DISCUSSION PAPER SERIES

IZA DP No. 9884

# Canary in a Coal Mine: Infant Mortality, Property Values, and Tradeoffs Associated with Mid-20th Century Air Pollution

Karen Clay
Joshua Lewis
Edson Severnini

April 2016

Forschungsinstitut
zur Zukunft der Arbeit
Institute for the Study
of Labor

# Canary in a Coal Mine: Infant Mortality, Property Values, and Tradeoffs Associated with Mid-20th Century Air Pollution

**Karen Clay**
*Carnegie Mellon University and NBER*

**Joshua Lewis**
*University of Montreal*

**Edson Severnini**
*Carnegie Mellon University and IZA*

Discussion Paper No. 9884
April 2016

IZA

P.O. Box 7240
53072 Bonn
Germany

Phone: +49-228-3894-0
Fax: +49-228-3894-180
E-mail: iza@iza.org

Any opinions expressed here are those of the author(s) and not those of IZA. Research published in this series may include views on policy, but the institute itself takes no institutional policy positions. The IZA research network is committed to the IZA Guiding Principles of Research Integrity.

The Institute for the Study of Labor (IZA) in Bonn is a local and virtual international research center and a place of communication between science, politics and business. IZA is an independent nonprofit organization supported by Deutsche Post Foundation. The center is associated with the University of Bonn and offers a stimulating research environment through its international network, workshops and conferences, data service, project support, research visits and doctoral program. IZA engages in (i) original and internationally competitive research in all fields of labor economics, (ii) development of policy concepts, and (iii) dissemination of research results and concepts to the interested public.

IZA Discussion Papers often represent preliminary work and are circulated to encourage discussion. Citation of such a paper should account for its provisional character. A revised version may be available directly from the author.

IZA Discussion Paper No. 9884
April 2016

# ABSTRACT

## Canary in a Coal Mine: Infant Mortality, Property Values, and Tradeoffs Associated with Mid-20th Century Air Pollution*

Pollution is a common byproduct of economic activity. Although policymakers should account for both the benefits and the negative externalities of polluting activities, it is difficult to identify those who are harmed and those who benefit from them. To overcome this challenge, our paper uses a novel dataset on the mid-20th century expansion of the U.S. power grid to study the costs and the benefits of coal-fired electricity generation. The empirical analysis exploits the timing of coal-fired power plant openings and annual variation in plant-level coal consumption from 1938 to 1962, when emissions were virtually unregulated. Pollution from the burning of coal for electricity generation is shown to have quantitatively important and nonlinear effects on county-level infant mortality rates. By 1962, it was responsible for 3,500 infant deaths per year, over one death per thousand live births. These effects are even larger at lower levels of coal consumption. We also find evidence of clear tradeoffs associated with coal-fired electricity generation. For counties with low access to electricity in the baseline, increases in local power plant coal consumption reduced infant mortality and increased housing values and rental prices. For counties with near universal access to electricity in the baseline, increases in coal consumption by power plants led to higher infant mortality rates, and lower housing values and rental prices. These results highlight the importance of considering both the costs and benefits of polluting activities, and suggest that demand for policy intervention may emerge only when the negative externalities are significantly larger than the perceived benefits.

JEL Classification: N32, N52, N72, N92, Q40, Q48, Q53, Q56, I15, J24, J30, R11

Keywords: mid-20th century air pollution, coal-fired electricity generation, infant mortality, housing values, tradeoffs

Corresponding author:

Edson Severnini
Heinz College
Carnegie Mellon University
4800 Forbes Ave
Pittsburgh, PA 15213
USA
E-mail: ersevernini@gmail.com

