Air Pollution, Power Grid, and Infant Health: Evidence from the Shutdown of TVA Nuclear Power Plants in the 1980s*

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Abstract

When environmental regulations focus on a subset of power plants, the ultimate goal of human health protection may not be reached. Because power plants are interconnected through the electrical grid, excessive scrutiny of a group of facilities may generate more pollution out of another group, with potential deleterious effects to public health. I study the impact of the shutdown of nuclear power plants in the Tennessee Valley Authority (TVA) in the 1980s, on health outcomes at birth. After the Three Mile Island accident in 1979, the Nuclear Regulatory Commission (NRC) intensifies inspections in nuclear facilities leading to the shutdown of many of them, including Browns Ferry and Sequoyah in the TVA area. I first show that, in response to the shutdown, electricity generation shifts one-to-one to coal-fired power plants within TVA, increasing air pollution in counties where they are located. Second, I find that babies born after the shutdown have both lower birth weight and lower gestational age in the counties most affected by the shutdown. Third, I highlight the presence of substantial heterogeneity in those effects depending on how much more electricity those coal-powered facilities are generating in response to the shutdown. Lastly, I use the heterogeneity in response to

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the shutdown to provide suggestive evidence on the "safe" threshold of exposure to total suspended particles (TSP), which may help the Environmental Protection Agency (EPA) to set the National Ambient Air Quality Standards (NAAQS) for particulate matters (PM). It may also help regulators to incentivize power companies to respond optimally to unexpected energy shortages.

Keywords: Nuclear Shutdown, Power Grid, Coal Power, Air Pollution, Birth Weight, Gestational Age

1 Introduction

Nuclear accidents usually generate a tremendous drop in support for nuclear energy. The Fukushima nuclear disaster in March 2011, for example, gave rise to a public backlash against the nuclear power industry around the world. As a result of such a pressure, some countries/states reacted promptly by enacting new regulations or by shutting down nuclear facilities. Germany, for instance, started a nuclear phase-out right away, permanently shutting down eight of its seventeen reactors by August 2011, and pledging to close the rest by the end of 2022. California followed suit by retiring the San Onofre Nuclear Generating Station (SONGS) in June 2013. Although media outlets focus attention on damages to public health potentially caused by exposure to high levels of radioactivity, the news coverage misses important aspects of the debate. Exceptionally, a recent New York Times editorial clearly points out some of those missing elements: *"Only Germany succumbed to panic after the Fukushima disaster and began to phase out all nuclear power in favor of huge investments in renewable sources like wind and sun. One consequence has been at least a temporary increase in greenhouse emissions as Germany has been forced to fire up old coal- and gas-powered plants. The dangers of nuclear power are real, but the accidents that have occurred, even Chernobyl, do not compare to the damage to the earth being inflicted by the burning of fossil fuels - coal, gas and oil."* (May 1, 2014).

In this paper, I document the shift in electricity generation from nuclear to coal-fired power plants after the shutdown of the nuclear facilities of the Tennessee Valley Authority

(TVA) in the 1980s, following the Three Mile Island accident in 1979, and provide evidence of the resulting increase in air pollution and reduction in birth weight and gestational age in the most affected counties. I show that these empirical findings are consistent with a simple general equilibrium model where consumers value electricity, air quality and health, but power generation damages air quality and health through emissions of pollutants and radioactivity. Also, I use the heterogeneity in response to the nuclear shutdown by coal-powered plants within the TVA power grid to shed light on the "safe" threshold of exposure to total suspended particles (TSP), which may help the Environmental Protection Agency (EPA) to set the National Ambient Air Quality Standards (NAAQS) for particulate matters (PM). It may also help regulators to incentivize power companies to respond optimally to unexpected energy shortages.

The Three Mile Island accident was a partial nuclear meltdown that occurred on March 28, 1979, in one of the two Three Mile Island nuclear reactors in Pennsylvania. Being the worst accident in U.S. commercial nuclear power plant history, the accident crystallized anti-nuclear safety concerns among activists and the general public. Following the public backlash, the Nuclear Regulatory Comission (NRC) started cracking down on nuclear facilities, leading to new regulations and the shutdown of several nuclear plants around the nation in the 1980s, including Browns Ferry and Sequoyah in the TVA area in 1985. I exploit this setting to study the substitution among energy sources in electricity generation, and potential consequences of the use of non-renewable sources in air quality and public health. I focus on the TVA because it has a diverse portfolio of power sources which are connected through the electrical grid - hydroelectric dams, coal- and gas-fired plants, and nuclear facilities -, and is self-sufficient in power generation. Hence, when an energy source faces a temporary shock, responses are likely to occur within the area.

I first investigate whether environmental regulations targeted at a subset of power plants in a network of energy production are effective at protecting public health. Chain reactions within the power grid may completely offset the perceived health benefits of the nuclear shutdown when the response is an increase in electricity generation through the burning of fossil fuels. By plotting monthly electricity generation data at the plant-fuel level from the Historic EIA-906 Form in figure 1, we can see that the such pattern indeed emerges after the shutdown of the TVA nuclear plants. By employing an empirical strategy similar to the dynamic reduced-form approach advanced by Cullen (2013), I estimate those responses and find out that the substitution between nuclear and coal seems to be one-to-one. That is, each megawatt-hour not produced by nuclear power plants due to the shutdown appears to be generated by coal-powered plants. Furthermore, summary statistics presented in the last row of table 1 show that the nuclear shutdown leads not only to a shift in power generation to coal-fired plants, but also an increase in TSP concentration, and a decrease in birth weight. Monthly measures of TSP concentration were constructed by aggregating daily readings from the network of monitoring stations provided by EPA. Natality data come from the National Vital Statistics System of the National Center for Health Statistics (NCHS's). Estimates from the econometric analysis corroborate the broad picture just described, and I conclude that targeted environmental regulations in network do not seem to protect public health.

Although the general results arising from the nuclear shutdown are already illuminating, a more detailed analysis reveals a rich pattern of heterogeneity in the responses of interest. By splitting the power generation response of coal-fired power plants into four groups - high, medium, small, and negligible -, the right-hand side of table 1 indicates that TSP and birth weight responses also differ across groups. To the best of my knowledge, this heterogeneity driven by responses within the power grid, which from now on will be referred to as *network heterogeneity*, has not been exploited in studies of air pollution, but has the potential to enrich the analysis. In fact, a single shock can generate multiple sources of variation in terms of pollution intensity and geographic areas. I take advantage of such heterogeneity by employing a difference-in-differences approach to estimate the impact of air pollution on birth weight and gestational age. I define the control group as the set of counties whose coal-fired power plants were not affected by the nuclear shutdown - the ones with negligible variation, and three treatment groups according to their pollution intensity.

The difference-in-differences approach exploiting the network heterogeneity allows me to address my second research question: are there levels of TSP concentration that are "safe" to infants? In a recent review of the literature on the impact of pollution on health outcomes, Currie et al. (2013) point out the preponderance of evidence of harmful effects of high levels of pollution, but emphasize the need to identify "safe" thresholds. This is a particularly important question for policy because it could guide EPA in the process of setting the NAAQS, for instance. It may also give regulators tools to incentivize power companies to respond optimally to unexpected energy shortages.

In this attempt to recover a curve of pollution effects as a function of pollution exposure motivated by Currie et al. (2013), notice that TSP concentrations displayed in the right-hand side of table 1 do not appear to respond proportionally to power generation. Although the high group generates 50 percent more electricity than the medium group on average, TSP responses seem to be very similar. In fact, the patterns depicted in figure 2 look a lot alike, with the only difference being the level of pollution that they begin with. The medium group starts in the 30s and jumps to the 40s $\mu g/m^3$, while the high group moves from the 40s to the 50s $\mu g/m^3$. Just for reference, the EPA annual standard for TSP is 75 $\mu g/m^3$ from 1971 to 1987. Difference-in-differences estimates reveal that even though TSP concentrations are below EPA standards in 1985, they are not at "safe" levels. Air pollution seems to decrease birth weight by roughly 3.7 percent, and gestational age by 0.67 weeks, when TSP concentration is above 50 $\mu g/m^3$. No statistically significant effects are found for TSP levels below 50 $\mu g/m^3$. Therefore, 50 $\mu g/m^3$ appears to be a "safe" threshold. When translating these TSP concentrations into particulate matter (PM) concentrations[1], my findings suggest that the EPA may have set the TSP and TSP-equivalent standards right only from 1997 onwards, as shown in table 2.

In summary, this study makes four contributions to the literature. First, it points out that

[1]In 1987, EPA stops setting TSP standards, and starts focusing on PM_{10} and $PM_{2.5}$. They provide correspondences between measures of those three elements.

environmental regulations focused on one node of an extensive network of energy production may trigger unanticipated chain reactions that go against the ultimate goal of protecting public health. Networks should be taken into account in the design of those regulations. Second, it shows that a curve relating effects of pollution on health and intensity of pollution exposure may be estimable through the use of networks. When shocks in one node produce different responses over other nodes, quasi-experimental variation in pollution exposure may arise. Third, it provides evidence that suspending nuclear energy production might not generate as many benefits as the public perceives. Lastly, it corroborates recent findings by Lavaine and Neidell (2013) that pollution externalities from energy production are also prominent, and should be seriously considered in the design of environmental policies.

The remainder of this paper is organized as follows. Section 2 provides a simple theoretical framework that guides the empirical analysis. Section 3 presents a brief historical background of the nuclear shutdown in the TVA area in the 1980s, and introduces the research design. Section 4 describes the data used in this study, and presents some descriptive statistics. Section 5 outlines the methodology for the empirical analysis. Section 6 reports and discusses results regarding the impact of the shutdown on coal-burning generation, air pollution, and health outcomes at birth. Finally, Section 7 provides some concluding remarks.

2 Theoretical Framework

To examine the trade-off between nuclear and coal power, and motivate the empirical analysis, I work with a simple general equilibrium model for electricity generation. I assume that consumers value electricity, air quality, and health, but that electricity generation damages air quality and health through emissions of pollutants and radioactivity.

2.1 Set-up

In the simplest-possible setting, suppose that there are two price-taking economic agents, a single consumer and a single firm, and three goods, clean air, health, and electricity produced by the firm.

The consumer has a Cobb-Douglas utility function $U(E, A, H) = E^{\alpha} A^{\beta} H^{\gamma}$, defined over his consumption of electricity E, clean air A, and health H. He has an endowment of $\overline{R}$ units of uranium and $\overline{M}$ units of coal, but no endowment of electricity. I assume that air quality responds negatively to the burning of coal in power generation, $A = \overline{M} - M$, and health is negatively related to both radioactivity released from nuclear reactors, and emissions from coal-powered plants, $H = (\overline{R} - R)(\overline{M} - M)$. As we can see, I assume a multiplicative function for health. This means that the deleterious effects on the consumer's health are intensified when he is exposed to both radioactive substances and other pollutants.

The firm uses inputs uranium R and coal M to produce electricity according to a perfect substitutes production function $F(R, M) = rR + mM$. Indeed, one kilogram of uranium generates as much electricity as 1,500 tonnes of coal, approximately. Thus, to produce the output, the firm must buy uranium and coal from the consumer. Assume that the firm seeks to maximize its profits, taking market prices as given. Letting p_E be the price of its electricity output, p_R be the price of uranium, and p_M the price of coal, the firm solves

$$\text{Max}_{R,M \in \mathbb{R}^2_+} p_E F(R, M) - p_R R - p_M M. \tag{1}$$

Given prices (p_E, p_R, p_M), the firm's optimal demands are $R(p_E, p_R, p_M)$ and $M(p_E, p_R, p_M)$, its output is $Q(p_E, p_R, p_M)$, and its profits are $\pi(p_E, p_R, p_M)$.

