are actually very similar (e.g., -0.0126 for LBW in column 3 Table 3 vs. -0.0129 for LBW in column 2 of Appendix Table A1). The result of this robustness check also confirms the finding of Yang et al.'s (2017) study (which dropped the same zip codes) about the similarity in the estimates obtained from the sample whether or not including those zip codes.

We conduct two additional robustness checks on the results reported in Table 3 by using

[19]These zip codes are 07823, 07832, 07833 and 08865. These are the same zip codes dropped from the estimation sample used by Yang et al.'s (2017) study.

alternative specifications. Specifically, in Appendix Table A2 we report the results obtained from adding two more time periods to the pre-shutdown period (i.e., $T = 0$) used in Table 3: (1) mother's LMP date on or after June 1, 2007 and birth date on or before December 31, 2008; and (2) mother's LMP date on or after June 1, 2006 and birth date on or before December 31, 2007. These two additional time periods include the same calendar months as what the pre-shutdown period used in Table 3 includes, and both the pre- and post-shutdown periods include the same calendar months. As a result of adding these two time periods, the sample size in Appendix Table A2 is more than twice as large as the sample size in Table 3. Despite this significant change in the sample size, the estimates remain very similar (e.g., -0.0089 for LBW in column 1 of Table 3 vs. -0.0081 for LBW in column 1 of Appendix Table A2).

In Appendix Table A3 we report the results obtained from redefining the "downwind" dummy variable used in equation (1). Here, we let the "downwind" dummy variable equal one when a zip code belongs to (any one of) the four counties—Hunterdon, Morris, Sussex, and Warren—which were identified as the counties impacted by the power plant in the NJDEP's petitions filed with the EPA; we let the "downwind" dummy variable equal zero when a zip code belongs to other New Jersey counties. It is expected that the four New Jersey counties impacted by the power plant will benefit from the shutdown of the power plant, for example, in terms of lowered likelihood of LBW. Indeed, in Appendix Table A3 we find that shutting down the power plant could reduce the likelihood of LBW by 0.88 (column 4) percentage points in the four-county area of New Jersey, which is very similar to what we find in Table 3: shutting down the power plant could reduce the likelihood of LBW by 0.89 percentage points in areas downwind of the power plant.

The downwind variable used in our regression model (equation 1) varies at the zip code-monthly level, with the geographic variation driven by zip codes and the time variation driven by wind directions. Throughout our analyses we use this downwind variable together with zip code fixed effects, which control for the distance between each zip code and the power plant. By doing so, we extract the variation in the downwind variable that is possibly driven by exogenous changes in wind directions. We next assess the plausibility of this exogeneity by running regressions based on equation (1) for the pre-shutdown period and using demographic variables averaged at the zip code-monthly level as dependent variables, which is similar to what Yang et al. (2017) did for checking the plausible exogeneity of the downwind variable used in that study. Our results are reported in Table 4, suggesting the exogeneity of the downwind variable plausibly at the zip code-monthly level. To be more specific, in Table 4 we find no statistically significant differences in the zip code-monthly level average demographic characteristics between the downwind and not downwind groups in the pre-shutdown period, except that the number of prenatal visits in the downwind group on average is smaller, but smaller only by a tiny magnitude (i.e., 0.0925 prenatal visits). The findings in Table 4 also lend us some support for imposing the common trend assumption needed for our DID analysis, since the downwind and not downwind groups on average appear to share similarities in some observables in the pre-shutdown period. However, we must admit that the balancing of those observable characteristics does not prove the truthfulness of the common trend assumption, which requires not only observables but also unobservables of the downwind and not downwind groups on average have the same change over time.

Next, we conduct a robustness check by repeating the estimations conducted in Table 3 but at the zip code-monthly level instead. The rationale for this robustness check is the following: If our individual-level DID analysis (conducted in Table 3) omits important individual-level heterogeneities, which can violate the common trend assumption if those important individual-level heterogeneities omitted are time-varying, then the aggregate-level analysis (i.e., at the zip code-monthly level) should produce results that are inconsistent with the results obtained from the individual-level analysis (i.e., the results in Table 3). We report the results of the zip code-monthly level analysis in Appendix Table A4, where the sample size is only about 17 to 18 percent of the sample size in Table 3. Despite the significant difference in sample size, the findings in these two tables are actually consistent: in the area downwind of the power plant, especially within 60 miles of the plant, there is a statistically significant decrease (or increase) in the LBW likelihood (or average birth weight) as a result of shutting down the power plant. Although the consistency in the results between the individual-level analysis (Table 3) and the aggregate-level analysis (Appendix Table A4) cannot prove the absence of important individual-level heterogeneities omitted in our empirical analysis, the consistency itself at least indicates the lack of direct evidence showing the presence of important, but omitted, individual-level heterogeneities that are correlated with the downwind variable used in our empirical analysis.

4.2 Further Checks on the Validity of the Main Results

We conduct a two-part analysis to further check the validity of the main results presented in Table 3. In the first part we examine whether there is an adverse effect on LBW of prenatal exposure to power plant emissions when the power plant's emission levels are high. In the second part we examine whether the adverse effect on LBW (if detected in the first part) will diminish when the power plant's emissions are significantly reduced.

Part I analysis is intended to replicate Yang et al.'s (2017) study, following their regression model specifications and their definition of the downwind variable, but with two important extensions. First, in this analysis we use births that occurred in 2007, 2008 and 2009, with the pregnancy periods going from 2006 to 2009. As Figure 2 (Panel A) shows, the power plant's emission levels were consistently high from 2006 to 2009. In contrast, the last year of birth used in Yang et al.'s (2007) study is 2006. Second, our study uses birth records obtained from the NJDOH, which include the gestational length information. In contrast, Yang et al.'s (2017) study uses the State Inpatient Database of the New Jersey Healthcare Cost and Utilization Project, in which the gestational length information is not available. So, this Part I analysis overcomes a major weakness of Yang et al.'s (2017) study by being able to take the length of a pregnancy into account. As a result, we are able to examine what

Yang et al.'s (2017) study is unable to examine, which is the presence of critical windows of prenatal exposure to power plant emissions that make fetuses most vulnerable to power plant emissions.

To examine the presence of critical windows of prenatal exposure to power plant emissions, we consider births that all have the same length of pregnancy, that is, fetuses that all have the same length of period *in utero*, during which they are exposed to power plant emissions (through the maternal exposure during pregnancy). To do so, we focus on full-term births, and for the same reasons previously given, we focus on live singleton births. A full-term birth has a pregnancy that is usually nine-month (i.e., 39 to 40-week) long.[20] Accordingly, in the estimation we include nine "downwind" terms for the nine months.[21]

Table 5 reports the results of our Part I analysis. In columns (1) and (2) we see that the estimated effects of being downwind of the power plant are similar, whether or not we control for important individual-level variables such as mother's age, education, race and ethnicity, all believed to correlate with birth outcomes (columns 1 vs. 2). This pattern suggests that the variations in those downwind variables are exogenous to those individual-level important covariates of birth outcomes, conditional on our use of zip code fixed effects to control for the distance between each New Jersey zip code and the power plant.

Results reported in Table 5 are largely consistent with Yang et al.'s (2017) results. Both this analysis and Yang et al.'s (2017) study focus on the impacted region including these four New Jersey counties: Hunterdon, Morris, Sussex, and Warren. Results in columns (1) through (4) of Table 5 confirm what Yang et al. (2017) find, which is the increased likelihood of LBW among mothers living in the impacted region downwind of the power plant. The magnitude of the estimated adverse effect (shown in columns 1–4 of Table 5) is about 0.4 to 0.5 percentage points (i.e., the magnitude of the increase in the LBW likelihood), which is

[20]Note that each calendar month includes four full weeks and up to three more days; February (not in a leap year) is the only month that includes exactly four weeks.

[21]In Appendix C we gave further explanations on why we focus on full-term LBW and why we consider each month of a full-term pregnancy separately, that is, not grouping them into three trimesters. In Appendix D we gave detailed explanations on why we do not include preterm births into our by-month *in utero* analysis.

similar to the magnitude of the estimated adverse effect reported in Yang et al.'s (2017) study (i.e., 0.4 percentage points, reported in their table 5), despite the substantial differences in the sample period (2007–2009 in this analysis vs. 1990–2006 in Yang et al. 2017) and the sample size (21,321 observations used in this analysis vs. 147,382 observations used in Yang et al. 2017).

Also consistent with what Yang et al. (2017) find in their robustness checks, in this Part I analysis we find no adverse effect on LBW in the area that is outside of the impacted region identified in the NJDEP's petitions filed with the EPA (results reported in column 5 of Table 5). Furthermore, in this Part I analysis we conduct several falsification checks, all showing that our regression model is able to predict zero effect when the effect indeed does not exist. Specifically, in column (3) of Table 5 our regression model correctly predicts zero effect on LBW of being downwind of the power plant during the month after birth. This effect should be zero because the infant weight measured at birth cannot be affected by the exposure to power plant emissions that occur after birth. In column (4) of Table 5 our regression model also correctly predicts zero effects on LBW of being downwind of the power plant during the months that are prior to the beginning of a pregnancy. These effects should be zero because during those months there is no fetus *in utero* that can be exposed to power plant emissions.

In this Part I analysis we find that the adverse effects are concentrated in the eight month prior to the birth month, which is approximately the first month of a normal pregnancy (which is usually nine month long), and also concentrated in the third month prior to the birth month, which is roughly the beginning part of the third trimester. Our finding on the timing (i.e., the critical windows) of the adverse effect on LBW is 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 (Maisonet et al., 2004). In contrast, Yang et al.'s (2017) study finds the adverse effect on LBW is concentrated in the birth month, and they add a cautionary note to their study, stating that "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" (p. 576). One explanation for the discrepancy in the findings about the timing of the adverse effect on LBW between our Part I analysis and Yang et al.'s (2017) study is the difference in the composition of the estimation sample. In our Part I analysis we have the gestational length information, and we use it to include only full-term births. In contrast, Yang et al.'s (2017) study includes both preterm and full-term births without being able to distinguish between the two, because of the lack of information on gestational length, and their results could be driven by preterm births.