---

* We thank Martha Bailey, Antonio Bento, Claudia Goldin, Michael Greenstone, Walker Hanlon, Matthew Kahn, Nicolai Kumino, Gary Libecap, Granger Morgan, Joseph Shapiro, and seminar participants at Carnegie Mellon, Oxford, LSE, RAND, UCLA, Warwick, U.S. EPA, Yale, the 2015 NBER Summer Institute (Children, DAE), 3rd Northeast Workshop on Energy Policy and Environmental Economics, 10th Meetings of the Urban Economics Association, 15th Occasional Workshop in Environmental and Resource Economics at UCSB, 27th Conference of the ISEE, 50th Meetings of the CNEH, 3rd Economics of Low-Carbon Markets Workshop at USP, 37th Meetings of the Brazilian Econometric Society, the 61th North American Meetings of the RSAI, and the 2015 PAA Meetings for valuable comments and suggestions.

# 1 Introduction

Pollution is a negative externality associated with many economic activities. When considering corrective policies, two questions are particularly relevant: First, how large are the externalities? Second, how do the negative externalities compare to the benefits from the economic output? These questions are critical for evaluating both the potential benefits of intervention and whether corrective policies are likely to be adopted. Despite their importance, our understanding of these tradeoffs is limited because of issues related to data availability, identification, and the fact that it is often difficult to identify those who are harmed by polluting activities and those who directly benefit from them.

The expansion of the power grid in the U.S. around mid-20th century presents a unique opportunity to examine these issues. First, coal-fired electricity generation was associated with clear tradeoffs: the benefits from electricity access versus the health costs of unregulated emissions. As in many developing countries today, access to electricity in the U.S. was far from universal in this period.[1] Second, because of the sector's reliance on coal, electricity was an important contributor to local air pollution (Hales, 1976). By mid-century the electricity industry was the leading source of domestic coal consumption. Prior to the passage of the Clean Air Act in 1963 there was little pollution mitigation by coal-fired power plants. Third, given limitations in transmission, many of the households that benefited from electricity access were directly exposed to emissions from coal-fired power plants. This unique feature implies that a well-defined population faced both the benefits and costs of coal-fired generation. Fourth, the opening of a large number of coal-fired power plants in the 1940s and 1950s allows for credible estimation of the impact of local air pollution on infant mortality during a period in which air pollution was severe, unregulated, and not systematically monitored.[2]

---

[1] One-quarter of U.S. households did not have electricity in 1940. In addition to the expansion in electricity access, this period also witnessed a substantial increase in electricity consumption per capita.

[2] Periodic readings during the mid-20th century indicate that the concentration of total suspended particulates (TSP) might have been more than 10 times higher than standards initially set out under the 1970 Clean Air Act Amendments.

Drawing on newly digitized power plant-level data as well as data on infant mortality and housing prices, this paper examines the negative externalities and tradeoffs associated with air pollution during the period 1938-1962. Our main focus is on infant mortality, because infants are very sensitive to environmental pollution, and their health is more reflective of contemporaneous air pollution than other populations. The analysis begins in 1938, the first year for which detailed power plant-level data is available, and ends in 1962, the year prior to the passage of the Clean Air Act. The power plant-level panel dataset includes detailed information on location, capacity, generation, and fuel consumption, covering a large percentage of U.S. electricity generation.[3] Information on the location of power plants makes it possible to match plants to county-level outcome variables such as infant mortality and housing and rental values. Further, it permits the construction of aggregate coal consumption and capacity within specific distances of county centroids. The resulting dataset includes almost 2,000 counties. The power plant dataset is also linked to air quality measures for 75 counties between 1957 and 1962.[4]

To establish the link between coal-fired power generation and mortality, we exploit (i) the timing of power plant openings, and (ii) the annual variation in plant-level coal consumption and generating capacity. The first strategy relies on the opening of 272 coal-fired power plants between 1938 and 1962. The opening of a power plant expanded access to electricity for counties within 90 miles, but pollution tended to be concentrated locally, within 30 miles. The analysis compares the relative outcomes in counties within this radius to outcomes in counties slightly farther away, before and after a plant opening. The second empirical strategy exploits spatial and temporal variation in the total annual coal consumption and generating capacity by electric utilities within a 30 mile radius of each county, in a fixed effects framework. Importantly, we estimate these models across different levels of baseline electricity access, which allows us to disentangle the costs of air pollution from the

---

[3] Information is available for all power plants with at least 2.5 MW of nameplate capacity. In 1962, the sample covers 94 percent of total generation of steam-electricity in the U.S.