Firms are owned by consumers. Thus, assume that the consumer is the sole owner of the firm and receives the profits earned by the firm $\pi(p_E, p_R, p_M)$. Therefore, the consumer's problem, given prices (p_E, p_R, p_M), is

$$\text{Max}_{E,A,H\in\mathbb{R}^3_+} U(E,A,H) \tag{2}$$
$$\text{s.t. } p_E E \leq p_R R + p_M M + \pi(p_E, p_R, p_M)$$

The budget constraint in (2) reflects the three sources of the consumer's purchasing power. If the consumer supplies $\left(\overline{R} - \left(\frac{H}{A}\right)\right)$ units of uranium to produce nuclear power, and $(\overline{M} - A)$ units of coal to produce thermal power, when prices are (p_E, p_R, p_M), then the total amount he can spend on electricity is $p_R\left(\overline{R} - \left(\frac{H}{A}\right)\right) + p_M(\overline{M} - A)$ plus the profit distribution from the firm $\pi(p_E, p_R, p_M)$. The consumer's optimal levels of demand in problem (2) for prices (p_E, p_R, p_M) are denoted by $(E(p_E, p_R, p_M),\ A(p_E, p_R, p_M),\ H(p_E, p_R, p_M))$.

2.2 Equilibrium

A Walrasian equilibrium in this economy involves a price vector (p^*_E, p^*_R, p^*_M) at which electricity, uranium and coal markets clear; that is, at which

$$\begin{aligned} Q(p^*_E, p^*_R, p^*_M) &= E(p^*_E, p^*_R, p^*_M), \\ R(p^*_E, p^*_R, p^*_M) &= \overline{R} - \frac{H(p^*_E, p^*_R, p^*_M)}{A(p^*_E, p^*_R, p^*_M)}, \\ M(p^*_E, p^*_R, p^*_M) &= \overline{M} - A(p^*_E, p^*_R, p^*_M). \end{aligned}$$

As is well-known[2], *a particular electricity-land-permit combination can arise in a competitive equilibrium if and only if it maximizes the consumer's utility subject to the economy's technological and endowment constraints*. Indeed, the Walrasian equilibrium allocation is the same allocation that would be obtained if a planner ran the economy in a manner that maximized the consumer's well-being. Therefore, the competitive equilibrium is also Pareto

[2] See, for example, Mas-Collel, Whinston and Green (1995), chapter 15.

optimal. The equilibrium problem is

$$\begin{aligned} &\text{Max}_{R,M\in\mathbb{R}^2_+} U(E,A,H) \\ \text{s.t. } E &= F(R,M), \\ A &= \overline{M}-M, \\ H &= (\overline{R}-R)(\overline{M}-M), \end{aligned}$$

which is equivalent to

$$\text{Max}_{R,M\in\mathbb{R}^2_+} U(F(R,M),(\overline{R}-M),(\overline{M}-M)).$$

Replacing the utility and production functions with their assumed functional forms, the competitive equilibrium problem becomes

$$\begin{aligned} &\text{Max}_{R,M\in\mathbb{R}^2_+} E^{\alpha}A^{\beta}H^{\gamma}, \qquad \{\alpha,\beta,\gamma\}\in(0,1) \\ \text{s.t. } E &= rR+mM, \quad \{r,m\}\in\mathbb{R}_+ \\ A &= \overline{M}-M, \\ H &= (\overline{R}-R)(\overline{M}-M), \end{aligned}$$

which is equivalent to

$$\text{Max}_{R,M\in\mathbb{R}^2_+}(rR+mM)^{\alpha}(\overline{R}-R)^{\gamma}(\overline{M}-M)^{\beta+\gamma}. \tag{3}$$

Solving problem (3) yields optimal allocations

$$\begin{aligned}
R^* &= \frac{(\alpha+\beta+\gamma)}{(\alpha+\beta+2\gamma)}\overline{R} - \frac{\gamma m}{(\alpha+\beta+2\gamma)r}\overline{M} \in (0,\overline{R}), && (4)\\
M^* &= -\frac{(\beta+\gamma)r}{(\alpha+\beta+2\gamma)m}\overline{R} + \frac{(\alpha+\gamma)}{(\alpha+\beta+2\gamma)}\overline{M} \in (0,\overline{M}), && (5)\\
E^* &= rR^* + mM^*. && (6)
\end{aligned}$$

Now, let (p_T^*, p_L^*, p_E^*) be a supporting price vector of the Pareto optimal allocations just identified. As a normalization, put $p_E^* = 1$. The zero-profit condition and the cost minimization condition of the electricity production imply that

$$p_R^* = p_M^* = \frac{rR^* + mM^*}{R^* + M^*}.$$

2.3 Model predictions

Notice that the trade-off between nuclear and coal power is evident in equations (4) and (5). Therefore, if environmental regulations are targeted at nuclear power plants, we should expect a shift in electricity generation to coal-powered plants. To see this, think of those regulations as a confiscation of part of the uranium endowment, that is, a reduction in $\overline{R}$. Such reduction implies a decrease in R^* by equation (4), an increase in M^* by equation (5), and a consequent reduction in air quality ($A^* = \overline{M} - M^*$) and health outcomes ($H^* = (\overline{R} - R^*)(\overline{M} - M^*)$). These model predictions will guide my empirical strategy in the next sections.

3 Historical Background and Research Design

To test the predictions of the model just discussed, it would be desirable to find exogenous variation in electricity generation by nuclear plants within a power grid with a diverse portfolio of power plants. As will be described in the data section, the TVA has a variety of large power plants, mainly hydroelectric dams, coal-powered plants, and nuclear facilities. Thus, in the empirical analysis, I exploit the shutdown of nuclear power plants in the TVA area in the 1980s as such an exogenous source of variation to identify substitution between energy sources and its consequences to air pollution and health outcomes. I now discuss some background information on such a nuclear shutdown in 1985. Figure 3 depicts a timeline with important events.

As mentioned before, the Three Mile Island Unit 2 reactor partially melted down on March 28, 1979, near Middletown, Pennsylvania. This was the most serious accident in U.S. commercial nuclear power plant operating history. It triggered the NRC to tighten and heighten its regulatory oversight, bringing about sweeping changes in many areas of nuclear power plant operations.

Two months before the 1979 Three Mile Island nuclear accident, the Union of Concerned Scientists (UCS) called upon the government to shut down the facility and 15 other nuclear reactors, based on analysis showing that the NRC had dramatically understated the probability of an accident[3]. The public backlash that followed the accident forced the NRC to crack down on nuclear facilities, leading to the shutdown of several nuclear reactors in the 1985 to 1990 time frame. The TVA Browns Ferry Units 1, 2 and 3, and Sequoyah Units 1 and 2, as well as Davis-Besse, Fort St. Vrain, Nine Mile Point Unit 1, Peach Bottom Units 2 and 3, Pilgrim, Rancho Seco, and Surry Unit 2, all had year-plus outages in this period (UCS, n.d.).

At Browns Ferry, NRC inspectors identified 652 violations between 1981 and 1984, and the agency imposed $413,000 in fines (USC, n.d.). In July 1984, the NRC issued an order requiring TVA to implement its Regulatory Performance Improvement Program (RPIP) and provide periodic status reports. In February 1985, reactor vessel water level instrumentation problems happened in Unit 3, leading TVA to cease operations in March 19 at all three Browns Ferry units to focus on programmatic improvements. By September 1985, NRC

[3]Ever since the Three Mile Island accident, federal, state, and local officials have looked to UCS for unbiased information about the safety of nuclear power plants.

stated that the RPIP had been ineffective and required TVA to try again with another plan. The shutdown of Browns Ferry would last for approximately five years.

Regarding Sequoyah, the NRC induced its outage based on new regulations taking effect in March 1985. After the agency informed TVA that Sequoyah would be one of the first plants to be audited according to the new requirements, the company brought in a contractor to pre-audit the facility. That independent review indicated that reactors could not be safely shut down in the event of an accident. Hence, TVA voluntarily ceased operations at both reactors in August 22, 1985, before the NRC's inspectors got a chance to do so (USC, n.d.). That shutdown would last until November 1988.

The UCS clearly states that "[t]hese back-to-back outages reflect a regulatory bias first identified by the various inquiries into the Three Mile Island Unit 2 accident and still not exorcised." (UCS, n.d., Report on Browns Ferry Unit 3 - p.2). Therefore, the Three Mile Island accident appears to have induced targeted environmental regulations. The nuclear facilities were under much more scrutiny than the coal- and gas-powered plants in those years. Furthermore, TVA annual reports indicate that the shutdown was unexpected. According to the reports, TVA had an extraordinary perfomance in 1985 due to "*unplanned reductions in nuclear (...) generation*" (TVA, 1985, p.26). This seems to be a desirable setting to test the predictions of the model discussed in the previous section.

4 Data

The data I use in this study come from three sources. To investigate the response of TVA hydro and coal-fired power plants to the shutdown of Browns Ferry and Sequoyah nuclear facilities in 1985, I utilize monthly electricity generation data at the plant-fuel level from the Historic EIA-906 Form. To obtain the impact of the nuclear shutdown on air pollution, I construct monthly measures of TSP at the county level. Daily TSP readings from the network of monitoring stations in the TVA area were provided by EPA under a Freedom of

Information Act (FOIA) request. To aggregate these daily readings into monthly measures, I employ the same procedure used by EPA to produce its annual summaries. To estimate the effect of the pollution arising from coal-fired power plants in response to the nuclear shutdown on birthweight, I use natality data from the National Vital Statistics System of the National Center for Health Statistics (NCHS's). The NCHS's birth data provide rich demographic and health information of infants and their mothers. I focus my analysis in the period 1983-1987, which covers eighteen months before and after the shutdown. Eighteen months just represent two pregnancy cycles, which is a natural time frame when undertaking the birth weight analysis.

The TVA was operating the nation's largest electric power system, and had a pretty diverse portfolio of power generation in 1985, the year of the nuclear shutdown. Focusing on large plants - 100 megawatts of capacity or more -, the TVA had 15 hydroelectric dams, 11 coal-fired plants, and two nuclear facilities, as you can see in figure (4). The blue squares represent hydro, the red circles coal, and the yellow triangles nuclear plants. Since hydro dams do not seem to respond to the nuclear shutdown, I focus my analysis on coal-powered plants. Figure (5) plots only those plants together with the nuclear generating stations. The different symbols represent the heterogeneity in power generation responses to the nuclear shutdown, as pointed out previously based on the summary statistics of table (1). The red diamond represents the Paradise coal-fired plant, with the highest variation in power generation due to the shutdown ($H - \triangle PG$), the red square represents Cumberland, with a medium response ($M - \triangle PG$), the red circles represent coal-powered plants with low responses ($L - \triangle PG$), and the red hollow circles represents facilities with negligible responses ($N - \triangle PG$).

With the exception of Allen Fossil Plant in the Memphis metropolitan area, all coal-fired plants are located in counties with low population density, as you can notice from the relatively small number of births in table (3). Observe that the high and medium groups are made of only one power plant each, so in my main analysis I compare these two distinctive counties with the group of counties with low responses, and with the control group. Recall that the control group is defined as the group of counties whose responses of their coal-powered plants to the nuclear shutdown are economically and statistically insignificant.