One drawback of our study and also Yang et al.'s (2017) study is the lack of information on the scope of the mother's daily activities, although both studies have the information on which zip code the mother lives in. It is possible that the mother spends most of her day at work, and the workplace is in a zip code that is far away from the mother's residential zip code. As a result, our measure of being downwind of the power plant is for potential exposure only, which can be substantially different from the mother's actual exposure to the power plant's emissions.

To assess the impact of this measurement error, we obtain the power plant's hourly emission data provided by the EPA's AMPD covering the period going from January 1, 2006 to December 31, 2009, which is the *in utero* period for births that occurred in 2007, 2008 and 2009 at the time when the power plant's emission levels were high (Panel A of Figure 2). Figure 7 indicates that on average the power plant's SO_2 emissions were peaked around 3:00 PM during this period. According to our wind data, the monthly average speed of the wind measured near the power plant is about six miles per hour. Panel B of Table 1 shows that the average distance between the mother's residential zip code and the power plant is 10.158 miles for Warren, 25.077 miles for Sussex, 25.207 miles for Hunterdon, and 30.638 miles for Morris. So, the travel time for SO_2 emitted from the power plant to reach the four counties could be between two and five hours, based on the wind speed of six miles per hour. Thus, it is conceivable for the SO_2 emissions that are peaked at 3:00 PM to reach the four counties between 5:00 PM and 8:00 PM, at the time when workers usually return home from work. Hence, even though the mothers from the four counties can spend most of the daytime at work, away from their homes, they still can be exposed to elevated pollution levels measured at their residential zip codes, because of the power plant's emissions that are peaked in the afternoons. Therefore, in both our study and Yang et al.'s (2017) study the variable of being downwind of the power plant, although relying on the mothers' residential zip codes, still can be meaningful for capturing a portion of the mothers' actual pollution exposure that is affected by the power plant's emissions.

Table 6 reports the results of our Part II analysis, which repeats the Part I analysis (using three birth years) but using different birth years, which are 2013, 2014 and 2015. So, in our Part II analysis the *in utero* years go from 2012 to 2015. As Figure 2 (Panel A) shows, the power plant's emission levels were significantly reduced in the period of 2012–2015 compared with the period of 2006–2009. Consistent with the significant reductions in the power plant's emissions and in contrast to the results in Table 5, here in Table 6 we find no statistically significant effect on the likelihood of LBW among mothers living in the impacted region downwind of the power plant. In Table 6 (columns 3–5) we also conduct the same falsification checks done in Table 5, and all these checks confirm zero effects in cases where the effects are indeed zero.

4.3 Additional Results

Table 7 reports the estimates of the effects of shutting down the power plant on additional birth and pregnancy outcomes: the occurrence of a preterm birth (Panel A) and gestational length (Panel B), based on the regression model explained in Section 3.2. In the estimation sample including all New Jersey zip codes (column 1), we find that shutting down the power plant could reduce the likelihood of a preterm birth by 2.83 percentage points (Panel A) or by about 28 percent (i.e., 2.83/10.28, shown in Table 2) in areas downwind of the power plant, which is also shown in Figure 5 constructed based on our DID setup explained in Section 2.2. In Table 7 we also find that the shutdown of the power plant could increase the gestational length on average by about 0.22 weeks or 1.5 days (Panel B) in areas downwind of the power plant.

One reason for the magnitude of the effect on LBW being smaller than that on preterm (i.e., -0.0089 shown in column 1 and Panel A of Table 3 vs. -0.0283 shown in column 1 and Panel A of Table 7) is that among the preterm births avoided due to the shutdown of the power plant some of them still can be LBW births because LBW can occur among full-term births (and the full-term LBW cases have been examined in Table 5 and Table 6). Also note that based on the fetal growth chart, a fetus gains about 106 grams per week over the period from the eighth week to the 43rd week of gestation.[22] So, an increase of 0.22 weeks (column 1 and Panel B of Table 7) of gestation could mean an increase of 23.32 grams of birth weight on average (over the period from the eighth week to the 43rd week of gestation), which is similar to the magnitude of the effect on average birth weight reported in Table 3 (i.e., 26.4039 grams, reported in column 1 and Panel A of Table 3). Thus, the magnitude of the effect on gestational length and the magnitude of the effect on birth weight found in our study are reasonable, according to the fetal growth chart.

Similar to the results shown in Table 3, in Table 7 we find that the effects on preterm birth and gestational length appear to be driven mainly by the sample including New Jersey zip codes that are within 50 miles (column 2) and within 60 miles (column 3) of the power plant, but not driven by the sample including New Jersey zip codes that are more than 60 miles away from the power plant. This pattern is reasonable since it is the area affected by the power plant's emissions that is expected to benefit from the shutdown of the power plant and all four New Jersey counties identified in the NJDEP petitions as the impacted counties are within 60 miles of the power plant. Panel B of Figure 6 further demonstrates that the magnitude of the effect of shutting down the power plant on preterm birth becomes smaller

[22]For a detailed fetal growth chart, see http://www.babyyourbaby.org/pregnancy/during-pregnancy/fetal-chart.php (accessed on August 20, 2017).

when the sample includes New Jersey zip codes that are farther away from the power plant. In addition, Panel D of Figure 6 shows that the impact of being downwind of the power plant on preterm birth among fetuses conceived prior to the shutdown of the power plant becomes greater when the sample excludes New Jersey zip codes that are farther away from the power plant.

In Table 8 we further examine the effects on birth and pregnancy outcomes of shutting down the power plant by sex (columns 1 and 2) and by maternal education level (columns 3 and 4). We find that female fetuses appear to benefit more from the shutdown of the power plant in terms of a greater reduction in the likelihood of LBW, and greater increases in average birth weight and average gestational length than male fetuses (columns 1 and 2). This pattern is consistent with the findings of the medical literature that female fetuses exhibit a higher level of "plasticity" than male fetuses in adapting to changes in environments *in utero* (Aiken and Ozanne, 2013). This pattern is also confirmed in our robustness check conducted in Appendix Table A5, in which we restrict the estimation sample to include New Jersey zip codes that are within 60 miles of the power plant.

Another pattern shown in Table 8 is that mothers who do not complete a four-year college education or higher appear to benefit more from the shutdown of the power plant in terms of a greater reduction in the likelihood of a preterm birth, and greater increases in average birth weight and average gestational length (columns 3 and 4). In the case of LBW (Panel A), the reduction in its likelihood, due to the shutdown of the power plant, appears to be mainly concentrated among mothers who do not complete a four-year college education or higher. We find the same pattern in our robustness check conducted in Appendix Table A5, in which the estimation sample includes only New Jersey zip codes that are within 60 miles of the power plant. One possible reason for the findings that mothers with lower education benefit more from the shutdown of the power plant in terms of greater improvements in birth and pregnancy outcomes is that mothers with higher education may have access to more resources, such as better health care that is usually associated with higher income (correlated with education) or better knowledge about coping with pollution impact during pregnancy. The utilization of these resources could mitigate the adverse effect of prenatal exposure to power plant emissions, making the benefit of shutting down the power plant become muted.

5 Conclusion

Under the U.S. system of federalism, environmental regulations imposed at the federal level typically rely on each individual state to implement. As a result, jurisdictional borders can give states perverse incentives for exporting pollution to their neighboring states that are downwind (Helland and Whitford, 2003) or downstream (Sigman, 2005). In fact, in the United States facilities that are major air polluters are more likely to be located near a state's downwind border than facilities whose hazardous wastes are mainly non-airborne (Monogan III, Konisky and Woods, 2017). The existence of strategic placing of air-polluting facilities near jurisdictional borders reflects the presence of environmental free riding—upwind states receiving the benefits of jobs and tax revenue while shifting the pollution cost to downwind states. Our study highlights one specific case where cross-border air pollution had not been effectively dealt with by a decentralized, state-by-state regulatory approach, leaving a coal-fired power plant—Portland Generating Station—located on the border between two states polluting the downwind state for years without being controlled.

To the best of our knowledge, we provide the first empirical study on the benefit of using direct federal level regulation on a *single* pollution source in solving the cross-border air pollution problem. Our study utilizes a landmark ruling by the U.S. EPA known as the Portland Rule, which results in the shutdown of Portland Generating Station in June 2014. The EPA's Portland Rule marks the *first-ever* federal level regulation under the CAA that overrides state-level regulations and is directly imposed upon a *single* pollution source. Prior to the shutdown, Portland Generating Station had an annual SO_2 emission that is more than double the SO_2 emissions from all electricity-generating facilities in the downwind state (New Jersey) combined (NJDEP, 2010a, p. 30).

Our study shows that the shutdown of Portland Generating Station reduces the likelihood of having a low birth weight baby by 0.89 percentage points or by about 15 percent, and also reduces the likelihood of a preterm birth by 2.83 percentage points or by about 28 percent, in areas downwind of the power plant. The benefits of avoiding low birth weight and preterm births can be far-reaching, on the basis of a robust association found in the literature between birth weight and outcomes during adulthood including health, educational attainment and earning (Currie and Rossin-Slater, 2015). Furthermore, these benefits potentially can be even greater for mothers with lower socioeconomic status, according to our finding that the improvements on birth outcomes from the shutdown of the power plant appear to concentrate among mothers who do not complete a four-year college education or higher.