[4] Monitoring of air pollution began in 1953. Coverage became wider and more systematic in 1957, but the network was still sparse.

local benefits of electricity access, and to evaluate the tradeoffs associated with coal-fired generation for infant mortality, and housing and rental values.

We find that there were substantial negative health externalities associated with the expansion of the power grid in the U.S. during the mid-20th century. Our preferred estimates imply that the rise in coal-fired electricity generation between 1938 and 1962 was responsible for over 35,000 infant deaths. By 1962, there around 3,500 infant deaths per year, more than one infant death per thousand live births. For reference, the infant mortality rate in the U.S. in 2010 was 6.1 deaths per thousand live births (CDC, 2013). We also find that the marginal impact of coal consumption on infant mortality was larger at lower levels of pollution, consistent with previous research on the concavity (or 'supralinearity') of the concentration-response function (Goodkind, Coggins, and Marshall, 2014; Pope III et al., 2015). These results suggest that the initial health effects of clean air initiatives may understate their longer-term benefits, as a country moves further down the concentration-response function.

Our estimates point to clear tradeoffs associated with local coal-fired electricity generation. In particular, we find that the negative effects of power plant emissions were offset by the health benefits of increased electricity access. In counties with a lower proportion of household with electricity access in the baseline, increased coal consumption reduced infant mortality. In counties with higher levels of access, expansions in coal consumption increased mortality. These relationships were mirrored in the housing market. Local coal consumption had positive and statistically significant effects on housing prices at lower levels of access and negative and statistically significant effects at high levels of access. Together these findings suggest that households traded-off the costs of coal-fired emissions against the benefits of electricity access.

This paper makes two key contributions to the literature. First, it examines the negative health externalities of severe, unregulated, and largely unmonitored air pollution. Previous work has focused on the post-Clean Air Act period, when pollution levels were significantly lower and less variable (Currie and Walker, 2011; Currie et al., 2015; Schlenker and Walker, forthcoming; and Severnini, 2015, for example). Given the wide spatial and temporal variation in air pollution during the mid-20th century, we are also able to provide new evidence on the shape of the concentration-response function, a relationship that has key implications for policy. Our empirical framework complements previous studies that evaluate the health effects of air pollution in settings in which air quality monitoring is unavailable (Clay and Troesken, 2011; Barreca, Clay and Tarr, 2014; Hanlon and Tian, 2015; and Hanlon, 2015, 2016).

Second, this study highlights how the negative externalities of air pollution can be offset by the benefits of the polluting activities. In our setting, increased electricity access associated with the expansion in coal-fired power generation led to improvements in infant health and increases in property values. A growing body of research has emphasized the benefits of electrification – for female employment (Dinkelman, 2011; Lewis, 2016), local development (Lipscomb, Mobarak, and Bahram, 2013; Severnini, 2014), agricultural output (Fishback and Kitchens, 2015; Lewis and Severnini, 2015), health (Lewis, 2015), and manufacturing productivity (Allcott, Collard-Wexler and O'Connell, 2016) – but has typically overlooked the environmental damage arising from emissions-intensive generation.

This paper proceeds as follows: Section 2 discusses the history of air pollution and the expansion of the electricity generation in the U.S. during the mid-20th century. Section 3 describes our data. Section 4 presents our empirical framework. Section 5 reports our findings, and Section 6 concludes.

# 2 Historical Background

## 2.1 Coal-Fired Electricity, Pollution, and Health

Coal-fired electricity generation rose substantially during the mid-20th century. Figures 1a and 1b report trends in electricity generation and U.S. coal consumption by source.