The sample for my birth weight analysis has almost 56,000 observations, as shown in table (3). The middle panel in the table contains the information of plants used in my analysis. I exclude Kingston and Bull Run coal-fired plants because they are located in neighboring counties, and I have not found reliable information on wind patterns for that area in that period of time, so I cannot control precisely for upwind pollution. The right-hand side panel of that table includes those two plants. Later on, I show that my results are not sensitive to the inclusion of those plants.

It is important to point out the difference in sample sizes for the counties hosting Paradise and Cumberland. Because the number of births around Cumberland is much smaller than around Paradise, one should expect less precision for estimates associated with the medium response group. A reweighting strategy based on number of births is used to check whether the results are robust to such heterogeneity.

5 Empirical Strategy

In this section, I present the methodology to provide empirical evidence on the consequences of the shutdown of the TVA nuclear facilities in the 1980s. Motivated by the predictions of the model discussed in section (2), I address three main topics: (i) how power generation changes after the shutdown both in hydro and coal-fired plants, (ii) how air pollution, measured as TSP concentration, respond to the shutdown because of additional emissions by coal-powered plants, and (iii) how birthweight is affected in counties where both power generation and air pollution increase after the shutdown. Throghout my analysis

5.1 Response of Power Generation

In order to estimate the response of coal and hydro power generation to the nuclear shutdown, I build on the approach advanced by Cullen (2013). Basically, I estimate the following equations for each power source - coal versus hydro:

$$PGen_{cm} = \beta_0 + \beta_{1c} DNucShut_m + Z_{cm}\delta + \gamma_c + \lambda_m + \theta_y + \varepsilon_{cm}, \tag{7}$$

$$\text{or } PGen_{cm} = \beta_0 + \beta_{1c} PGenNuc_m + \beta_{2c} PGenNuc_{m-1} + Z_{cm}\delta + \gamma_c + \lambda_m + \theta_y + \varepsilon_{cm}, \tag{8}$$

where c stands for county, m for month, and y for calendar year. $PGen$ represents power generation measured in megawatt-hours, $PGenNuc$ is power generated by nuclear plants, $DNucShut$ represents a dummy variable that takes value one from the shutdown onwards, and Z is a set control variables such as temperature and precipitation.

Notice that this approach accounts for dynamics in the production process. As discussed in Cullen (2011), the operating decision of a coal-powered plant is inherently dynamic due to costs associated with startup, shut down, and ramping up and down production. Therefore, in the estimation one must include not only contemporaneous covariates, but also elements of the information set which the electric utility - TVA, in this case - considers when adjusting its optimal production. At the end of the day, the estimating equation recovers the reduced-form optimal policy function coming from the dynamic programming problem of each generator, taking into account firm's expectations. For the sake of completeness, lagged variables are also included in Z. In fact, Z contains a quadratic function of contemporaneous and lagged precipitation and temperature.

The time frame of my analysis is eighteen months before and after the shutdown. It is equivalent to two full-term pregnancies, and is less than the typical two years to construct a coal-fired power plant. Because eighteen months are not enough for electric utilities to adjust production by increasing capacity, the responses captured in β_{1c}'s are in the intensive margin. In this sense, the nuclear shutdown represents an exogenous source of variation in power generation, since it can be seen as a shock to the other power plants.

Finally, I estimate equations (7) and (8) separately for counties with coal versus hydro power plants. My underlying assumption is that TVA's decision making may be different for coal and hydro generation. In any case, the variables of interest are interacted with counties so that responses can be obtained for each and every power plant.

5.2 Response of Air Pollution

Regarding the estimation of air pollution responses, I follow the approach developed for responses of power generation. I just substitute TSP concentration for power generation as the dependent variable in the estimating equations. That is,

$$TSP_{cm} = \beta_0 + \beta_{1c} DNucShut_m + Z_{cm}\delta + \gamma_c + \lambda_m + \theta_y + \varepsilon_m, \quad (9)$$

$$\text{or } TSP_{cm} = \beta_0 + \beta_{1c} PGenNuc_m + \beta_{2c} PGenNuc_{m-1} + Z_{cm}\delta + \gamma_c + \lambda_m + \theta_y + \varepsilon_m. \quad (10)$$

On the one hand, coal-burning power plants are important sources of particle pollution - the tiny particles of fly ash and dust that are expelled from the combustion of coal. On the other hand, coal power generation involves essentially dynamic decisions. As explained before, it is costly to fire up coal-fired boilers, so electric utilities do so only when they expect to generate large amounts of electricity. Therefore, power generation and particle pollution are both dynamic processes. In fact, pollution data exhibit great temporal dependence. Hence, it is natural to employ a similar estimation strategy for both cases.

Again, the estimation is carried out separately for counties with coal plants and counties with hydro dams. Geographic conditions determining the installation of coal-powered plants and hydroelectric dams probably differ. Those same features may also affect TSP concentration in distinctive ways.

5.3 Response of Birth Weight (and Weeks of Gestation)

Lastly, I assess the impact of the nuclear shutdown on health outcomes at birth, proxied by birth weight. As well-known, low birth weight infants experience severe health and developmental difficulties that can impose large costs on society (Almond, Chay, and Lee, 2005). I estimate difference-in-differences models to exploit the heterogeneity in responses of power generation and TSP concentration. My treatment group consists of babies born in counties with coal-fired power plants affected by the shutdown, and my control group contains infants born in counties whose coal plants did not respond statistically or economically to the shutdown.

As with any difference-in-differences design, the key underlying assumption for identification is that the control group serves as a valid counterfactual for the treatment group with parallel trends. In my setting, this seems like a reasonable assumption because all women having babies in my sample are living near coal-powered plants. Thus, they might have similar preferences for pollution. In fact, all of them are being exposed to air pollution, with the only difference being in intensity, which is affected by the response of coal plants to the nuclear shutdown. Furthermore, I am focusing my analysis on a short period of time - eighteen months -, which limits migration in response to additional TSP concentration.

I implement this approach by estimating the following equation:

$$\begin{aligned} BWeight_{icm} = \beta_0 &+ \beta_1 (DNucShut \times H\Delta PG)_{cm} \\ &+ \beta_2 (DNucShut \times M\Delta PG)_{cm} \\ &+ \beta_3 (DNucShut \times L\Delta PG)_{cm} \\ &+ X_{icm}\delta + \gamma_c + \phi_{my} + \varepsilon_{icm}, \end{aligned} \tag{11}$$

where i stands for infant, c for county, m for month, and y for calendar year. $DNucShut$ represents a dummy variable that takes value one from the nuclear shutdown onwards, the three dummy variables for ΔPG represent the intensity of the power generation response of coal plants to the shutdown - high, medium, low -, and X is a set control variables such as county temperature and precipitation, and characteristics of infants and their mothers. I also include county fixed effects (γ_c) to control for their time-invariant attributes, and control for seasonal and temporal patterns by including month-by-year dummies in ϕ_{my}.

Besides exploiting the variation in exposure to additional pollution at the county level, I use variation in exposure depending on months of gestation. If women are in early versus late months of pregnancy by the time of the nuclear shutdown, then their babies are exposed to different amounts of additional TSP. I make use of dummy variables for infants born in the first, second or third trimester after the shutdown to incorporate that source of treatment heterogeneity into my econometric model. Babies born in the first trimester following the shutdown face less pollution in utero than those born in the last trimester. The estimating equation can be expressed as

$$\begin{aligned} BWeight_{icm} = {} & \beta_0 + \beta_1(DNucShut \times H\Delta PG \times DTrimBirth)_{cm} \\ & + \beta_2(DNucShut \times M\Delta PG \times DTrimBirth)_{cm} \\ & + \beta_3(DNucShut \times L\Delta PG \times DTrimBirth)_{cm} \\ & + X_{icm}\delta + \gamma_c + \phi_{my} + \varepsilon_{icm}, \end{aligned} \tag{12}$$

where the only difference relative to equation (11) is the additional interaction with $DTrimBirth$, a dummy for trimester of birth after the shutdown.

It is important to mention that the same approach is used to estimate the impact of the nuclear shutdown on incidence of low birth weight (less than 2,500 grams), gestational age, and shorter gestation (less than 37 weeks of gestation). In each case, I just replace the dependent variable with one of these outcomes.

6 Results

6.1 Response of Power Generation and Air Pollution

I start by examining the responses of power generation and TSP concentration to the nuclear shutdown. Table 4 presents the estimates for coal-fired power plants, and table 5 for hydroelectric dams.

The first column of table 4 shows the average monthly amount of electricity generated due to the shutdown, whereas the second column provides similar information in log points. Paradise, for example, increases its production in approximately 434 gigawatt-hours (GWh) in a typical month, which is an increase of roughly 0.64 log points in its output. I classify Paradise coal plant as having a high response to the nuclear shutdown. The corresponding numbers for Cumberland, the plant with medium response, are 297 GWh and 0.37 log points. The low response group consists of Johnsonville, Shawnee, Widows Creek, and Colbert, and Kingston. Finally, the control group, or set of plants with negligible responses to the shutdown, is made of Bull Run, Allen, John Sevier, and Gallatin.

The third column of table 4 reveals where the electricity not produced by Browns Ferry and Sequoyah ended up being generated. Roughly a fourth of each megawatt-hour (MWh) not produced by the two TVA nuclear plants was generated by Paradise. The other three fourths were almost equally split among the other coal plants with non-negligible response to the shutdown. In fact, one cannot rule out that the substitution between nuclear and coal power is one to one, as shown at the bottom of that table. This means that electricity generation shifted completely from the nuclear facilities shut down to coal-powered plants. Similar conclusion can be reached for the total amount of nuclear power generation. One cannot rule out that the average monthly 1,800 GWh produced by Browns Ferry and Sequoyah before the shutdown were being generated by coal plants afterwards.

Concerning air pollution, the response of TSP concentration is similar in the counties where the coal plants with the highest responses are located. As noticeable from the fourth column of table 4, even though Paradise generates more electricity than Cumberland due to the nuclear shutdown, TSP responses in their host counties are almost identical. This evidence corroborates the raw data plotted in figure 2. No statistically significant TSP effects are consistently found for the counties where the other power plants are situated. Nevertheless, observe that the point estimates seem to be strongly associated with the responses of coal-powered plants to the shutdown. Indeed, in the bottom of the fourth column, I present the correlation between the coefficients of columns 1 and 4, as well as the R-squared of a simple linear regression of TSP coefficients on power generation responses, and they are both above 0.60.

I also examine the response of sulfur dioxide (SO_2) levels to the nuclear shutdown. SO_2 is another criteria pollutant with a good network of monitoring stations in the TVA area. The estimates are shown in the fifth and sixth columns of table 4. Although Paradise's excess power generation seems to affect this pollutant concentration as well, SO_2 levels appear to increase more in counties where coal plants do not respond to the shutdown. In fact, the correlation between the coefficients of columns 1 and 6 is virtually zero. This is the main reason why I focus my analysis on TSP.

When we turn to responses of hydroelectric dams in table 5, we can see that some changes also happen in their power generation. However, as a whole, the drop in electricity generated by those facilities is relatively small. Furthermore, one cannot rule out that such reduction was compensated by additional power generated in coal-fired power plants, as evident from the bottom of tables 4 and 5. This is consistent with the high cost to adjust production in coal-powered plants. It may be the case that, in order to be profitable, coal plants might have had to generate more electricity than the foregone output from the nuclear facilities.

Reductions in hydropower generation in that period may also be attributed to a harsh drought in 1985. "*This year was one of the driest on record and this limited TVA's hydroelectric power production to about 13.6 billion kilowatthours, about 5 billion less than in a typical year and the second lowest annual amount since the 1950s.*" (TVA, 1985, p.26).