It is also important to point out that the geographic area we focus on is New Jersey, which is the second wealthiest state of the United States (ranked only below the state of Maryland). Given that household income *ceteris paribus* is positively associated with residential area's air quality (Banzhaf and Walsh, 2008), high-income households in our study region may invest more in improving indoor air quality, for example, by using high-quality (and costly) air cleaners to remove indoor fine particles and gaseous pollutants that can be elevated by outdoor air pollution.[23] As a result, our findings on the improvement on birth outcomes from the shutdown of the power plant can be an underestimation for a general population, since the improvement we detected can be a muted result due to possible mitigation of adverse pollution impact by high-income households prior to the shutdown of the power plant. Nonetheless, from a policy perspective this underestimation may still be informative for assessing a minimum of positive health effects that warrants policy interventions.

Our findings provide empirical evidence in support of federal level regulations imposed directly upon specific pollution sources. The empirical setting of our study is an important

[23] See https://www.epa.gov/indoor-air-quality-iaq/guide-air-cleaners-home for details (accessed on August 28, 2017).

manifestation of negative interjurisdictional externalities in the case of cross-border air pollution that had not been effectively dealt with by a decentralized, state level policymaking. While the development of renewable energy sources such as solar, wind, and hydropower is underway, coal is expected to remain in the U.S. energy portfolio in the foreseeable future. In fact, the empirical setting of Severnini's (2017) study highlights a case where coal became a fallback option in the 1980s, when nuclear power plants in the Tennessee Valley were closed in the wake of the Three Mile Island accident that occurred 1979.[24] In this regard, proper regulation on coal-fired power plants, preventing environmental free riding induced by jurisdictional borders, is needed and also imperative.

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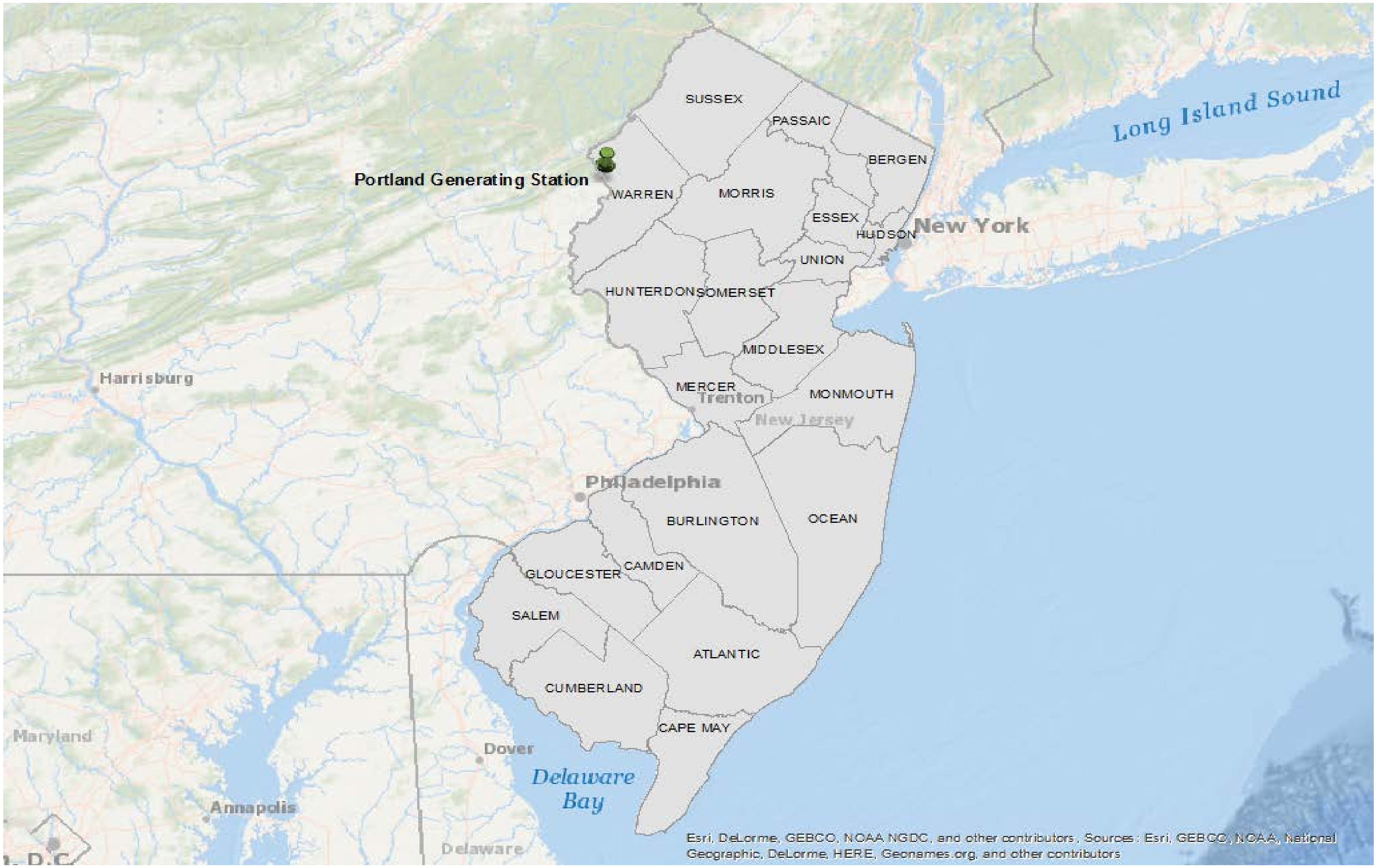

Figure 1: Portland Generating Station and New Jersey Counties

Note: The address of the Portland Generating Station (indicated on the map) is 40897 River Road, Portland, Pennsylvania 18351.

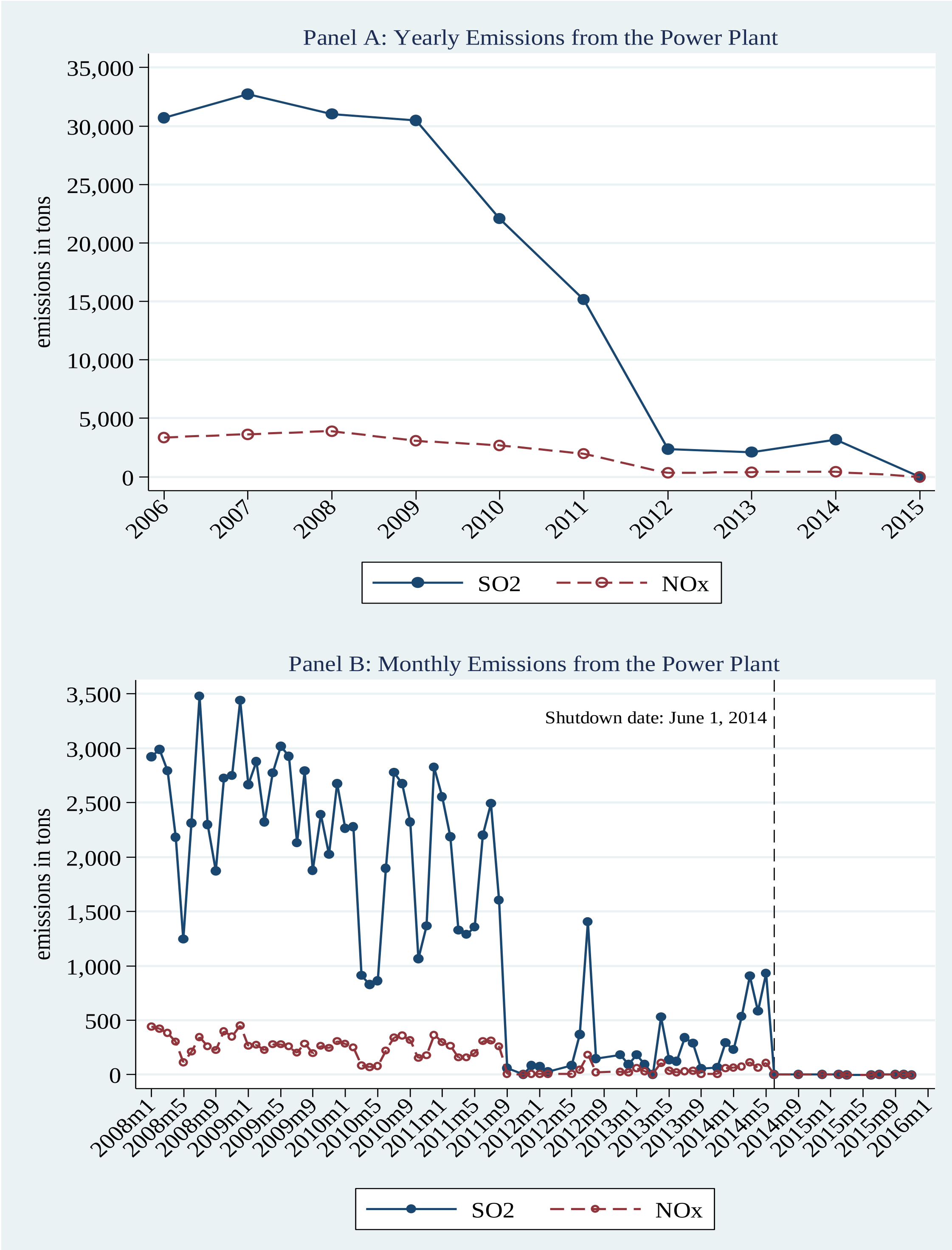

Figure 2: Yearly and Monthly Emissions from the Portland Generating Station

Note: Depicted are the emissions of sulfur dioxide and nitrogen oxides from the Portland Generating Station based on the EPA's Air Markets Program Data.