Between 1938 and 1962, the U.S. experienced a seven fold increase in electricity production, primarily driven by the expansion in coal-fired electricity generation.[5] Electric utilities became an increasingly important source of domestic coal consumption. Utility coal consumption increased from 38.4 million short tons in 1938 to 193.2 million short tons in 1962.[6] As a share of overall consumption, coal for electricity generation rose from 15 percent to 54 percent, as other uses such as coal for home heating and coal for railways declined.

Air quality in U.S. cities in the late 19th and early 20th centuries was so poor that it had become a significant source of public concern. Cities often passed legislation aimed at reducing pollution, although in most cases the legislation appears to have been ineffective.[7] Monitoring of air pollution was rare before the 1950s, but sporadic readings during the first half of the 20th century suggest that air pollution was severe and comparable to levels found in cities in developing countries today (Table A.1).

Coal-fired power plants were an important contributor to air pollution. Prior to the passage of the 1963 Clean Air Act, electric utilities did little to mitigate the consequences of air pollution. Experimentation with scrubbing did not begin until the late 1960s in the United States (Biondo and Marten, 1977). The height of power plant smokestacks – a key determinant of pollutant dispersion – was relatively constant from 1938 to 1962 and below current levels (see Figure A.1(a)). The primary mitigation of pollution came from siting plants farther from population centers, as advances in transmission technology allowed electricity to be shipped over longer distances (see Figure A.2). As transmission constraints eased, cost factors – such as local availability of fuel sources – played an increasingly important role

---

[5] Over this period, 125 GW of coal-fired capacity and 27 GW of hydroelectric capacity were added. Most of the growth occurred as new larger plants were built and older, smaller plants were taken offline. In fact, despite the larger increases in capacity, the total number of electric utility plants actually fell from 3,903 in 1938 to 3,435 in 1962 (United States Bureau of the Census, 1976, Series S53-54, p.822, 824).

[6] 97 percent of the coal used was bituminous coal. Anthracite coal by use is only reported beginning in 1954. In 1954 it was 3 percent and it remained low through 1962. United States Bureau of Mines, Minerals Yearbook (1958), Table 38 (anthracite), p. 188. Table 53 (bituminous), p. 102.

[7] In 1912, the Bureau of Mines reported that 23 of 28 cities with populations over 200,000 were trying to combat smoke, the remaining five used relatively little coal and so were not significantly affected (Goklany, 1999, p. 15). Dozens of smaller cities also passed legislation (see Table A.2 for a summary of smoke abatement legislation prior to 1930).

in power plant site selection. Similarly, the desire to integrate the grid across markets led to the siting of plants in locations accessible to multiple markets. However, there is little evidence that concerns over public health played a significant role in this trend.

The combustion of coal produces a number of air pollutants, such as sulfur dioxide, nitrogen oxides, and particulate matter that are harmful to both infant and adult health.[8] Particle pollution tends to be locally concentrated. Figure 2a plots the average density of PM2.5 by distance to the source, based on study of nine large power plants in Illinois in 1998 (Levy et al., 2002).[9] The relationship between distance and PM2.5 exposure was highly nonlinear. Over 40 percent of PM2.5 exposure occurred within 30 miles of the plant; less than 20 percent occurred at a distance between 30 and 90 miles. When differences in land area are taken into account, these differences are even starker: the average resident within 30 miles of a plant was exposed to concentrations that were 11 times greater than the average resident located between 30 and 90 miles from a plant. This dispersion pattern is consistent with more recent estimates by the EPA. In 2011, the EPA found that emissions from the coal-fired Portland Generating Station led to violations of the National Ambient Air Quality Standards (NAAQS) in counties up to 40 miles away (EPA, 2011).