Since I have controlled flexibly for climate variables in my regressions, the results discussed above are already conditional on temperature and precipitation. In any case, because hydro facilities do not produce air pollutants, TSP and SO_2 concentrations do not seem to increase systematically in counties with hydro dams after the shutdown[4].

It is encouraging to notice that my findings corroborate statements from TVA annual reports. The 1985 report, for instance, mentions that "*[t]he coal-fired plants, which represent 55 percent of TVA's installed generating capacity, supplied about 70 percent of TVA's generating requirements, or about 74 billion kilowatthours, during 1985. They did this with a budget and staff based on previous production estimates of only 65 billion kilowatthours. In May and June, the coal-fired plants supplied more than 80 percent of the system requirements. This extraordinary performance was a consequence of unplanned reductions in nuclear and hydro generation.*" (TVA, 1985, p.25-26).

6.2 Response of Birth Weight (and Weeks of Gestation)

Having found a relationship between the shutdown of the TVA nuclear power plants in 1985 and air pollution, I now turn to the effects of the shutdown on health at birth. Tables 6 and 11 show the results of the impact of exposure to the shutdown anytime during pregnancy on birth weight and gestation, respectively. They present my main findings in log points, levels (grams/weeks), and probability of an undesirable outcome (low birth weight/ preterm birth). For each dependent variable, I explore sensitivity to control variables such as county fixed effects, month-year dummies interacted with a cubic function of elevation of power plant locations, infant and mother characteristics, temperature and precipation during pregnancy in trimesters (Currie and Schwandt, 2013), per capita income and wages/salaries at the county level, and, for birth weight, a quartic function of gestational age. Tables 7 and 12 present an example of these results for the log-level equation. The last columns in these tables are the first ones in the former tables. Those estimates come from my preferred

[4]Observe that the network of monitoring stations for TSP and SO_2 does not cover counties with hydro dams very well. In general, air pollution monitors are closer to coal plants, which actually emit pollutants.

specification, which includes all controls at the same time.

Starting with birth weight in table 6, I find that it decreases by approximately 3.7 log points, or 116 grams, after the nuclear shutdown. Keep in mind that the mean birth weight before the shutdown is roughly 3,267 grams. Notice, though, that the effect shows up only when coal power generation responds strongly to the shutdown, and TSP concentration jumps from the 40s to the 50s $\mu g/m^3$. If we assume that the only pollutant affected by coal power generation in response to the shutdown is TSP, we can compute the impact of TSP on birth weight by dividing the effect of the shutdown on birth weight by the effect of the shutdown on TSP, as shown in table 4, akin to instrumental variables (IV). This procedure suggests that exposure to an additional 1 $\mu g/m^3$ of TSP during pregnancy after the shutdown decreases birth weight by approximately 10 grams. As discussed by Lavaine and Neidell (2013) in a similar context, one should be cautious in interpreting this last finding. Coal-fired power plants may have affected other pollutants in their response to the nuclear shutdown, and this would violate the exclusion restriction of a valid IV. Indeed, as mentioned before and shown in table 4, the shutdown might have increased SO_2 levels as well, even though such increase seems to be uncorrelated with responses from coal plants.

Turning to the indicator for low birth weight - less than 2,500 grams -, my estimate from the third column of table 6 seems counterintuitive. One would expect an increase in the incidence of low birth weight, but I find that the shutdown induced a decrease in that rate by approximately 3.9 percent. This might be only a particularity of the birth weight distrubtuion in the TVA area. Indeed, even before the shutdown, the tenth percentile was already above that threshold: 2,580 grams. Alternatively, my estimate might reveal that the response to the shutdown may have improved the economic status of households by bringing more economic activity to locations with coal-powered plants. Although I control for changes in per capita income and per capita wages/salaries at the county level, those variables might not capture well changes in earnings at the household level. In such a case, my estimate would reflect only the net effect of additional pollution and earnings.

One could be interested in disentangling the negative impact of the shutdown on birth weight into two components: (i) slower fetal growth, and (ii) shorter gestation. The reduction of 116 grams has already been flexibly controlled for weeks of gestation, as mentioned previously. Thus, it suggests growth retardation. For gestational age, I find similar troubling results. My estimates from table 11 indicate that the shutdown decreases weeks of gestation by roughly 1.7 log points, or 0.67 weeks, or 4.7 days. Keep in mind that the baseline mean is approximately 39 weeks. This yields an "IV" estimate of a reduction of 0.39 days of gestational length for each 1 $\mu g/m^3$ increase in TSP concentration driven by the shutdown. From another angle, the shutdown increases the probability of short gestation - less than 37 weeks - by 5.7 percent.

To compare the estimates of birth weight and gestation, I follow Lavaine and Neidell (2013) and perform the following calculation. Fetuses gain about 200 grams in weight per week in the final month of pregnancy (Cunningham et al., 2010). Hence, the 0.67 week decrease in gestation translates into an extra 134 grams in weight, which is similar to my estimate of the impact on birth weight. Therefore, it appears that the nuclear shutdown induces deleterious effects on health at birth through both channels: growth retardation and shorter gestation. Moreover, these effects seem to have almost identical economic significance. These results differ from those of the impact of a recent strike in oil refineries in France, studied by Lavaine and Neidell (2013). They suggest that the increase in birth weight, driven likely by a decrease in SO_2 concentration, might be solely due to shorter gestation, rather than growth retardation.

It is important to say that all these results survive a number of robustness checks. First, they are robust to the time frame used in the estimation, as we can see in tables 8 and 13, where I present estimates from one to three full pregnancy windows. Also, as shown in tables 14 and 14, they are not very sensitive to (i) eliminating the interaction of month-year fixed effects with elevation of power plants, (ii) changing the frequency of climate variables from quarterly to monthly, (iii) including per capita government transfer payments at the county level as an additional control variable, (iv) incorporating infants from two neighboring counties which both contain coal-powered plants (Kingston and Bull Run Coal Plants), (v) excluding babies from the county where Allen Fossil Plant is located, which is in the control group but has the majority of observations in my sample, (vi) weighting a few observations from states that reported only half of the births.

Given that women are in different stages of pregnancy by the time of the shutdown, it is possible to determine whether the impact on health outcomes at birth depends on the length of the exposure to TSP. To exploit this source of variation, I interact the dummy of the nuclear shutdown with the trimester the baby was born after the shutdown. If the infant is born in the first quarter following the shutdown, for instance, that means that exposure to additional air pollution *in utero* was at most three months. Tables 10 and 15 present my results controlling for the same covariates mentioned previously for my preferred specification.

Although I provide suggestive evidence that even babies born in the first trimester after the shutdown are negatively affected, I find that most of the impact of the shutdown on birth weight comes from infants that are exposed to additional TSP for at least six months. The effect is 7.2 log points, or 182 grams for infants born in the third trimester following the shutdown, and 4.7 log points, or 137 grams, for babies born thereafter. The drop in the latter effect may reflect migration responses to higher TSP concentration, since households have more than nine months to find a location with lower levels of pollution. Again, the impact is found only for the group experiencing the highest coal power generation response. Here, the "IV" estimates suggest that exposure to an additional 1 $\mu g/m^3$ of TSP during full pregnancy after the shutdown decreases birth weight by approximately 15 or 11.5 grams, for infants born in the third trimester following the shutdown, or afterwards, respectively.

For gestational age, I find that exposure to the shutdown has already an impact in the second trimester of pregnancy, and it becomes stronger when full gestation happens after the nuclear shutdown. The effect is close to the average reduction presented above - 1.7 log points, or 0.67 weeks -, but it reaches 2.7 log points, or 1 week, for pregnancies carried out entirelly after the shutdown. This shorter gestation for full pregnancies happening after the shutdown translates into roughly 207 grams, which is a bit larger than the effect estimated for birth weight.

Because of strong seasonal patterns of pollution and other environmental confounders, I evaluate the validity of my research design by running a falsification test. Basically, I assign the date of the nuclear shutdown to have occured in March 1983, two years before the actual one. Recall that my time frime for the estimation is eighteen months before and after the shutdown. This is the reason why I do not assign the placebo shutdown to have happened in the year immediately before the actual one. As shown in tables 16, 17 and 18, I find that the placebo shutdown is broadly neither associated with TSP levels[5] nor measures of health at birth.

6.3 "Safe" Threshold for Exposure to TSP

Having found plenty of evidence that high levels of pollution are harmful, Currie et al. (2013) suggest that a *"particularly important question for policy is whether there is a safe level of these substances."* (p.20) for fetuses and young children. In other words, they urge recovering a curve of pollution effects as a function of pollution exposure. My attempt to infer such a curve in the context of my study is quite primitive, but might still shed some light on the safe threshold for TSP, and may inspire further research.

I begin by noticing that TSP concentrations displayed in the right-hand side of table 1 do not appear to respond proportionally to the coal power generation driven by the nuclear shutdown. While the high group generates 50 percent more electricity than the medium group on average, TSP responses seem to be very similar. Indeed, when I plot the smoothed

[5] Although TSP seems to be increasing in some counties after the placebo shutdown, notice that its coefficients are statistically significant only where responses from coal-powered plants are not significant. The apparent spatially heterogeneous increase in TSP might be related to emissions from other sectors, which may be recovering from the severe U.S. recession that began in July 1981 and ended in November 1982. Chay and Greenstone (2003) actually exploit the substantial variation across sites in air pollution, induced by the 1981-1982 recession, to study the impact of air pollution on infant mortality.

data on TSP concentration in figure 2, the only difference in the observed patterns seems to be the level of pollution that each group starts with. The medium group jumps from the 30s to the 40s $\mu g/m^3$, whereas the high group moves from the 40s to the 50s $\mu g/m^3$. Just for reference, the EPA annual standard for TSP is 75 $\mu g/m^3$ from 1971 to 1987.

Proceeding with my difference-in-differences estimation approach, I find that, in 1985, even though TSP concentrations are below EPA standards, they are not at safe levels. When TSP concentration is above 50 $\mu g/m^3$, but still below the standard of 75 $\mu g/m^3$, air pollution seems to decrease birth weight by roughly 3.7 percent, and gestational age by 0.67 weeks, as discussed previously. However, no statistically significant effects are found for TSP levels below 50 $\mu g/m^3$. From this comparison, I primitively infer that 50 $\mu g/m^3$ might be a safe threshold for exposure to TSP.

In 1987, EPA replaces the earlier TSP air quality standard with a PM_{10} standard. A decade later, a $PM_{2.5}$ standard is added. The new standards focus on smaller particles that are likely responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract. I use EPA correspondences between measures of those three elements[6] to translate TSP to PM levels, and to evaluate the standards vis-à-vis the inferred threshold. My findings suggest that EPA might have set the TSP and PM standards right only from 1997 onwards, as shown in table 2. This illustrates that the research design used in this study might help EPA setting the NAAQS for other pollutants.

7 Concluding Remarks

When environmental regulations focus on a subset of power plants, the ultimate goal of human health protection may not be reached. Because power plants are interconnected through the electrical grid, excessive scrutiny of a group of facilities may generate more pollution out of another group, with potential deleterious effects to public health. In this study,

[6]The TSP/PM_{10} ratio is 0.48 (Pace and Frank, 1986, Table 1), and the $PM_{10}/PM_{2.5}$ ratio is 0.58 (Parkhurst et al., 1999, Table 3).

I investigate the impact of the shutdown of nuclear power plants in the Tennessee Valley Authority (TVA), in 1985, on health outcomes at birth. After the Three Mile Island accident in 1979, the Nuclear Regulatory Commission (NRC) intensified inspections in nuclear facilities leading to shutdown of many of them, including Browns Ferry and Sequoyah in the TVA area.