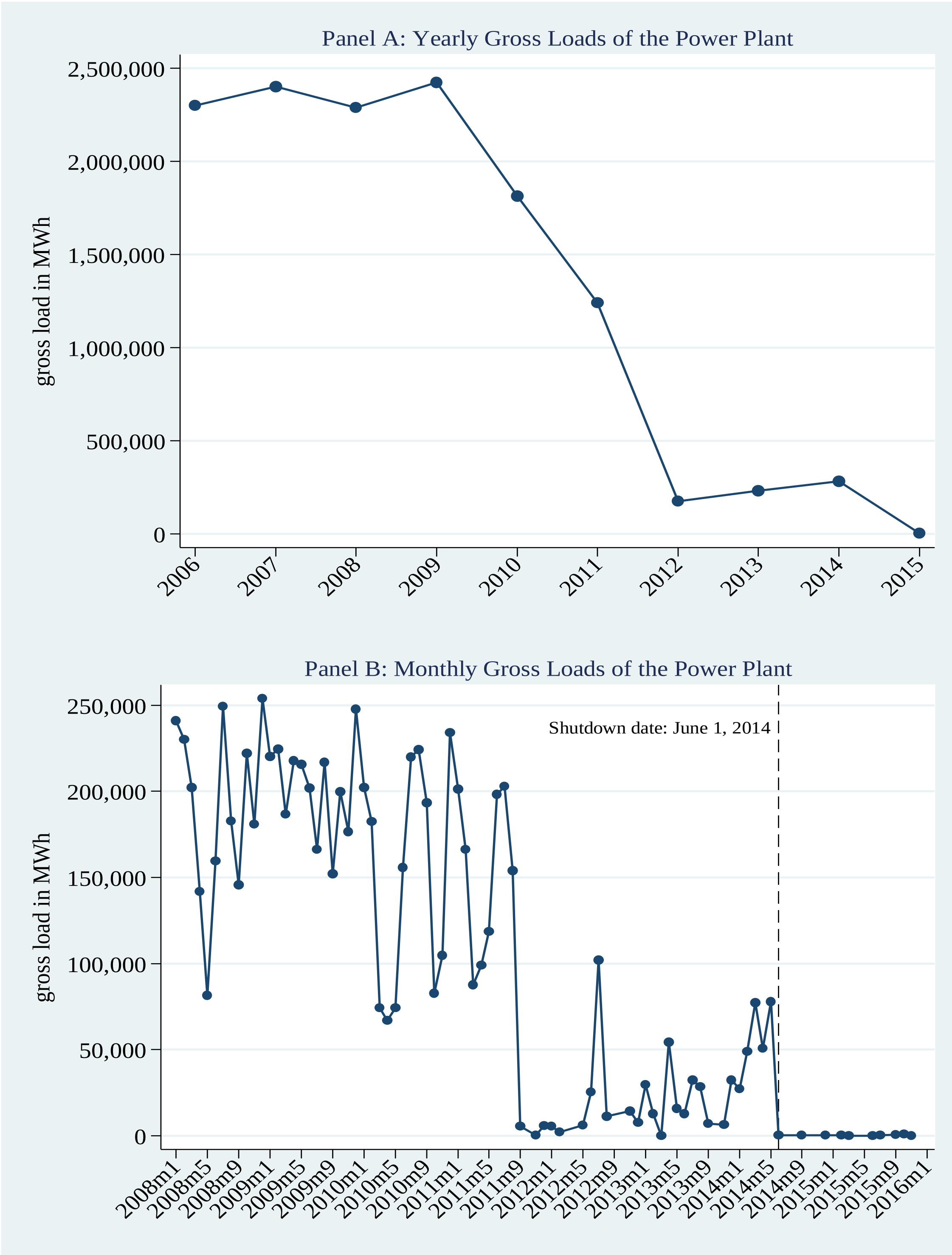

Figure 3: Yearly and Monthly Gross Loads of the Portland Generating Station

Note: Gross load (in MWh) measures the total electrical generation of the power plant. Depicted are the gross loads of the Portland Generating Station based on the EPA’s Air Markets Program Data.

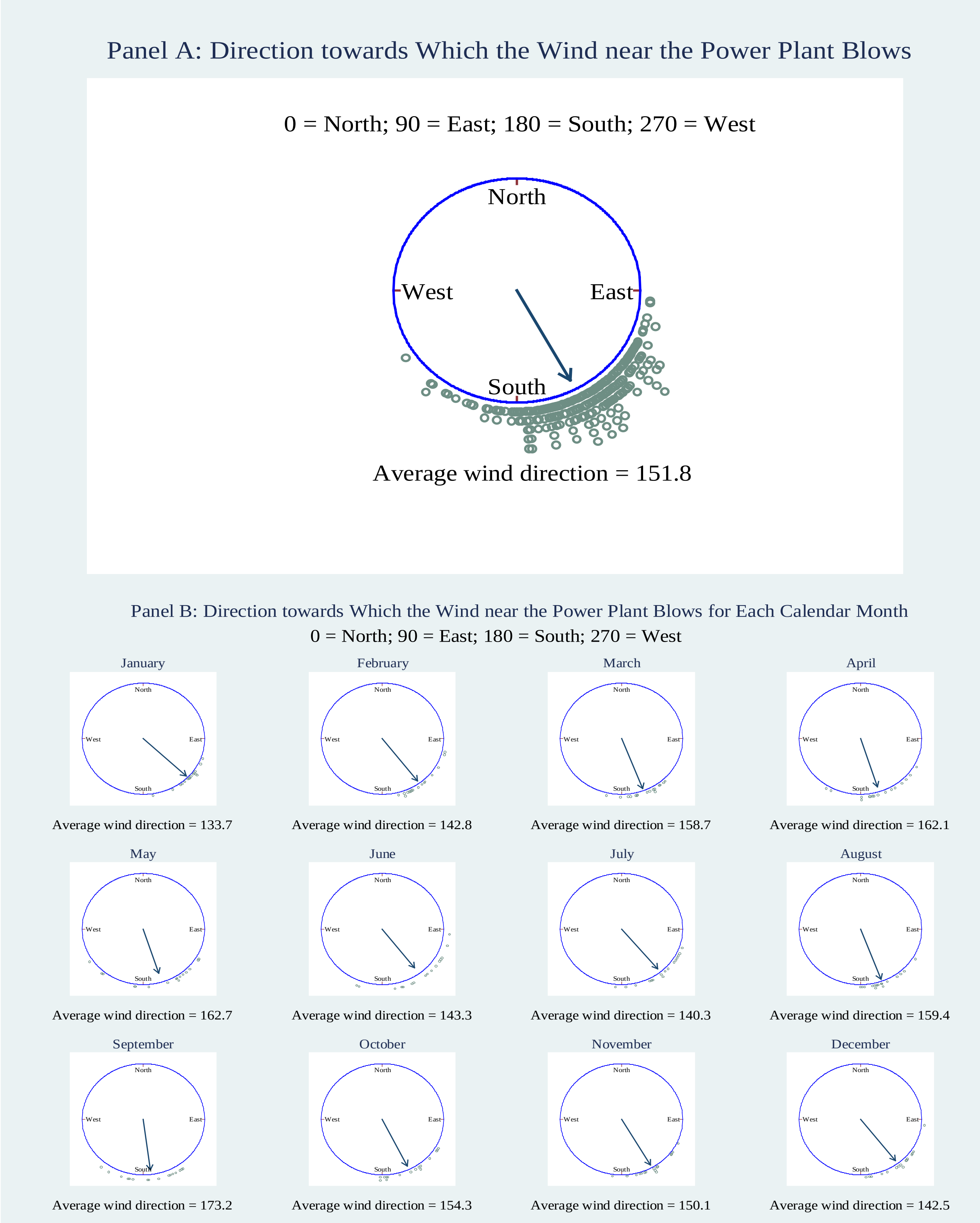

Figure 4: Wind Directions near the Portland Generating Station

Note: In Panel A, the average wind direction is the monthly average over the period of 2000–2015. In Panel B, the average wind directions are the monthly averages by calendar month (January through December) over the period of 2000–2015. In each plot the 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.