Coal-fired electricity generation also offered benefits to the local population. In 1940, roughly one quarter of households in the U.S. did not have electricity. Much like the developing world today, electricity brought a range of new household technology including pumped running water, lights, and modern appliances. These innovations reduced the burden of household hygiene by making it easier to keep people, clothes, dishes, and the general environment clean, and electricity access has been linked to reduction in infant mortality (Gohlke et al., 2011; Lewis, 2015). Expansion of electricity generation had additional benefits

---

[8] See Chay and Greenstone (2003a, 2003b), Currie and Neidell (2005), and Currie et al. (2014) for the effects on infant mortality; Pope III et al. (1992), Samet et al. (2000), Clancy et al. (2002), Medley et al. (2002), Pope III et al. (2002), Pope III et al. (2004), Pope III et al. (2007) Clay and Troesken (2011), and Gohlke et al. (2011) for the effects on all-age mortality. For infants, health is affected through both prenatal exposure (Currie and Walker, 2011), and postnatal exposure (Woodruff et al., 2008; Arceo-Gomez et al., 2012).

[9] These grandfathered power plants were not subject to emissions regulation. Average stack height for these plants was 132 meters, slightly higher than those in our sample.

on the intensive and extensive margins for industry, farming, and medical care.

Figure 2b provides evidence on the relationship between power plant openings and electricity access. The figure plots the regression estimates from a fixed effects model relating the fraction of households with electricity to the opening of large coal-fired power plants, by county-centroid distance to the plant.[10] The benefits of electricity access were locally concentrated. Electrification rates increased by 7 percentage points for residents within 60 miles of a power plant. Beyond 60 miles, the impact on electricity access decreased monotonically with distance, consistent with historical limitations in transmission. Importantly, the spatial distribution over who benefited from increased electricity access is distinct from the spatial distribution of pollution exposure. This distinction will allow us to disentangle the health costs associated with pollution from the benefits associated with electricity production.

## 2.2 Tradeoffs Associated with Coal-Fired Electricity Generation

Coal-fired electricity generation contributed to local air pollution but also brought residents the benefits associated with increased electricity access. As electricity was extended to virtually all households by the mid-1950s, the marginal benefits of increases in coal-fired capacity decreased. In contrast, in the absence of pollution abatement, there were health costs associated with the burning of coal by electric utilities throughout the sample period. Figure 3 illustrates the benefit-cost tradeoffs of increased coal-fired electricity generation as a function of electricity access.[11] The opening of a coal-fired power plant should have two opposing effects on infant mortality and on local housing prices. On the one hand, increased availability of electricity will tend to decrease infant mortality and increase housing values. On the other hand, increases in air pollution will tend to increase infant mortality and decrease housing prices. In locations where electricity access is widespread, the costs

---

[10] The model is estimated for the years 1940, 1950, and 1960. The dependent variable is the fraction of households with electrical services. The econometric specification includes county and state-by-year fixed effects, and four bins for distance to the nearest power plant in each year: within 30 miles, 30-60 miles, 60-90 miles, and 90-120 miles. The omitted bin is more than 120 miles.

[11] In Appendix A.2, we present a conceptual framework that formalizes the tradeoffs.

of additional power plant pollution will be more likely to overwhelm marginal benefits of expanding access.

The response in the housing market may or may not fully capture the tradeoffs associated with coal-fired electricity. In the hedonic model, the local housing price response identifies household's willingness-to-pay for electricity access and air quality.[12] If residents are poorly informed about the health effects of air pollution, however, the hedonic estimates will not reflect the true benefits and costs of coal-fired electricity generation. Information in this context is likely to have been poor. Highly publicized events, such as the 1948 Donora smog and the 1952 London fog, enhanced public awareness of the relationship between air pollution and health. Nevertheless, epidemiological evidence on health effects of daily exposure to more moderate levels of air pollution did not emerge until the 1970s (Lave and Seskin, 1970, 1972).

# 3 Data

Our data are drawn from four main sources: Federal Power Commission reports on power plants, county-level infant and all age mortality rates from the *Vital Statistics of the United States*, housing and rental values, and other county-level covariates available in the Censuses of Housing and Population, and air quality monitor data from the EPA.