I have four main findings. I first show that, in response to the shutdown, electricity generation shifted mostly to coal-fired power plants within the TVA, increasing air pollution in counties where they were located. I provide evidence that the substitution of coal for nuclear power generation may be one to one. Also, that TSP concentration, my measure of pollution, responds only in counties hosting the coal-powered plants with the highest increases in coal-burning generation due to the shutdown.

Second, I find that babies born after the nuclear shutdown have both lower birth weight and lower gestational age in those counties with coal-fired power plants that do respond to the shutdown. This indicates that exposure to higher levels of TSP may deteriorate infant health via two channels: growth retardation and shorter gestation. Third, I highlight the presence of substantial heterogeneity in those effects depending on how much more electricity those coal-powered facilities were generating in response to the shutdown. For the group with the highest response in terms of both coal-burning generation and TSP concentration, it seems that exposure to an additional 1 $\mu g/m^3$ of TSP during pregnancy after the shutdown induces a reduction of roughly 10 grams in birth weight, and 0.39 days in gestational length. By translating days in grams, as discussed previously, the latter estimate becomes 11 grams, approximately. Therefore, both fetal growth and gestational length appear to be affected negatively by the shutdown. I find no statistically significant effects when coal generation responses to the shutdown are medium or low.

Lastly, I use the heterogeneity in response to the nuclear shutdown to provide suggestive evidence on the "safe" threshold of exposure to TSP, which can potentially guide the Environmental Protection Agency (EPA) in setting the National Ambient Air Quality Standards

(NAAQS) for particulate matters. Although I find no significant impact on health at birth associated with medium coal generation response to the shutdown, TSP levels do increase in those locations. The crucial difference among counties with high and medium responses is the level of TSP that they start with. In the high response group, it jumps from the 40s to the 50s $\mu g/m^3$, whereas in the medium response group it moves from the 30s to the 40s $\mu g/m^3$. Hence, the "safe" threshold for exposure to TSP might be 50 $\mu g/m^3$, which is close to the current EPA standards for PM when translated to the PM_{10} and $PM_{2.5}$ scales.

Taking together, these findings make four contributions to the literature and policymaking. First, they point out that environmental regulations focused on one node of an extensive network of energy production may trigger unanticipated chain reactions that go against the ultimate goal of protecting public health. Networks should be taken into account in the design of those regulations. Second, they show that a curve relating effects of pollution on health and intensity of pollution exposure may be estimable through the use of networks. When shocks in one node produce different responses over other nodes, quasi-experimental variation in pollution exposure may arise. As already discussed, this methodology has the potential to guide EPA when setting the NAAQS. Third, they provide evidence that suspending nuclear energy production might not generate as many net benefits as the public perceives. The retirement of the San Onofre Nuclear Generating Station in California, and the denuclearization Germany intensified after the Fukushima disaster, may actually bring about unintended net costs to society. Lastly, they corroborate recent findings by Lavaine and Neidell (2013) that pollution externalities from energy production are also prominent, and should be seriously considered in the design of environmental policies.

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“TVA burned 35.5 million tons of coal in 1986, up sharply from the 31.1 million tons burned in 1985. (...) The average cost of coal burned continued to drop from a high of $43.77 a ton in 1983 to $36.18 for 1986.” (TVA, 1986, p.21)

“TVA’s coal-fired plants generated some 85 billion kilowatthours of electricity and set national records for efficient performance during 1986. Largely because of this, the agency maintained its favorable electric rates, and power supplies were adequate during a year of serious challenges. TVA’s nuclear plants generated no electric power during the year. Two licensed nuclear plants remained out of service to address various concerns about plant safety and management. In addition, the worts drought in 96 years of record-keeping reduced hydroelectric generation to its lowest level since TVA’s basic reservoir system was completed.” (TVA, 1986, p.20)

“TVA’s average power rates remained at about two-thirds the national average, despite increased cost that pushed consumers’s rates up by an average of 6 percent.” (TVA, 1986, p.20)

“Over the past five years, TVA power costs to consumers have been held below the level of general inflation. After four years of virtually flat rate levels, consumers’ bills increased an average of about 6 percent.” (TVA, 1986, p.20)

“This year TVA recorded some major successes, including the efficient generation of record amounts of electric power by the TVA coal-fired plants. Residents in the TVA region continued to have adequate electricity supplies and fairly stable rates, despite a Valleywide drought and no generation from its nuclear facilities (...)” (TVA, 1986, p.20)

“The Tennessee Valley suffered its worst drought ever - cutting hydroelectric production to about half the typical output and threatening a regionwide water crisis.” (TVA, 1986, p.20)

“In operating the nation’s largest electric power system, TVA balances the region’s need for energy, a clean environment, and a sound economy. In 1985, TVA and local power distributors kept overall electric rates here among the lowest in the country. While maintaining stable rates, TVA also continued to explore new approaches for more efficient production and use. One outstanding example of this is found in TVA's contributions to new technology for cleaner burning of coal for generating electricity. Very troubling, however, was the state of TVA's nuclear power program in 1985. During the year, Browns Ferry and Sequoyah nuclear plants were taken out of service for extended periods, fuel-loading was delayed at Watts Bar Unit 1 while various safety concerns were investigated (...)" (TVA, 1985, Intro)

"The coal-fired plants, which represent 55 percent of TVA's installed generating capacity, supplied about 70 percent of TVA's generating requirements, or about 74 billion kilowatthours, during 1985. They did this with a budget and staff based on previous production estimates of only 65 billion kilowatthours. In May and June, the coal-fired plants supplied more than 80 percent of the system requirements. This extraordinary performance was a consequence of unplanned reductions in nuclear and hydro generation." (TVA, 1985, p.25-26)

"On March 27, after extended maintenance and refueling outages at Browns Ferry Nuclear Plant, the TVA Board decided not to restart the plant's three units while an intensive modification program brings this oldest TVA nuclear facility up to current standards. In another move reflecting TVA's determination to operate its nuclear plants with safety and efficiency as the first priorities of operation, TVA on August 21 voluntarily shut down both units at Sequoyah Nuclear Plant while a thorough check of safety-related documentation and equipment proceeded. As a result of these decisions, nuclear generation for 1985 totaled only 17.7 billion kilowatthours, compared to 24.8 billion kilowatthours in 1984." (TVA, 1985, p.26)

"This year was one of the driest on record and this limited TVA's hydroelectric power production to about 13.6 billion kilowatthours, about 5 billion less than in a typical year and the second lowest annual amount since the 1950s." (TVA, 1985, p.26)

"Employees at Browns Ferry worked millions of manhours to revise plant procedures, examine equipment, and perform major modifications on many safety systems. Other initiatives at Brown Ferry include an Employee Involvement Program that is establishing better communications between management and employees. The site director initiated this program in April and met personally with all 2,200 Browns Ferry employees in small working groups. The groups were encouraged to identify concerns and suggest ways the quality of plant activities could be improved. In all, 368 concerns or suggestions were identified." (TVA, 1985, p.27)

Figure 1: TVA Power Generation (Terawatt Hours)

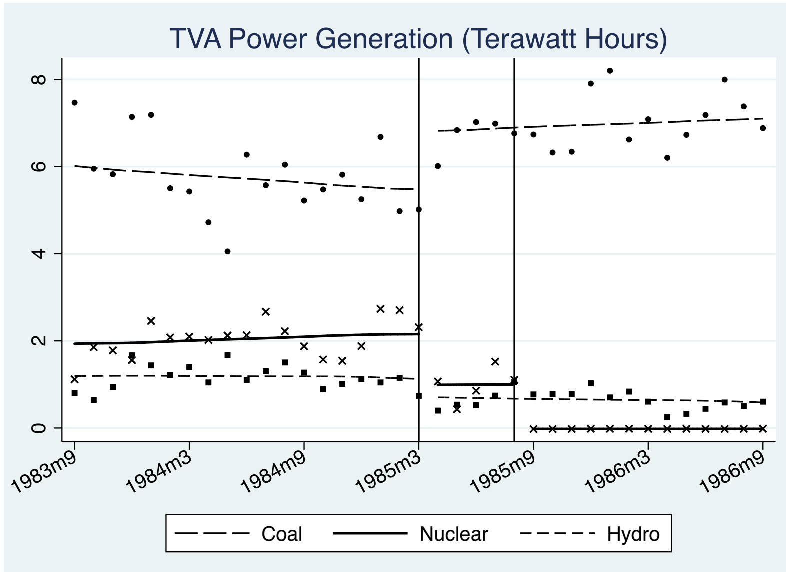


Figure 2: TVA TSP Concentration - $>50\ \mu g/m^3$ vs. $<50\ \mu g/m^3$

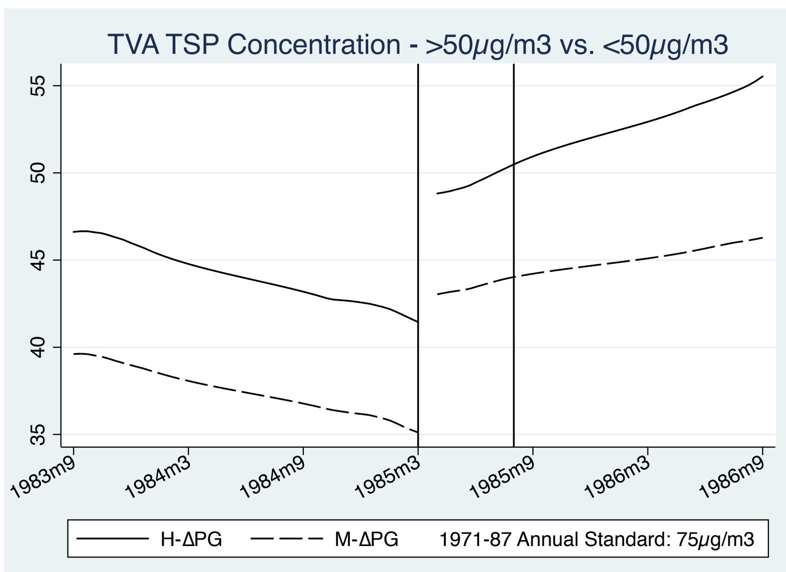
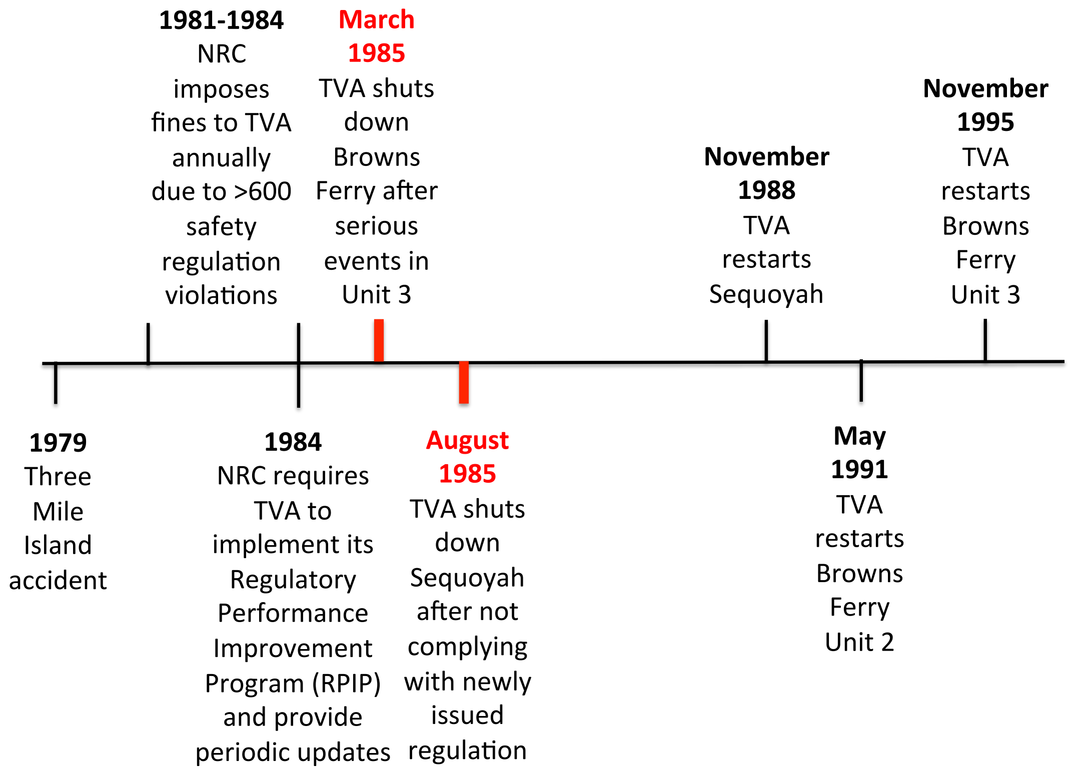


Figure 3: Timeline - TVA Nuclear Shutdown



Source: Documents from the Union of Concerned Scientists (UCS).
Note: "… outages reflect a regulatory bias first identified by the various inquiries into the Three Mile Island Unit 2 accident."