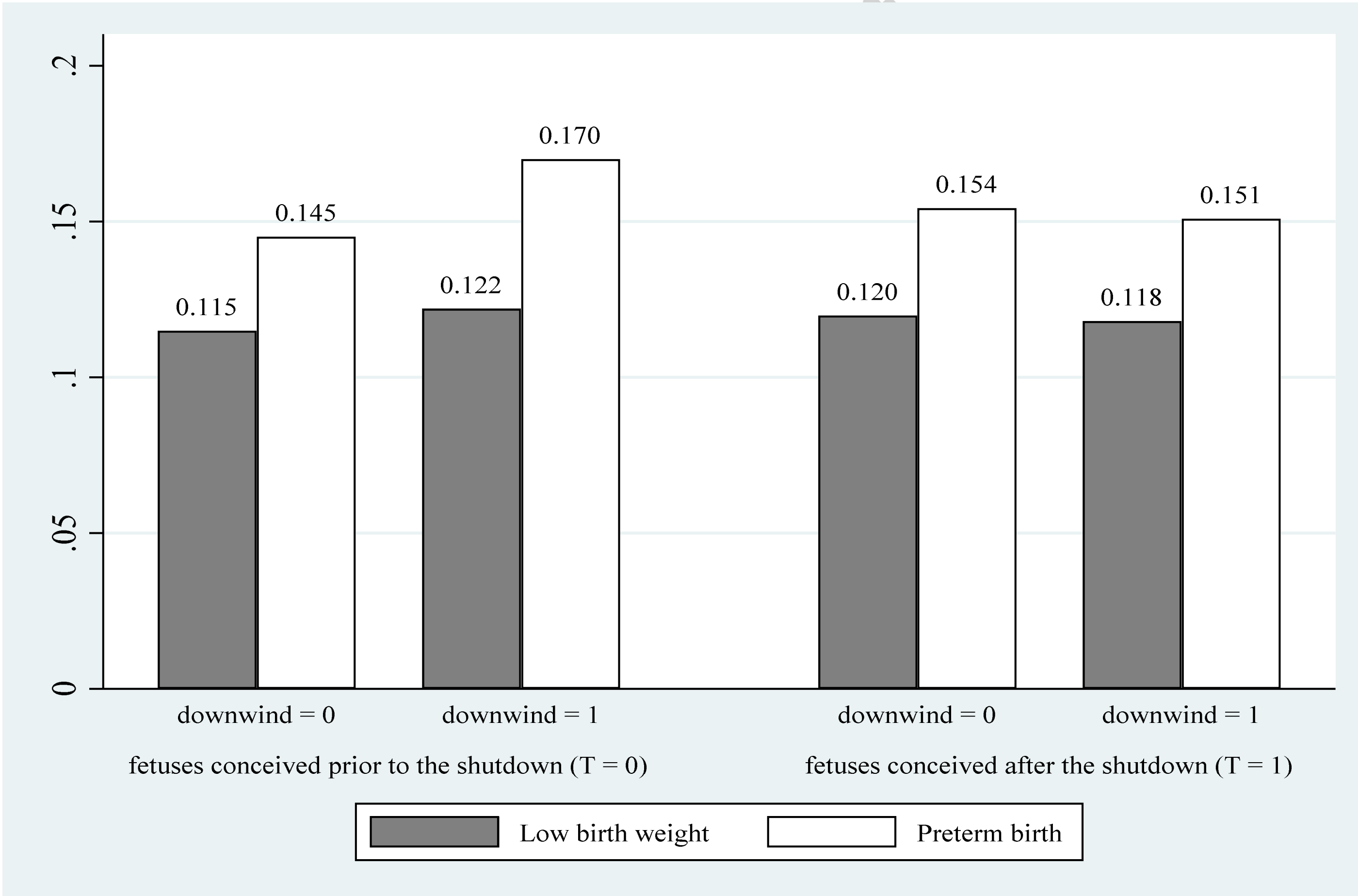

Figure 5: Comparisons of Birth Outcomes

Note: Depicted are the average rates of residualized low birth weight and residualized preterm birth among live and singleton births that occurred in New Jersey. Both residualized outcomes (i.e., low birth weight and preterm birth) are adjusted for infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, maternal smoking (1/0), zip code fixed effects, and year-month conception fixed effects. The average rate of each residualized outcome is calculated for each of the four groups defined by the "T (1/0)" variable and the "downwind (1/0)" variable. The "T (1/0)" variable is equal to 1 if the mother's last menstrual period (LMP) date ≥ June 1, 2014, which is the shutdown date of the power plant, and birth date ≤ December 31, 2015; it is equal to 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009. The "downwind (1/0)" variable varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

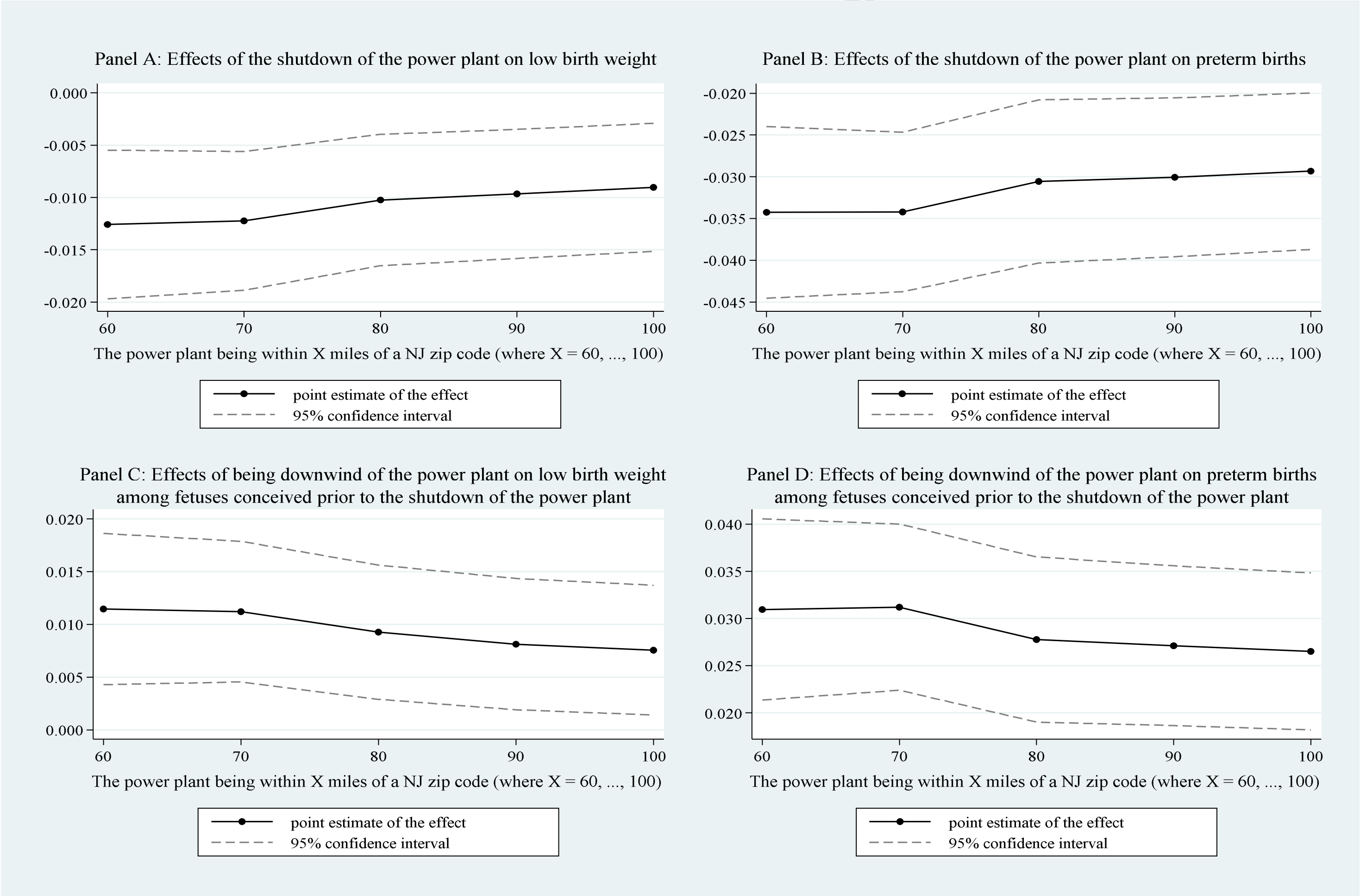

Figure 6: Estimates of the Fetal Health Effects of Prenatal Exposure to the Power Plant

Note: Panels A and B show the point estimates of α_1 and the associated confidence intervals obtained based on the regression model described by equation (1) in Section 3.2. Panels C and D show the estimates of α_0 and the associated confidence intervals obtained based on the regression model described by equation (1) in Section 3.2. In all four panels the regression model is applied to samples including live and singleton births that occurred in New Jersey zip codes (where the mothers live) that are within X miles of the power plant (where X = 60, 70, ..., 100).