## 3.1 Power Plant Data

In 1938 the Federal Power Commission began collecting annual information on steam-electric power plants. The reports provide detailed information on the operations of roughly 500 of the largest power plants in the U.S., representing 90 percent of all power plant coal consumption nationwide (FPC, 1947, 1948-1962). Information was collected on power plant capacity, electricity generation, fuel consumption, and other characteristics.[13] We digitized

---

[12] There is a large literature that uses the hedonic price method to estimate the economic value of non-market amenities, such as electricity access and clean air. See Ridker and Henning (1967), Rosen (1974), and Chay and Greenstone (2005), for example.

[13] In Appendix A.3, we show a page of the 1957 report as an example.

annual data on the total nameplate capacity and the total amount of coal burned by plant for the period 1938 to 1962. We also digitized information on the first year of operation for 272 coal-fired power plants that opened between 1938 and 1962. This data is combined with information on the location of power plants, which we have digitized from a set of seven maps conducted by the Federal Power Commission in 1962 (FPC, 1962). Power plants are linked to counties based on latitude and longitude.

The first empirical strategy relies on a dataset of pairwise combinations of power plants and county-level outcomes. For each power plant opening, treatment status is assigned based on county-centroid distance to the plant. Based on the pollution transport literature, a treatment radius of 30 miles was chosen. Control counties are located between 30 and 90 miles. Households within these control counties also benefited from increased access to electricity, but were exposed to markedly different levels of air pollution (see Section 2.1 for a discussion). To ensure a balanced sample of control counties, we restrict the control group to counties that were not within 30 miles of a power plant at any point between 1938 and 1962.

The second estimation strategy relies on local exposure to power plant coal consumption, independently of the particular plant responsible for the emissions. Information on power plant coal consumption and capacity is totaled within a 30-mile radius of each county centroid. The data are collapsed to a county-year observation. Exposure is measured as total annual power plant coal consumption (in 100,000s of tons) or coal-fired capacity (in MWs) within 30 miles of the county-centroid. The final sample is a balanced panel of 1,983 counties that were located within 120 miles of an operational coal-fired power plant at some point between 1938 and 1962.[14]

---

[14] This sample restriction excludes counties for which power plants had negligible effects on air quality or electricity access. In Table A.5, we examine the sensitivity of the results to this cutoff.

## 3.2 Vital Statistics Data

The health outcome variables are drawn from annual volumes of the *Vital Statistics of the United States.*[15] The primary outcome is the infant mortality rate (per 1,000 live births). Given the low migration rates of pregnant women and infants, the focus on infant mortality should limit misspecification caused by the fact that current pollution concentrations at a particular location may not reflect lifetime exposure. Effects found for infant mortality also represent substantial losses in terms of life expectancy, whereas effects of air pollution on adult mortality are typically concentrated among the elderly and very ill, and may represent smaller losses in actual life expectancy than is often suggested by the literature (see Currie et al., 2014).

## 3.3 Housing Values and Additional Covariates

To study the effects of power plant emission on the housing market, we rely on county-level property values from the Census of Housing for 1940 to 1960 (Haines and ICPSR, 2010; DOC and ICPSR, 2012). Our main outcomes of interest are (decadal) median dwelling value and (decadal) median dwelling rent.

Additional variables are used as controls in the analysis. "Geography" variables include county-centroid latitude and longitude, and annual precipitation, temperature, degree days below 10 degrees Celsius, and degree days above 29 degrees Celsius. "Economy" covariates include total population, total employment, and manufacturing employment in 1940, available in the Census of Housing and Census of Manufactures (1940). The 1940 Census of Housing also reports information on the proportion of households with electric lighting, which is used as a proxy for baseline electricity access. This variable is also used to explore the extent to which the benefits and negative externalities of coal-fired electricity generation varied with initial electricity access. We split U.S. counties into two bins – above median (H)

---

[15] Price Fishback et al. (s.d.) generously provided the data from 1938-1951. We digitized additional data for the period 1952-1958 (HEW, 1952-1958), and assembled the available microdata at the county level for the period 1959-1962 from the NBER Public Use Data Archive.

and below median (L) – according to baseline electricity access.[16] There were wide differences in electricity access across the two groups of counties: the mean baseline electrification rates were 55 and 96 percent for the low and high bins, respectively.