Figure 4: Map of TVA Power Plants - 1985

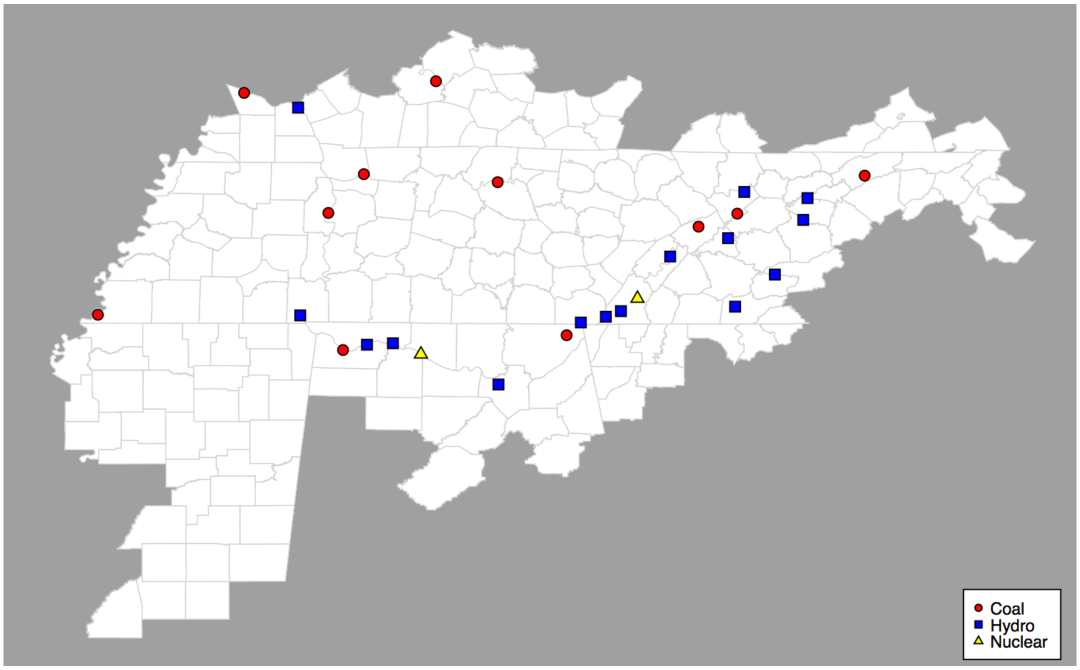


Figure 5: Map of TVA Coal and Nuclear Power Plants -1985

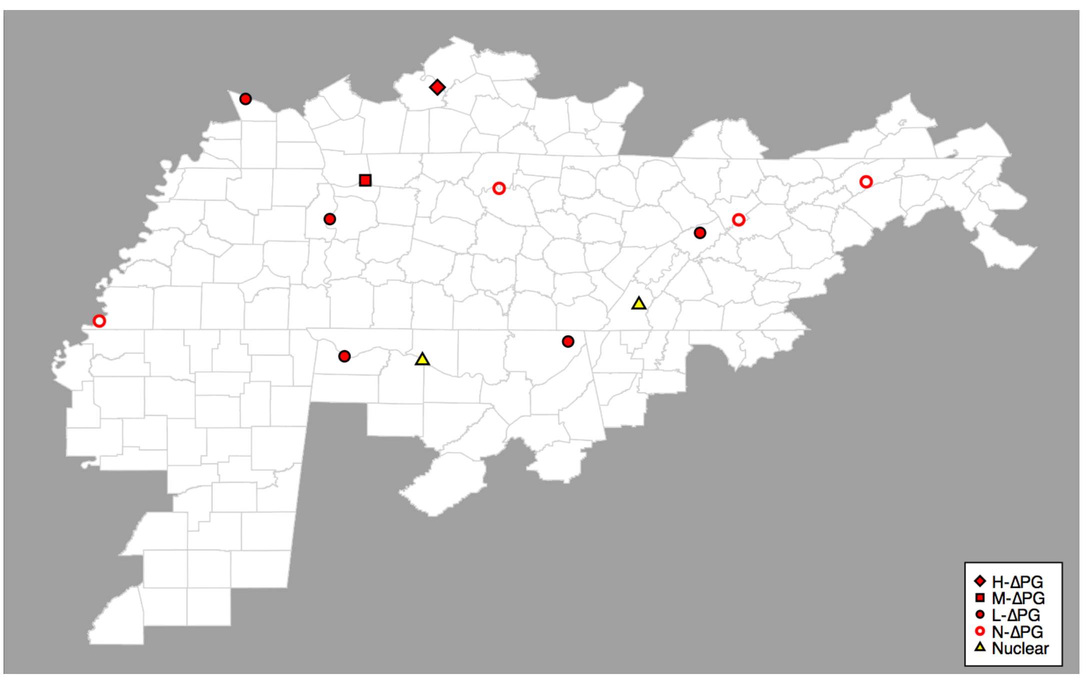


Table 1: Heterogeneity in response to nuclear shutdown

Groups - Coal Power Plants	Before Nuclear Shutdown			After Nuclear Shutdown		
	PG (GWh)	TSP ($\mu g/m^3$)	BWeight (g)	ΔPG (GWh)	ΔTSP ($\mu g/m^3$)	ΔBWeight (g)
H-ΔPG	280.26	43.61	3395.12	186.90	9.06	-93.34
M-ΔPG	511.44	37.13	3438.60	121.75	7.63	-49.53
L-ΔPG	218.77	43.94	3381.11	54.20	1.41	-15.89
T-ΔPG	183.14	48.44	3314.72	-4.15	-0.30	36.56
Total	**232.85**	**45.17**	**3360.27**	**46.88**	**1.83**	**-3.80**

Table 2: EPA Standards and "Safe" Threshold - TSP, PM_{10} and $PM_{2.5}$

Annual Standards	TSP	PM_{10}	$PM_{2.5}$
1971-87	$75 \mu g/m^3$		
1987-97		$50 \mu g/m^3$	
1997-06		$50 \mu g/m^3$	$15 \mu g/m^3$
2006-12			$15 \mu g/m^3$
2012-...			$12 \mu g/m^3$
Suggestive Threshold	$50 \mu g/m^3$	$24 \mu g/m^3$	$14 \mu g/m^3$

Source: epa.gov/ttn/naaqs/standards/pm/s_pm_history.html

Table 3: Sample for Birthweight Analysis

Coal Plants	Group	Obs - Main	Percentage	Obs	Percentage
Paradise	H-ΔPG	1177	2.10	1177	1.96
Cumberland	M-ΔPG	235	0.42	235	0.39
Johnsonville	L-ΔPG	511	0.91	511	0.85
Shawnee	L-ΔPG	2437	4.36	2437	4.06
Widows Creek	L-ΔPG	1967	3.52	1967	3.28
Colbert	L-ΔPG	2096	3.75	2096	3.50
Kingston	L-ΔPG	0	0.00	1640	2.73
Bull Run	T-ΔPG (Control)	0	0.00	2406	4.01
Allen	T-ΔPG (Control)	42195	75.45	42195	70.36
John Sevier	T-ΔPG (Control)	1573	2.81	1573	2.62
Gallatin	T-ΔPG (Control)	3730	6.67	3730	6.22
Total	**All**	55921	100.00	59967	100.00

Table 4: Response of Power Generation and Pollution - Coal

Dep Var RHS Var	Class of ΔPG	GenCoal DNucShut (1)	ln(GenCoal) DNucShut (2)	GenCoal GenNuc (3)	TSP DNucShut (4)	ln(TSP) DNucShut (5)	SO2 DNucShut (6)	ln(SO2) DNucShut (7)
Paradise	H-ΔPG	433,985***	0.6429***	-0.2301***	11.97***	0.28***	1.42*	0.21*
		(65,805)	(0.1063)	(0.0390)	(3.75)	(0.08)	(0.80)	(0.12)
Cumberland	M-ΔPG	297,304**	0.3744***	-0.1186**	9.08***	0.25***	-0.26	-0.07
		(115,275)	(0.1436)	(0.0587)	(3.47)	(0.08)	(0.70)	(0.10)
Johnsonville	L-ΔPG	217,003***	0.5195***	-0.1041***	4.55	0.14*	0.95*	0.13
		(37,418)	(0.0898)	(0.0193)	(3.19)	(0.08)	(0.50)	(0.08)
Shawnee	L-ΔPG	184,261***	0.4633***	-0.1010***	6.26*	0.15**	0.48	0.01
		(59,767)	(0.1320)	(0.0241)	(3.57)	(0.07)	(0.53)	(0.09)
Widows Creek	L-ΔPG	168,955**	0.6049**	-0.0878**	3.96	0.10	0.52	0.07
		(72,373)	(0.2885)	(0.0396)	(3.27)	(0.08)	(0.55)	(0.10)
Colbert	L-ΔPG	142,013***	0.2921***	-0.0793***	1.99	0.06	1.70***	0.29***
		(38,075)	(0.0883)	(0.0190)	(3.44)	(0.08)	(0.57)	(0.10)
Kingston	L-ΔPG	130,349**	0.2421***	-0.0743***	-2.94	-0.05	-0.47	-0.15**
		(54,176)	(0.0807)	(0.0225)	(3.70)	(0.08)	(0.48)	(0.07)
Bull Run	Control	62,318	0.1298	-0.0338	-0.14	0.01	2.04***	0.24***
	(N-ΔPG)	(107,122)	(0.1426)	(0.0355)	(3.43)	(0.07)	(0.70)	(0.09)
Allen	Control	55,979	0.1473	-0.0259	-1.47	0.00	2.60***	0.34***
	(N-ΔPG)	(41,773)	(0.1136)	(0.0228)	(2.98)	(0.06)	(0.60)	(0.09)
John Sevier	Control	49,463	0.1275	-0.0302	5.49	0.13	-0.51	-0.02
	(N-ΔPG)	(41,149)	(0.1020)	(0.0214)	(3.49)	(0.09)	(0.76)	(0.10)
Gallatin	Control	-11,400	0.0215	-0.0001	1.05	0.08	0.15	-0.00
	(N-ΔPG)	(43,280)	(0.1003)	(0.0239)	(6.72)	(0.13)	(0.97)	(0.11)
Pooled		163,129***	0.3216***	-0.0805***	3.31	0.10*	0.80*	0.10
		(51,306)	(0.0876)	(0.0258)	(2.46)	(0.06)	(0.45)	(0.06)
F-tests		Sum = 1800GWh		Sum = -1MWh	Corr((1),(4))		Corr((1),(6))	
F-stat		0.04		0.44	0.79		-0.01	
Prob > F-stat		0.8435		0.5094	R^2 LRM: 0.62		R^2 LRM: 0.00	
F-tests		Sum = 2100GWh		Sum = -1.15MWh				
F-stat		1.10		2.32				
Prob > F-stat		0.2958		0.1283				
Observations		444	403	444	408	408	402	402