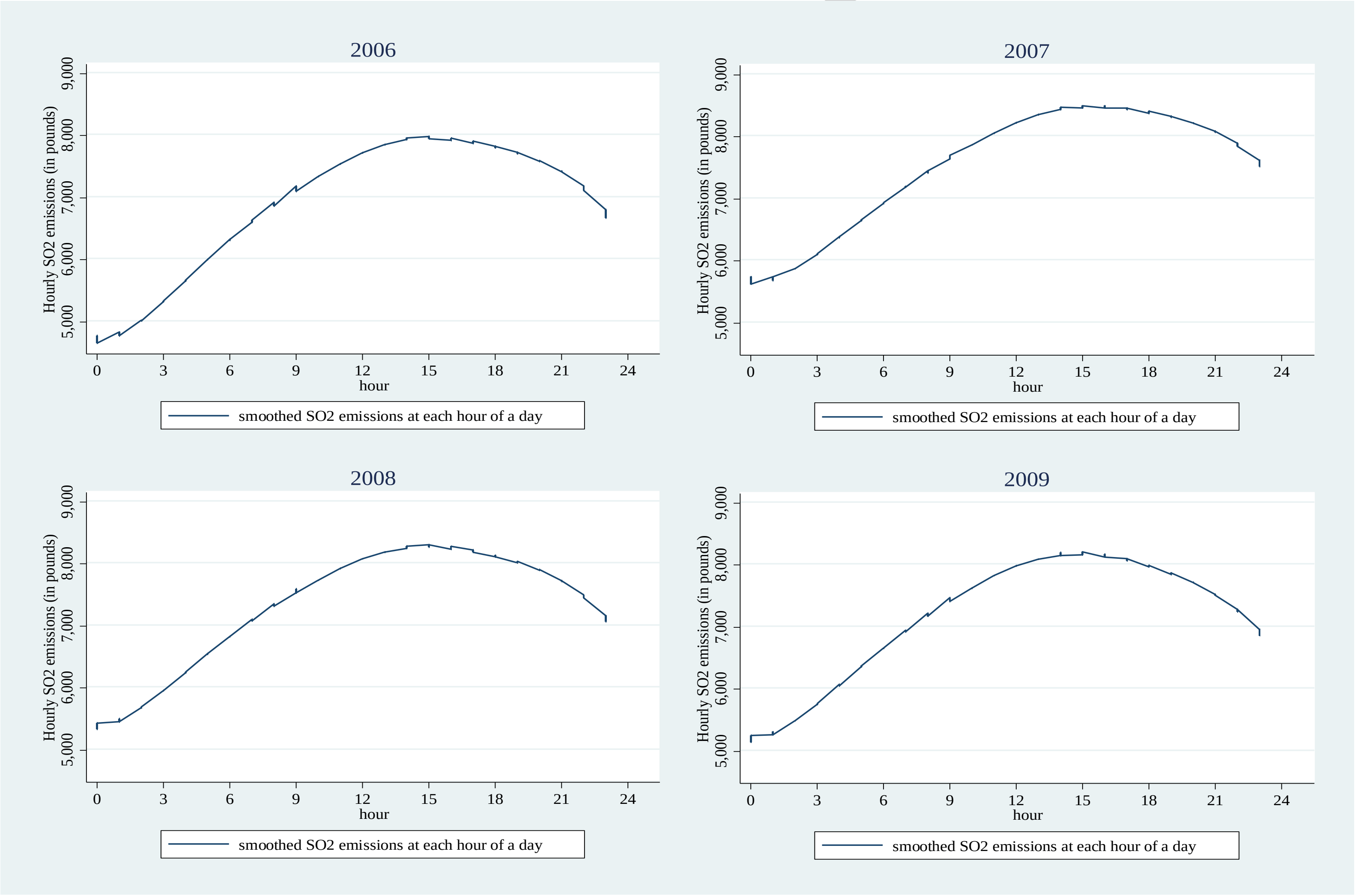

Figure 7: Hourly Sulfur Dioxide Emissions from the Portland Generating Station

Note: The hourly emissions are measured in pounds at each hour of a day (0:00 through 23:00). Depicted in the panels are locally weighted scatterplot smoothing (i.e., "lowess") values with the default bandwidth 0.8 used for years 2006, 2007, 2008 and 2009, respectively. The power plant's emission data are from the EPA's Air Markets Program Data.

Table 1: Summary Statistics, Part I

Panel A: Portland Generating Station (PGS), a coal-fired power plant located in Pennsylvania	During 06/2008–12/2009	During 06/2014–12/2015
PGS SO_2 monthly emissions (in tons)	2,596.648	0.031
	(462.645)	(0.031)
PGS NO_x monthly emissions (in tons)	279.384	0.132
	(67.529)	(0.127)
PGS monthly gross load (in MWh)	201,049.600	254.871
	(32,811.570)	(261.869)
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	160.235	153.932
	(26.459)	(22.403)

Panel B: Four counties of New Jersey	Hunterdon	Morris	Sussex	Warren
Distance (in miles) between a New Jersey zip code centroid and the PGS	25.207	30.638	25.077	10.158
	(5.895)	(6.716)	(7.606)	(3.742)
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	157.514	98.226	57.419	125.754
	(15.418)	(10.449)	(14.966)	(44.568)
Number of zip codes	28	55	27	18
	during 06/2008–12/2009 and 06/2014–12/2015			
Being downwind of the power plant (1/0): equal to 1 if the difference between monthly average wind vector azimuth and New Jersey zip code azimuth is less than 45 degrees, and 0 otherwise	0.880	0.322	0.021	0.560
	(0.325)	(0.467)	(0.145)	(0.497)

Panel C: Zip code-monthly level averages of weather variables for New Jersey during 06/2008–12/2009 and 06/2014–12/2015	
Daily mean temperature (Fahrenheit)	55.947
	(16.169)
Daily maximum temperature (Fahrenheit)	65.737
	(16.834)
Daily minimum temperature (Fahrenheit)	46.141
	(15.624)
Total monthly rainfall (inches)	3.715
	(1.817)
Total monthly snowfall (inches)	1.657
	(3.699)
Number of days in a month with minimum temperature less than or equal to 0.0 Fahrenheit	0.105
	(0.640)
Number of days in a month with minimum temperature less than or equal to 32.0 Fahrenheit	7.379
	(10.021)
Number of days in a month with maximum temperature greater than or equal to 90.0 Fahrenheit	1.777
	(2.896)
Number of days in a month with maximum temperature less than or equal to 32.0 Fahrenheit	1.438
	(3.526)
Number of days in a month with greater than or equal to 1.0 inches of precipitation	0.979
	(0.801)
Extreme maximum daily precipitation total within a month (inches)	1.312
	(0.651)
Number of zip codes	723
Number of observations	27,060

Note: Means and standard deviations (in parentheses) are reported for each variable listed in this table. Gross load (in MWh) measures the total electrical generation of the power plant. Azimuth is used for measuring the wind direction near the power plant and also the zip code direction relative to the power plant.

Table 2: Summary Statistics, Part II

Panel A: Means and standard deviations	Conceived after the power plant's shutdown (1/0) = 0		Conceived after the power plant's shutdown (1/0) = 1		Full sample	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Birth weight (measured in grams)	3,314.0480	521.2375	3,306.4510	539.5480	3,310.5050	529.8660
Low birth weight (1/0): birth weight < 2,500 grams	0.0572	0.2322	0.0607	0.2387	0.0588	0.2352
Very low birth weight (1/0): birth weight < 1,500 grams	0.0057	0.0754	0.0084	0.0911	0.0070	0.0831
Gestational length (measured in weeks)	39.1757	2.2353	39.1206	2.2664	39.1500	2.2500
Preterm (1/0): gestational lengh < 37 weeks	0.1029	0.3038	0.1027	0.3036	0.1028	0.3037
Female infant (1/0)	0.4850	0.4998	0.4904	0.4999	0.4875	0.4998
Mother's age	29.7360	6.0247	30.5676	5.6518	30.1238	5.8684
Mother white (1/0)	0.6806	0.4663	0.6320	0.4823	0.6579	0.4744
Mother black (1/0)	0.1782	0.3827	0.1599	0.3665	0.1697	0.3753
Mother hispanic (1/0)	0.2753	0.4467	0.2881	0.4529	0.2813	0.4496
Mother having completed a four-year college education or higher (1/0)	0.3937	0.4886	0.4303	0.4951	0.4108	0.4920
Mother married (1/0)	0.6393	0.4802	0.6591	0.4740	0.6485	0.4774
Number of prenatal visits	10.2449	3.4374	10.6529	3.2356	10.4351	3.3510
Smoking (1/0)	0.0612	0.2397	0.0715	0.2576	0.0660	0.2483
Number of observations	80,389		70,234		150,623	

Panel B: Mean comparisons	Conceived after the power plant's shutdown (1/0) = 0		Conceived after the power plant's shutdown (1/0) = 1		
Low birth weight (1/0): birth weight < 2,500 grams	Mean	No. of obs.	Mean	No. of obs.	Difference in means
Downwind (1/0) = 1	0.05643	49,741	0.06009	52,739	0.00366
Downwind (1/0) = 0	0.05837	30,648	0.06236	17,495	0.00399
			Difference in the two differences		-0.00033
Preterm (1/0): gestational lengh < 37 weeks	Mean	No. of obs.	Mean	No. of obs.	Difference in means
Downwind (1/0) = 1	0.10354	49,741	0.09940	52,739	-0.00414
Downwind (1/0) = 0	0.10187	30,648	0.11272	17,495	0.01085
			Difference in the two differences		-0.01499

Notes: The summary statistics ae based on the sample including live and singleton births. The variable "conceived after the power plant's shutdown (1/0)" is equal to 1 if the mother's last menstrual period (LMP) date ≥ June 1, 2014 and birth date ≤ December 31, 2015; it is equal to 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009. The "downwind (1/0)" variable varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and $D_t = 1$ if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

Table 3: Effects of the shutdown of the power plant on infant birth outcomes

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015, and T = 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009.

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

	All zip codes of New Jersey	Distance between the power plant and New Jersey zip codes		
		≤ 50 miles	≤ 60 miles	> 60 miles
	(1)	(2)	(3)	(4)
Panel A: Dependent variable is low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)				
Downwind × T	-0.0089***	-0.0126***	-0.0126***	0.0233
	(0.0031)	(0.0043)	(0.0036)	(0.0256)
Downwind	0.0071**	0.0140***	0.0115***	-0.0116
	(0.0031)	(0.0047)	(0.0036)	(0.0144)
Panel B: Dependent variable is very low birth weight (1/0, equal to 1 if birth weight < 1,500 grams)				
Downwind × T	-0.0017	-0.0014	-0.0028**	0.0017
	(0.0010)	(0.0015)	(0.0011)	(0.0133)
Downwind	0.0019*	0.0058***	0.0034***	-0.0007
	(0.0010)	(0.0015)	(0.0012)	(0.0035)
Panel C: Dependent variable is birth weight (measured in grams)				
Downwind × T	26.4039***	28.3969***	30.2023***	-11.2664
	(6.6219)	(9.8644)	(7.6506)	(66.8745)
Downwind	-28.2494***	-35.5726***	-30.8306***	-23.8835
	(6.2918)	(9.0201)	(7.2587)	(28.6701)
Control variables used in Panels A, B and C				
Individual level demographic variables	Yes	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes	Yes
Year-month of conception fixed effects	Yes	Yes	Yes	Yes
Number of observations	150,623	65,732	102,240	48,383

Notes: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are infant being female (1/0), mother’s age, mother’s race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother’s last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Table 4: Comparisons of maternal and newborn's characteristics in the period prior to the shutdown of the power plant

Pre-shutdown period considered in the sample: mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

Dependent variables measured at the zip code-monthly level	Proportion of newborns who are female	Average age of mothers	Proportion of mothers who are white	Proportion of mothers who are black	Proportion of mothers who are hispanic	Proportion of mothers who have completed a four-year college education or higher	Proportion of mothers who are married	Average number of prenatal visits	Proportion of mothers who smoke
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Downwind	-0.0028	0.0172	-0.0013	0.0028	0.0011	-0.0057	-0.0035	-0.0925***	0.0029
	(0.0045)	(0.0548)	(0.0040)	(0.0032)	(0.0035)	(0.0038)	(0.0039)	(0.0280)	(0.0019)
Other control variables									
Zip code fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month of conception fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	5,967	5,967	5,967	5,967	5,967	5,967	5,967	5,967	5,967

Notes: The estimation sample includes live and singleton births and all New Jersey zip codes. Dependent variables are averaged over each pair of a mother's residential zip code and her year and month of conception. Each column (one through nine) uses a zip code-monthly level weighted least squares regression, with the weight being the number of births for each mother's residential zip code-year and month of conception pair. Standard errors (reported in parentheses) are clustered at the zip code level. * p -value < 0.1; ** p -value < 0.05; *** p -value < 0.01.