## 3.4 Summary Statistics

The first empirical strategy relies on the opening of 272 power plants. Table 1 reports the summary statistics for the sample. There are 728 counties located within a 30-mile radius circle of a new power plant. These counties form the basis of the treatment group in the empirical analysis. There are 1,196 counties located between 30 and 90 miles from a plant (Figure A.3 displays the map of treatment and control counties that are used in the analysis). This group serves as the control group, since dispersion of particulates is primarily concentrated within 30 miles. In the empirical analysis, we examine whether the health impact of power plant openings varied by plant size. We identify small and large power plants as those operating with less than and greater than 75 MW of nameplate capacity, respectively.[17] At the time of opening, there were 138 large power plants and 134 small power plants. Of the latter, 75 were upgraded to large plants during the sample period.[18] The average large power plants had 147 MW of nameplate capacity and burned 710,000 tons of coal per year. In contrast, the average small power plant had only 15 MW of nameplate capacity and burned 90,000 tons of coal per year. This heterogeneity in the amount of pollution being produced across these two types of power plants will be exploited in the empirical analysis.

Panels B and C of Table 1 report summary statistics across treatment and control counties. Treatment counties were located closer to a power plant and were exposed to 15 times more power plant coal consumption and coal-fired capacity than control counties. These

---

[16] The sample is split evenly between the two bins in an effort to improve the precision in the mortality regressions (weighted by the number of county births).

[17] Figure A.1(b) reports average size of coal-fired power plants by initial year of operation.

[18] These plants are categorized as small in years when capacity was below 75 MW and large in years when capacity was above 75 MW.

differences in exposure were driven primarily by counties located near a large power plant. Despite the high levels of pollution exposure, treatment counties had slightly lower infant mortality rates. Treatment and control counties differed according to baseline economic characteristics. Treatment counties had higher initial access to electrical services, were more populous, and had higher levels of manufacturing activity. Importantly, we exploit several years of pre-treatment data, to assess the common trends assumption.

Table 2 reports the summary statistics for the sample of 1,983 counties that form the basis of the second empirical strategy. The sample is split according to counties with high and low baseline electricity access. High baseline electricity counties had lower infant mortality rates, higher property values and wages, and a greater share of white residents and residents with a high school diploma. These counties were also more populous and had a larger manufacturing sector. Coal consumption and coal-fired capacity was roughly 10 times higher in these high electricity access counties.

# 4 Empirical Strategy

Our empirical strategy involves two different, complementary approaches. First, we exploit the openings of coal-fired power plants to estimate the impact on infant mortality for the period 1938 to 1962. Second, we estimate regressions based on annual variation in power plant coal consumption and capacity. These fixed effect models are used to estimate the impact on infant mortality for the period 1938 to 1962, and to assess how the tradeoffs for infant mortality are capitalized into the housing markets in decadal years 1940, 1950, and 1960.

## 4.1 Analysis Based on the Opening of Power Plants

Our first empirical approach relies on the opening of coal-fired power plants. The analysis relies on 272 coal-fired power plants that opened between 1938 and 1962. We adopt a difference-in-differences strategy that compares health outcomes in counties "near" a power plant to counties slightly farther away. We define counties within 30 miles of a power plant as treatment counties, and counties 30-90 miles as control counties.[19] Given the nonlinear and highly localized dispersion of particulate matter, residents in treatment and control counties would have been exposed to markedly different levels of air pollution following a power plant opening despite enjoying similar benefits from increased electricity access (see Figures 2a and 2b). Thus, the research design identifies the health impact of a power plant opening net of the benefits associated with greater electricity access.