Notes: Newey-West standard errors with three lags in parentheses. (ΔNucPG ≈ −1776.25GWh)

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Response of Power Generation and Pollution - Hydro

Dep Var RHS Var	GenCoal DNucShut (1)	ln(GenCoal) DNucShut (2)	GenCoal GenNuc (3)	TSP DNucShut (4)	ln(TSP) DNucShut (5)	SO2 DNucShut (6)	ln(SO2) DNucShut (7)
Wilson	-106,465***	-0.2182	0.0538***	3.35	0.09	1.81	0.08
	(22,870)	(0.1868)	(0.0109)	(3.07)	(0.07)	(1.45)	(0.11)
Wheeler	-36,569***	-0.0309	0.0164**	0.36	0.06		
	(12,485)	(0.2095)	(0.0075)	(2.60)	(0.07)		
Guntersville	-20,703***	-0.1312	0.0090***	0.39	0.02		
	(4,719)	(0.1848)	(0.0026)	(2.01)	(0.04)		
Kentucky	-17,938***	0.1432	0.0099***	1.69	0.06		
	(5,625)	(0.1668)	(0.0031)	(4.45)	(0.08)		
Hiwassee	-11,018**	-0.2671	0.0044*				
	(4,634)	(0.2478)	(0.0024)				
Fontana	-32,686***	-0.2273	0.0164***				
	(9,010)	(0.1987)	(0.0054)				
Norris	-6,685**	-0.0880	0.0033*	-2.17	-0.03	3.97***	0.28**
	(3,402)	(0.2220)	(0.0017)	(3.98)	(0.08)	(1.50)	(0.13)
Raccoon Mountain	-8,311	0.0234	0.0040	-3.37*	-0.05		
	(19,184)	(0.1708)	(0.0094)	(1.95)	(0.04)		
Pickwick Landing	-37,497***	-0.0126	0.0196***	0.52	0.03		
	(9,217)	(0.1624)	(0.0050)	(2.50)	(0.06)		
Cherokee	-3,728	-0.0436	0.0010				
	(3,512)	(0.2221)	(0.0018)				
Fort Loudoun	-9,272	0.0257	0.0042				
	(10,547)	(0.4273)	(0.0053)				
Nickajack	-14,881***	-0.0724	0.0074***	-1.46	-0.02		
	(3,138)	(0.1652)	(0.0017)	(3.20)	(0.08)		
Watts Bar Hydro	-25,292***	-0.0696	0.0120***				
	(5,169)	(0.1730)	(0.0029)				
Douglas	-10,629**	-0.1560	0.0059**				
	(4,460)	(0.2167)	(0.0023)				
Pooled	-1,297	0.0895	-0.0002	-5.49**	-0.09*	-0.19	0.04
	(4,868)	(0.1995)	(0.0025)	(2.37)	(0.05)	(1.20)	(0.08)
F-tests	Sum = 0GWh		Sum = 0MWh	Corr((1),(4))			
F-stat	71.47		58.94	-0.78			
Prob > F-stat	0.0000		0.0000	R^2 LRM: 0.61			
F-tests	Sum = -300GWh		Sum = 0.15MWh				
F-stat	1.06		0.65				
Prob > F-stat	0.3027		0.5094				
Observations	1,147	1,058	1,147	609	609	302	302

Notes: Newey-West standard errors with three lags in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Response of Birth Weight - Comparison

Dep Var	ln(BWeight)	BWeight	BWeight<2500
	(1)	(2)	(3)
H-ΔPG	-0.0372***	-116.4655***	-0.0389**
	(0.0135)	(38.2118)	(0.0166)
M-ΔPG	-0.0033	-19.4251	-0.0367
	(0.0256)	(73.1329)	(0.0392)
L-ΔPG	-0.0073	-29.7927	-0.0138
	(0.0106)	(33.0156)	(0.0161)
All Controls	Yes	Yes	Yes
Observations	55,921	55,921	55,921
R-squared	0.4675	0.3601	0.2908

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Response of Birth Weight - Preferred Specification

Dep Var: ln(BWeight)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
H-ΔPG	0.0046	-0.0420***	-0.0452***	-0.0476***	-0.0579***	-0.0540***	-0.0372***
	(0.0102)	(0.0065)	(0.0135)	(0.0088)	(0.0177)	(0.0180)	(0.0135)
M-ΔPG	0.0674***	0.0079	0.0067	-0.0042	-0.0059	-0.0038	-0.0033
	(0.0099)	(0.0090)	(0.0181)	(0.0134)	(0.0242)	(0.0300)	(0.0256)
L-ΔPG	0.0353***	-0.0006	-0.0020	0.0062	0.0041	0.0033	-0.0073
	(0.0107)	(0.0104)	(0.0129)	(0.0071)	(0.0108)	(0.0119)	(0.0106)
County FE	No	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year FE x Elevation PP[3]	No	No	Yes	Yes	Yes	Yes	Yes
Mother/Infant Characteristics	No	No	No	Yes	Yes	Yes	Yes
Temp/Prec over Pregn - Trim	No	No	No	No	Yes	Yes	Yes
PCI and PCWages/Salaries	No	No	No	No	No	Yes	Yes
Weeks of Gestation[4]	No	No	No	No	No	No	Yes
Observations	55,921	55,921	55,921	55,921	55,921	55,921	55,921
R-squared	0.0013	0.0080	0.0109	0.1730	0.1731	0.1732	0.4675

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Response of Birth Weight - Robustness Checks

Dep Var: ln(BWeight)	NucShut ± 9m	NucShut ± 12m	NucShut ± 15m	NucShut ± 18m	NucShut ± 21m	NucShut ± 24m	NucShut ± 27m
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
H-ΔPG	-0.0171	-0.0304*	-0.0364***	-0.0372***	-0.0237*	-0.0170	-0.0236**
	(0.0167)	(0.0162)	(0.0131)	(0.0135)	(0.0135)	(0.0106)	(0.0095)
M-ΔPG	-0.0310	-0.0364	-0.0062	-0.0033	-0.0183	-0.0225*	-0.0172
	(0.0540)	(0.0389)	(0.0297)	(0.0257)	(0.0206)	(0.0132)	(0.0142)
L-ΔPG	-0.0300	-0.0307*	-0.0166	-0.0073	-0.0051	-0.0072	-0.0083
	(0.0223)	(0.0161)	(0.0122)	(0.0105)	(0.0084)	(0.0101)	(0.0088)
All Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	29,122	37,823	46,495	55,921	65,092	73,772	82,614
R-squared	0.4923	0.4781	0.4697	0.4675	0.4639	0.4634	0.4648

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Response of Birth Weight - Robustness Checks

Dep Var: ln(BWeight)	Mo/Yr FE	Temp/Prec Mo	PCTransfers	W/ CoalNeigb	W/o Allen	W/ weights	Reweighting
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
H-ΔPG	-0.0282***	-0.0329**	-0.0349**	-0.0331**	-0.0292*	-0.0371***	-0.0425***
	(0.0101)	(0.0160)	(0.0143)	(0.0133)	(0.0166)	(0.0134)	(0.0151)
M-ΔPG	0.0182	-0.0089	-0.0008	-0.0082	0.0004	-0.0035	-0.0107
	(0.0159)	(0.0211)	(0.0266)	(0.0187)	(0.0270)	(0.0256)	(0.0308)
L-ΔPG	-0.0040	-0.0043	-0.0111	-0.0035	-0.0067	-0.0073	-0.0124
	(0.0065)	(0.0123)	(0.0110)	(0.0072)	(0.0185)	(0.0105)	(0.0102)
All Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	55,921	55,921	55,921	59,967	13,726	55,925	9,298,098
R-squared	0.4667	0.4677	0.4675	0.4665	0.4251	0.4675	0.4716

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Response of Birth Weight - Trimesters

Dep Variable	ln(BWeight) (1)	BWeight (2)
(H-ΔPG) x (Birth in 1st Trim After NucShut)	-0.0248*	-94.7116**
	(0.0131)	(41.3306)
(H-ΔPG) x (Birth in 2nd Trim After NucShut)	-0.0184	-86.7877
	(0.0218)	(61.4765)
(H-ΔPG) x (Birth in 3rd Trim After NucShut)	-0.0716***	-182.3720***
	(0.0177)	(43.6484)
(H-ΔPG) x (Birth in 4th+ Trim After NucShut)	-0.0470***	-137.0661***
	(0.0160)	(44.0336)
(M-ΔPG) x (Birth in 1st Trim After NucShut)	-0.0090	-35.4381
	(0.0589)	(184.1184)
(M-ΔPG) x (Birth in 2nd Trim After NucShut)	-0.0038	-11.2953
	(0.0310)	(89.6316)
(M-ΔPG) x (Birth in 3rd Trim After NucShut)	-0.0205	-40.8864
	(0.0393)	(125.3815)
(M-ΔPG) x (Birth in 4th+ Trim After NucShut)	-0.0220	-82.1079
	(0.0269)	(90.5956)
(L-ΔPG) x (Birth in 1st Trim After NucShut)	-0.0190	-47.1790
	(0.0130)	(38.0518)
(L-ΔPG) x (Birth in 2nd Trim After NucShut)	-0.0012	-15.6126
	(0.0099)	(29.2637)
(L-ΔPG) x (Birth in 3rd Trim After NucShut)	-0.0117	-55.1349
	(0.0149)	(43.9326)
(L-ΔPG) x (Birth in 4th+ Trim After NucShut)	-0.0018	-16.9400
	(0.0177)	(52.5826)
Observations	55,921	55,921
R-squared	0.4676	0.3602

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Response of Weeks of Gestation- Comparison

Dep Var	ln(GWeeks) (1)	GWeeks (2)	GWeeks<37 (3)
H-ΔPG	-0.0174**	-0.6692***	0.0566***
	(0.0073)	(0.2557)	(0.0218)
M-ΔPG	-0.0115	-0.4875	0.0006
	(0.0090)	(0.3710)	(0.0445)
L-ΔPG	0.0060	0.2040	-0.0050
	(0.0041)	(0.1476)	(0.0177)
All Controls	Yes	Yes	Yes
Observations	55,921	55,921	55,921
R-squared	0.1158	0.1121	0.0951

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 12: Response of Weeks of Gestation - Preferred Specification