Table 5: Effects of being downwind of the power plant during pregnancy on low birth weight among full-term births that occurred in 2007, 2008 and 2009

Dependent variable: low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)

Being downwind of the power plant (1/0) = D = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

Year and month of birth = t = 01/2007, …, 12/2007, 01/2008, …, 12/2008, 01/2009, …, 12/2009 (monthly)

New Jersey counties included:	Hunterdon, Morris, Sussex, and Warren				All other counties
	(1)	(2)	(3)	(4)	(5)
D_{t+1} (during the month after birth)			0.00225		
			(0.00244)		
D_{t} (during the month of birth)	-0.00034	-0.00044	-0.00082	-0.00035	-0.00099
	(0.00342)	(0.00343)	(0.00346)	(0.00318)	(0.00100)
D_{t-1} (during the 1st month before birth)	-0.00062	-0.00061	-0.00052	-0.00025	0.00028
	(0.00361)	(0.00367)	(0.00367)	(0.00377)	(0.00093)
D_{t-2} (during the 2nd month before birth)	-0.00259	-0.00218	-0.00205	-0.00208	-0.00093
	(0.00283)	(0.00284)	(0.00285)	(0.00263)	(0.00091)
D_{t-3} (during the 3rd month before birth)	0.00459*	0.00488*	0.00499**	0.00514**	-0.00053
	(0.00252)	(0.00249)	(0.00250)	(0.00250)	(0.00097)
D_{t-4} (during the 4th month before birth)	-0.00358	-0.00391	-0.00391	-0.00381	-0.00014
	(0.00318)	(0.00327)	(0.00327)	(0.00325)	(0.00092)
D_{t-5} (during the 5th month before birth)	0.00154	0.00163	0.00171	0.00182	-0.00017
	(0.00395)	(0.00388)	(0.00390)	(0.00391)	(0.00094)
D_{t-6} (during the 6th month before birth)	-0.00138	-0.00114	-0.00113	-0.00111	0.00025
	(0.00245)	(0.00242)	(0.00243)	(0.00244)	(0.00085)
D_{t-7} (during the 7th month before birth)	0.00081	0.00080	0.00097	0.00116	-0.00011
	(0.00290)	(0.00288)	(0.00292)	(0.00285)	(0.00100)
D_{t-8} (during the 8th month before birth)	0.00380*	0.00369*	0.00407*	0.00337	-0.00023
	(0.00215)	(0.00214)	(0.00212)	(0.00214)	(0.00087)
D_{t-9} (during the 9th month before birth)				0.00234	
				(0.00235)	
D_{t-10} (during the 10th month before birth)				-0.00078	
				(0.00241)	
D_{t-11} (during the 11th month before birth)				0.00101	
				(0.00289)	
D_{t-12} (during the 12th month before birth)				0.00029	
				(0.00257)	
Individual level demographic variables	No	Yes	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes	Yes	Yes
Year-month of birth fixed effects	Yes	Yes	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes	Yes	Yes
Number of observations	21,321	21,321	21,321	21,321	242,319

Notes: The estimation sample includes live and singleton births with full terms (i.e., nine months of pregnancy). Individual level demographic variables controlled for are infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). Weather variables are the nine-month (i.e., full term of pregnancy) averages of the following variables all measured at the zip code-monthly level: 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. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Table 6: Effects of being downwind of the power plant during pregnancy on low birth weight among full-term births that occurred in 2013, 2014 and 2015

Dependent variable: low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)					
Being downwind of the power plant (1/0) = *D* = 1 if -45 degrees < wind vector azimuth averaged over *t* - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.					
Year and month of birth = *t* = 01/2013, …, 12/2013, 01/2014, …, 12/2014, 01/2015, …, 12/2015 (monthly)					
New Jersey counties included:	Hunterdon, Morris, Sussex, and Warren				All other counties
	(1)	(2)	(3)	(4)	(5)
D_{t+1} (during the month after birth)			0.00024		
			(0.00354)		
D_t (during the month of birth)	-0.00429	-0.00429	-0.00423	-0.00492	0.00048
	(0.00326)	(0.00325)	(0.00334)	(0.00334)	(0.00098)
D_{t-1} (during the 1st month before birth)	-0.00280	-0.00293	-0.00293	-0.00193	-0.00092
	(0.00354)	(0.00358)	(0.00357)	(0.00396)	(0.00112)
D_{t-2} (during the 2nd month before birth)	0.00235	0.00240	0.00242	0.00162	-0.00104
	(0.00365)	(0.00361)	(0.00370)	(0.00374)	(0.00106)
D_{t-3} (during the 3rd month before birth)	-0.00432	-0.00462	-0.00462	-0.00539	0.00078
	(0.00312)	(0.00303)	(0.00302)	(0.00346)	(0.00096)
D_{t-4} (during the 4th month before birth)	0.00289	0.00278	0.00278	0.00395	-0.00073
	(0.00275)	(0.00270)	(0.00270)	(0.00276)	(0.00109)
D_{t-5} (during the 5th month before birth)	-0.00108	-0.00127	-0.00133	-0.00023	-0.00084
	(0.00324)	(0.00320)	(0.00342)	(0.00337)	(0.00119)
D_{t-6} (during the 6th month before birth)	0.00596	0.00595	0.00596	0.00556	0.00128
	(0.00400)	(0.00401)	(0.00401)	(0.00396)	(0.00105)
D_{t-7} (during the 7th month before birth)	0.00310	0.00292	0.00297	0.00233	0.00101
	(0.00411)	(0.00413)	(0.00428)	(0.00423)	(0.00126)
D_{t-8} (during the 8th month before birth)	-0.00242	-0.00265	-0.00262	-0.00299	-0.00003
	(0.00381)	(0.00381)	(0.00385)	(0.00384)	(0.00112)
D_{t-9} (during the 9th month before birth)				0.00146	
				(0.00422)	
D_{t-10} (during the 10th month before birth)				-0.00261	
				(0.00339)	
D_{t-11} (during the 11th month before birth)				-0.00353	
				(0.00399)	
D_{t-12} (during the 12th month before birth)				0.00379	
				(0.00343)	
Individual level demographic variables	No	Yes	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes	Yes	Yes
Year-month of birth fixed effects	Yes	Yes	Yes	Yes	Yes
Weather variables	Yes	Yes	Yes	Yes	Yes
Number of observations	17,840	17,840	17,840	17,840	218,497

Notes: The estimation sample includes live and singleton births with full terms (i.e., nine months of pregnancy). Individual level demographic variables controlled for are infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). Weather variables are the nine-month (i.e., full term of pregnancy) averages of the following variables all measured at the zip code-monthly level: 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. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Table 7: Effects of the shutdown of the power plant on other birth outcomes

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015, and T = 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009.

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

	All zip codes of New Jersey	Distance between the power plant and New Jersey zip codes		
		≤ 50 miles	≤ 60 miles	> 60 miles
	(1)	(2)	(3)	(4)
Panel A: Dependent variable is preterm (1/0, equal to 1 if gestational length < 37 weeks)				
Downwind × T	-0.0283***	-0.0325***	-0.0343***	-0.0017
	(0.0047)	(0.0060)	(0.0052)	(0.0333)
Downwind	0.0248***	0.0247***	0.0310***	0.0235
	(0.0042)	(0.0062)	(0.0049)	(0.0157)
Panel B: Dependent variable is gestational length (measured in weeks)				
Downwind × T	0.2225***	0.2248***	0.2698***	0.1215
	(0.0402)	(0.0461)	(0.0398)	(0.3155)
Downwind	-0.3206***	-0.3544***	-0.3550***	-0.4930***
	(0.0353)	(0.0503)	(0.0387)	(0.1543)
Control variables used in Panels A and B				
Individual level demographic variables	Yes	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes	Yes
Year-month of conception fixed effects	Yes	Yes	Yes	Yes
Number of observations	150,623	65,732	102,240	48,383

Notes: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are infant being female (1/0), mother’s age, mother’s race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother’s last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Table 8: Effects of the shutdown of the power plant on birth outcomes by infant sex and by maternal education

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015, and T = 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009.

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

Subpopulation:	Sex of the infant		Whether mother having completed a four-year college education or higher	
Estimation sample including all zip codes of New Jersey	Male (1)	Female (2)	Yes (3)	No (4)
Panel A: Dependent variable is low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)				
Downwind × T	-0.0073*	-0.0105***	-0.0039	-0.0121***
	(0.0041)	(0.0039)	(0.0038)	(0.0045)
Panel B: Dependent variable is very low birth weight (1/0, equal to 1 if birth weight < 1,500 grams)				
Downwind × T	-0.0015	-0.0018	-0.0017	-0.0017
	(0.0013)	(0.0017)	(0.0013)	(0.0015)
Panel C: Dependent variable is birth weight (measured in grams)				
Downwind × T	17.1868*	37.1811***	17.5140*	32.6997***
	(9.2742)	(8.7743)	(9.8869)	(9.2049)
Panel D: Dependent variable is preterm (1/0, equal to 1 if gestational length < 37 weeks)				
Downwind × T	-0.0286***	-0.0286***	-0.0167***	-0.0375***
	(0.0060)	(0.0057)	(0.0049)	(0.0069)
Panel E: Dependent variable is gestational length (measured in weeks)				
Downwind × T	0.2149***	0.2327***	0.1109***	0.3178***
	(0.0486)	(0.0456)	(0.0373)	(0.0572)
Control variables used in Panels A, B, C, D and E				
Individual level demographic variables	Yes	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes	Yes
Year-month of conception fixed effects	Yes	Yes	Yes	Yes
Number of observations	77,194	73,429	61,871	88,752

Notes: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are infant being female (1/0) except columns 1 and 2, mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0) except columns 3 and 4, mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother's last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Appendix Table A1: Effects of the shutdown of the power plant on infant birth outcomes, dropping from the estimation sample zip codes in Warren County of New Jersey that are next to the power plant

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015, and T = 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009.

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

Zip codes dropped from the estimation sample:	Distance between the power plant and New Jersey zip codes	
07823, 07832, 07833 and 08865	≤ 50 miles	≤ 60 miles
	(1)	(2)
Panel A: Dependent variable is low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)		
Downwind × T	-0.0131***	-0.0129***
	(0.0043)	(0.0036)
Downwind	0.0145***	0.0118***
	(0.0047)	(0.0036)
Panel B: Dependent variable is very low birth weight (1/0, equal to 1 if birth weight < 1,500 grams)		
Downwind × T	-0.0015	-0.0029**
	(0.0015)	(0.0011)
Downwind	0.0059***	0.0034***
	(0.0015)	(0.0012)
Panel C: Dependent variable is birth weight (measured in grams)		
Downwind × T	29.1972***	30.7391***
	(9.8949)	(7.6651)
Downwind	-36.4828***	-31.4027***
	(9.0356)	(7.2642)
Control variables used in Panels A, B and C		
Individual level demographic variables	Yes	Yes
Zip code fixed effects	Yes	Yes
Year-month of conception fixed effects	Yes	Yes
Number of observations	65,437	101,945

Notes: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother's last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Appendix Table A2: Effects of the shutdown of the power plant on infant birth outcomes, with an alternative definition of the zero value of the dummy variable "conceived after the power plant's shutdown (1/0)"

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015; and T = 0 if (a) the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009, (b) the mother's LMP date ≥ June 1, 2007 and birth date ≤ December 31, 2008, or (c) the mother's LMP date ≥ June 1, 2006 and birth date ≤ December 31, 2007.

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

	All zip codes of New Jersey	Distance between the power plant and New Jersey zip codes	
		≤ 50 miles	≤ 60 miles
	(1)	(2)	(3)
Panel A: Dependent variable is low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)			
Downwind × T	-0.0081***	-0.0108***	-0.0122***
	(0.0025)	(0.0034)	(0.0028)
Downwind	0.0056***	0.0104***	0.0101***
	(0.0017)	(0.0025)	(0.0019)
Panel B: Dependent variable is very low birth weight (1/0, equal to 1 if birth weight < 1,500 grams)			
Downwind × T	-0.0013	-0.0011	-0.0026**
	(0.0009)	(0.0013)	(0.0010)
Downwind	0.0014**	0.0041***	0.0026***
	(0.0006)	(0.0008)	(0.0007)
Panel C: Dependent variable is birth weight (measured in grams)			
Downwind × T	20.2268***	18.5567**	24.6797***
	(5.8011)	(8.3114)	(6.3057)
Downwind	-19.8926***	-30.1500***	-25.2981***
	(3.7517)	(4.9940)	(4.3090)
Control variables used in Panels A, B and C			
Individual level demographic variables	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes
Year-month of conception fixed effects	Yes	Yes	Yes
Number of observations	316,339	140,029	215,367

Notes: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother's last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Appendix Table A3: Effects of the shutdown of the power plant on low birth weight, with an alternative definition of the dummy variable "downwind (1/0)"

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015, and T = 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009.

Downwind (1/0) = D = 1 for these four New Jersey counties—Hunterdon, Morris, Sussex, and Warren, and D = 0 for all other counties of New Jersey.

Dependent variable: low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)

	(1)	(2)	(3)	(4)
Panel A: All zip codes of New Jersey included in the estimation sample				
D × T	-0.0085*	-0.0084*	-0.0087*	-0.0088*
	(0.0049)	(0.0048)	(0.0049)	(0.0047)
Number of observations	150,623	150,623	150,623	150,623
Panel B: All zip codes of New Jersey except four (07823, 07832, 07833 and 08865) that are next to the power plant				
D × T	-0.0095*	-0.0093*	-0.0097*	-0.0098**
	(0.0049)	(0.0048)	(0.0050)	(0.0048)
Number of observations	150,328	150,328	150,328	150,328
Control variables used in Panels A and B				
Individual level demographic variables	No	No	Yes	Yes
Zip code fixed effects	No	Yes	Yes	Yes
Year-month of conception fixed effects	No	Yes	No	Yes

Notes: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother's last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * *p* -value < 0.1; ** *p* -value < 0.05; *** *p* -value < 0.01.

Appendix Table A4: Effects of the shutdown of the power plant on infant birth outcomes, zip code-monthly level analysis

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015, and T = 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009.

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where *t* denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over *t* - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

	All zip codes of New Jersey	Distance between the power plant and New Jersey zip codes ≤ 50 miles	≤ 60 miles
	(1)	(2)	(3)
Panel A: Dependent variable is zip code-monthly proportion of low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)			
Downwind × T	-0.0047	-0.0072*	-0.0069**
	(0.0031)	(0.0042)	(0.0035)
Downwind	-0.0042	-0.0002	-0.0016
	(0.0030)	(0.0043)	(0.0034)
Panel B: Dependent variable is zip code-monthly level proportion of very low birth weight (1/0, equal to 1 if birth weight < 1,500 grams)			
Downwind × T	-0.0017	-0.0007	-0.0024*
	(0.0012)	(0.0017)	(0.0013)
Downwind	-0.0003	0.0024	0.0006
	(0.0010)	(0.0015)	(0.0011)
Panel C: Dependent variable is zip code-monthly level average birth weight (measured in grams)			
Downwind × T	19.1730***	18.4367*	17.5349**
	(6.4587)	(9.5829)	(7.1988)
Downwind	-1.1529	-3.0908	0.3896
	(6.4073)	(8.5666)	(6.9992)
Control variables used in Panels A, B and C			
Individual level demographic variables averaged at the zip code-monthly level	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes
Year-month of conception fixed effects	Yes	Yes	Yes
Number of observations	26,343	11,608	17,344

Notes: The estimation sample includes live and singleton births. Dependent variables and individual level demographic variables are averaged over each pair of a mother's residential zip code and her year and month of childbirth. Individual level demographic variables averaged at the zip code-monthly level include infant being female (1/0), mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0), mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). Each regression is weighted by the number of births for each mother's residential zip code-year and month of birth pair. The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother's last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * *p* -value < 0.1; ** *p* -value < 0.05; *** *p* -value < 0.01.

Appendix Table A5: Effects of the shutdown of the power plant on birth outcomes by infant sex and by maternal education, estimation sample including New Jersey zip codes that are within 60 miles of the power plant

Conceived after the power plant's shutdown (1/0) = T = 1 if the mother's LMP date ≥ June 1, 2014 and birth date ≤ December 31, 2015, and T = 0 if the mother's LMP date ≥ June 1, 2008 and birth date ≤ December 31, 2009.

Downwind (1/0) varies monthly and also by zip code. It is equal to 1 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is ≥ 0.5 and equal to 0 if the average of D_t, D_{t-1}, …, D_{t-11} (i.e., over a 12-month period) is < 0.5, where t denotes the year and month of a birth, and D_t = 1 if -45 degrees < wind vector azimuth averaged over t - New Jersey zip code azimuth relative to the power plant < 45 degrees, and 0 otherwise.

Subpopulation:	Sex of the infant		Whether mother having completed a four-year college education or higher	
Estimation sample including New Jersey zip codes that are within 60 miles of the power plant	Male (1)	Female (2)	Yes (3)	No (4)
Panel A: Dependent variable is low birth weight (1/0, equal to 1 if birth weight < 2,500 grams)				
Downwind × T	-0.0110**	-0.0146***	-0.0059	-0.0178***
	(0.0050)	(0.0045)	(0.0042)	(0.0053)
Panel B: Dependent variable is very low birth weight (1/0, equal to 1 if birth weight < 1,500 grams)				
Downwind × T	-0.0025	-0.0033*	-0.0023	-0.0033**
	(0.0015)	(0.0018)	(0.0015)	(0.0016)
Panel C: Dependent variable is birth weight (measured in grams)				
Downwind × T	20.6457*	42.1520***	16.2000	43.2980***
	(11.1773)	(9.6242)	(10.8507)	(10.3244)
Panel D: Dependent variable is preterm (1/0, equal to 1 if gestational length < 37 weeks)				
Downwind × T	-0.0334***	-0.0357***	-0.0189***	-0.0473***
	(0.0066)	(0.0067)	(0.0057)	(0.0078)
Panel E: Dependent variable is gestational length (measured in weeks)				
Downwind × T	0.2545***	0.2880***	0.0950**	0.4217***
	(0.0524)	(0.0468)	(0.0416)	(0.0565)
Control variables used in Panels A, B, C, D and E				
Individual level demographic variables	Yes	Yes	Yes	Yes
Zip code fixed effects	Yes	Yes	Yes	Yes
Year-month of conception fixed effects	Yes	Yes	Yes	Yes
Number of observations	52,390	49,850	45,661	56,579

Notes: The estimation sample includes live and singleton births. Individual level demographic variables controlled for are infant being female (1/0) except columns 1 and 2, mother's age, mother's race and ethnicity (1/0 dummy variables for White, Black, and Hispanic), mother having completed a four-year college education or higher (1/0) except columns 3 and 4, mother being married (1/0), the number of prenatal visits, and maternal smoking (1/0). The year-month of conception fixed effects are applied to each year-month of conception that is determined by the mother's last menstrual period (LMP) date. Standard errors (reported in parentheses) are clustered at the zip code level. * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.