Dep Var: ln(GWeeks)	(1)	(2)	(3)	(4)	(5)	(6)
H-ΔPG	-0.0008	-0.0140***	-0.0123***	-0.0150***	-0.0164**	-0.0174**
	(0.0026)	(0.0021)	(0.0042)	(0.0046)	(0.0068)	(0.0073)
M-ΔPG	0.0128***	-0.0101***	-0.0071	-0.0079*	-0.0070	-0.0115
	(0.0031)	(0.0022)	(0.0052)	(0.0041)	(0.0067)	(0.0090)
L-ΔPG	0.0092**	-0.0017	-0.0001	0.0030	0.0034	0.0060
	(0.0041)	(0.0042)	(0.0050)	(0.0025)	(0.0042)	(0.0041)
County FE	No	Yes	Yes	Yes	Yes	Yes
Month-Year FE x Elevation PP^3	No	No	Yes	Yes	Yes	Yes
Mother/Infant Characteristics	No	No	No	Yes	Yes	Yes
Temp/Prec over Pregn - Trim	No	No	No	No	Yes	Yes
PCI and PCWages/Salaries	No	No	No	No	No	Yes
Observations	55,921	55,921	55,921	55,921	55,921	55,921
R-squared	0.0007	0.0047	0.0092	0.1155	0.1158	0.1158

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 13: Response of Weeks of Gestation - Robustness Checks

Dep Var: ln(GWeeks)	NucShut ± 9m	NucShut ± 12m	NucShut ± 15m	NucShut ± 18m	NucShut ± 21m	NucShut ± 24m	NucShut ± 27m
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
H-ΔPG	0.0037	-0.0046	-0.0114	-0.0173**	-0.0133**	-0.0162***	-0.0106**
	(0.0159)	(0.0136)	(0.0093)	(0.0081)	(0.0063)	(0.0049)	(0.0047)
M-ΔPG	-0.0195*	-0.0138	-0.0069	-0.0117	-0.0123	-0.0272***	-0.0089
	(0.0111)	(0.0124)	(0.0104)	(0.0092)	(0.0078)	(0.0091)	(0.0069)
L-ΔPG	-0.0045	-0.0006	0.0066	0.0061	0.0047	0.0034	0.0057*
	(0.0095)	(0.0084)	(0.0050)	(0.0039)	(0.0037)	(0.0034)	(0.0031)
All Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	29,132	37,836	46,510	55,939	65,113	73,793	82,641
R-squared	0.1229	0.1153	0.1169	0.1172	0.1167	0.1192	0.1206

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 14: Response of Weeks of Gestation - Robustness Checks

Dep Var: ln(GWeeks)	Mo/Yr FE	Temp/Prec Mo	PCTransfers	W/ CoalNeigb	W/o Allen	W/ weights	Reweighting
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
H-ΔPG	-0.0153***	-0.0159**	-0.0157*	-0.0153**	-0.0145*	-0.0175**	-0.0180**
	(0.0045)	(0.0062)	(0.0090)	(0.0061)	(0.0088)	(0.0073)	(0.0080)
M-ΔPG	-0.0082	-0.0108	-0.0161	-0.0144**	-0.0106	-0.0115	-0.0085
	(0.0061)	(0.0098)	(0.0109)	(0.0070)	(0.0106)	(0.0090)	(0.0109)
L-ΔPG	0.0038	0.0062**	0.0067	0.0027	0.0036	0.0060	0.0060
	(0.0024)	(0.0030)	(0.0043)	(0.0040)	(0.0048)	(0.0040)	(0.0044)
All Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	55,921	55,921	55,921	59,989	13,726	55,925	9,298,098
R-squared	0.1138	0.1160	0.1158	0.1184	0.1140	0.1158	0.1143

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 15: Response of Weeks of Gestation - Trimesters

Dep Variable	ln(GWeeks)	GWeeks
	(1)	(2)
(H-ΔPG) x (Birth in 1st Trim After NucShut)	0.0077	0.2159
	(0.0122)	(0.4512)
(H-ΔPG) x (Birth in 2nd Trim After NucShut)	-0.0183**	-0.7356**
	(0.0089)	(0.3353)
(H-ΔPG) x (Birth in 3rd Trim After NucShut)	-0.0175**	-0.5958**
	(0.0082)	(0.2663)
(H-ΔPG) x (Birth in 4th+ Trim After NucShut)	-0.0272***	-1.0348***
	(0.0061)	(0.2384)
(M-ΔPG) x (Birth in 1st Trim After NucShut)	-0.0389***	-1.5391***
	(0.0123)	(0.4316)
(M-ΔPG) x (Birth in 2nd Trim After NucShut)	-0.0036	-0.2396
	(0.0140)	(0.5271)
(M-ΔPG) x (Birth in 3rd Trim After NucShut)	0.0041	0.1934
	(0.0088)	(0.4134)
(M-ΔPG) x (Birth in 4th+ Trim After NucShut)	-0.0178**	-0.7820**
	(0.0085)	(0.3363)
(L-ΔPG) x (Birth in 1st Trim After NucShut)	0.0079*	0.2591
	(0.0048)	(0.1734)
(L-ΔPG) x (Birth in 2nd Trim After NucShut)	0.0080	0.2782
	(0.0056)	(0.2200)
(L-ΔPG) x (Birth in 3rd Trim After NucShut)	0.0073*	0.2456
	(0.0043)	(0.1553)
(L-ΔPG) x (Birth in 4th+ Trim After NucShut)	0.0007	0.0421
	(0.0048)	(0.1861)
Observations	55,921	55,921
R-squared	0.1160	0.1123

Notes: Standard errors clustered by county and month/year in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 16: Response of Power Generation and Pollution - Coal - Placebo

Dep Var RHS Var	Class of ΔPG	GenCoal DNucShut (1)	ln(GenCoal) DNucShut (2)	GenCoal GenNuc (3)	TSP DNucShut (4)	ln(TSP) DNucShut (5)
Paradise	H-ΔPG	-229,856**	-0.2757	-0.0144	-3.99	-0.10
		(91,777)	(0.2126)	(0.1294)	(3.68)	(0.08)
Cumberland	M-ΔPG	349,560**	0.5208**	-0.0451	-0.43	-0.03
		(136,241)	(0.2423)	(0.0893)	(3.17)	(0.07)
Johnsonville	L-ΔPG	59,272	0.2374	-0.0640*	5.89	0.10
		(53,633)	(0.1793)	(0.0359)	(3.62)	(0.08)
Shawnee	L-ΔPG	-126,638*	-0.2450	-0.1251*	1.40	0.01
		(67,324)	(0.1977)	(0.0656)	(4.03)	(0.08)
Widows Creek	L-ΔPG	-19,380	0.0690	-0.1348**	9.03***	0.19***
		(89,731)	(0.3533)	(0.0616)	(2.91)	(0.07)
Colbert	L-ΔPG	68,904	0.2317	-0.1199***	9.54***	0.20***
		(59,458)	(0.1761)	(0.0376)	(3.29)	(0.07)
Kingston	L-ΔPG	67,233	0.1622	-0.2141**	7.28**	0.12
		(101,802)	(0.2338)	(0.0859)	(3.07)	(0.07)
Bull Run	Control	63,552	0.4164	0.0747	10.28**	0.18*
	(N-ΔPG)	(115,522)	(0.2787)	(0.0815)	(5.21)	(0.11)
Allen	Control	50,704	0.2542	-0.0392	2.84	0.04
	(N-ΔPG)	(54,897)	(0.2265)	(0.0396)	(3.65)	(0.07)
John Sevier	Control	15,272	0.1185	-0.0080	10.89***	0.21**
	(N-ΔPG)	(58,540)	(0.1815)	(0.0416)	(4.12)	(0.09)
Gallatin	Control	78,767	0.2162	-0.0793	23.06***	0.44***
	(N-ΔPG)	(65,619)	(0.1979)	(0.0556)	(6.91)	(0.13)
Pooled		57,228	0.1652	-0.0676**	9.37***	0.20***
		(60,272)	(0.1667)	(0.0294)	(2.53)	(0.06)
F-tests		Sum = 0GWh		Sum = -0.30MWh	Corr((1),(4))	
F-stat		0.46		2.48	0.20	
Prob > F-stat		0.4993		0.1162	R^2 LRM: 0.04	
Observations		444	416	444	416	416

Notes: Newey-West standard errors with three lags in parentheses. (ΔNucPG ≈ −22.88GWh vs. −1776.25GWh)
*** p<0.01, ** p<0.05, * p<0.1

Table 17: Response of Birth Weight and Weeks of Gestation - Placebo

Dep Var	ln(BWeight) (1)	BWeight (2)	ln(GWeeks) (3)	GWeeks (4)
H-ΔPG	-0.0058	-19.5320	-0.0058	-0.2465
	(0.0228)	(61.6835)	(0.0062)	(0.2315)
M-ΔPG	-0.0185	-49.9580	-0.0058	-0.2226
	(0.0178)	(46.5109)	(0.0094)	(0.3475)
L-ΔPG	0.0016	-0.7460	-0.0076*	-0.2774*
	(0.0158)	(40.5463)	(0.0044)	(0.1647)
All Controls	Yes	Yes	Yes	Yes
Observations	56,334	56,334	56,334	56,334
R-squared	0.4538	0.3627	0.1243	0.1227

Notes: Standard errors clustered by county and month/year in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 18: Response of Birth Weight and Weeks of Gestation - Trimesters - Placebo

Dep Variable	ln(BWeight) (1)	BWeight (2)	ln(GWeeks) (3)	GWeeks (4)
(H-ΔPG) x (Birth in 1st Trim After NucShut)	-0.0069	-38.5282	0.0024	0.0627
	(0.0297)	(90.7896)	(0.0079)	(0.2899)
(H-ΔPG) x (Birth in 2nd Trim After NucShut)	-0.0081	-14.4035	-0.0018	-0.0188
	(0.0334)	(116.8861)	(0.0162)	(0.6497)
(H-ΔPG) x (Birth in 3rd Trim After NucShut)	0.0089	36.6813	-0.0084	-0.3526
	(0.0274)	(73.4484)	(0.0103)	(0.3638)
(H-ΔPG) x (Birth in 4th+ Trim After NucShut)	0.0021	-4.8799	-0.0058	-0.2576
	(0.0352)	(90.5206)	(0.0101)	(0.3774)
(M-ΔPG) x (Birth in 1st Trim After NucShut)	-0.0210	-87.1880	-0.0004	-0.0583
	(0.0226)	(80.0795)	(0.0196)	(0.7015)
(M-ΔPG) x (Birth in 2nd Trim After NucShut)	0.0137	58.8380	-0.0263	-1.0152
	(0.0260)	(93.6562)	(0.0183)	(0.7226)
(M-ΔPG) x (Birth in 3rd Trim After NucShut)	-0.0298	-88.6636	-0.0043	-0.1595
	(0.0312)	(85.5410)	(0.0118)	(0.4472)
(M-ΔPG) x (Birth in 4th+ Trim After NucShut)	-0.0280	-66.3213	-0.0049	-0.1726
	(0.0226)	(59.5935)	(0.0067)	(0.2518)
(L-ΔPG) x (Birth in 1st Trim After NucShut)	0.0024	1.2691	-0.0037	-0.1336
	(0.0241)	(60.6561)	(0.0051)	(0.1923)
(L-ΔPG) x (Birth in 2nd Trim After NucShut)	-0.0017	-17.4828	-0.0113**	-0.3959*
	(0.0140)	(38.5276)	(0.0055)	(0.2045)
(L-ΔPG) x (Birth in 3rd Trim After NucShut)	-0.0037	-10.6525	-0.0097**	-0.3791**
	(0.0144)	(45.2353)	(0.0044)	(0.1509)
(L-ΔPG) x (Birth in 4th+ Trim After NucShut)	0.0135	35.3797	-0.0023	-0.0523
	(0.0231)	(59.0829)	(0.0080)	(0.2981)
Observations	56,334	56,334	56,334	56,334
R-squared	0.4538	0.3627	0.1243	0.1227

Notes: Standard errors clustered by county and month/year in parentheses.

*** p<0.01, ** p<0.05, * p<0.1