We match county-power plant pairs based on longitude and latitude, and estimate the relationship between power plant openings and infant mortality according to the following econometric model:

$$\begin{aligned} IMR_{cpt} = \alpha + \beta \cdot 1[PPOpen]_{pt} + \gamma \cdot 1[Near]_{cp} + \delta \cdot \left(1[PPOpen]_{pt} \times 1[Near]_{cp}\right) \\ + \psi X_{cpt} + \theta_t Z_{cp} + \eta_{cp} + \lambda_{st} + \epsilon_{cpt} \end{aligned} \tag{1}$$

where $IMR_{cpt}$ denotes infant mortality rate in county $c$ associated with plant $p$ in year $t$. For each plant, there are two types of observations per year: treatment counties (within 30 miles of the plant) and control counties (30-90 miles from the plant).

The variable $1[PPOpen]_{pt}$ is an indicator for whether plant $p$ is operating in year $t$, and $1[Near]_{cp}$ is equal to one for counties within 30 miles of a plant site. The model includes a vector of county-plant pair fixed effects, $\eta_{cp}$, to control for time-invariant determinants of infant mortality at a given distance from each plant.[20] It also includes a vector of state-by-year fixed effects, $\lambda_{st}$, to control for state-level trends in infant mortality that may be related to unobserved time-varying determinants of health that differed across states. $X_{cpt}$ represents a set of time-varying covariates for geography (annual precipitation, temperature,

---

[19] In Table A.3, we report results based on the sub-sample of control counties located in the ring 30-60 miles of a power plant. These results are similar to the baseline findings.

[20] In practice, the treatment indicator, $1[Near]_{cp}$, is collinear with the county-plant pair fixed effects, $\eta_{cp}$.

degree days below 10 degrees Celsius, and degree days above 29 degrees Celsius). The term $\theta_t Z_{cp}$ denotes a vector of year fixed effects interacted with geographic characteristics (county-centroid longitude and latitude) and baseline economic conditions (total population, total employment, and manufacturing employment in 1940).[21]

The parameter of interest, $\delta$, is the coefficient on the interaction term, $1[PPOpen]_{pt} \times 1[Near]_{cp}$. Because equation (1) includes the vector of county-plant pair fixed effects, $\eta_{cp}$, this parameter is identified by the timing of the opening of power plants. It captures the differential impact of a plant opening on infant mortality rates across treatment and control counties.

The estimates of $\delta$ capture the average health impact across the sample of 272 plants that opened between 1938 and 1962. These average treatment effects mask substantial differences in the amount of coal that was burned post-opening. Figure 4 plots average annual coal consumption and generating capacity for power plants above and below 75 MW of nameplate capacity. In the first year of operation, large plants burned six times more coal than smaller plants, and this gap widened over time as the larger plants expanded production and brought additional generating capacity online. To take advantage of this additional source of variation, we estimate a refined version of equation (1) in which the term $1[PPOpen]_{pt}$ is replaced by two separate indicators $1[SmallPPOpen]_{pt}$ and $1[LargePPOpen]_{pt}$. The term $1[SmallPPOpen]_{pt}$ is equal to one in all years when a power plant in operation is small ($<$75 MW) and zero otherwise. Likewise, the term $1[LargePPOpen]_{pt}$ is equal to one in all years when a plant in operation is large ($>$75 MW) and zero otherwise. The two parameters of interest, $\delta^{Small}$ and $\delta^{Large}$, are not constrained to be equal, which allows us to compare the health impacts across power plants that burned widely different amounts of coal on

---

[21] Equation (1) includes three additional covariates: (i) the distance between the county centroid and power plant interacted with year fixed effects, to allow for trends in mortality by county-plant distance, ensuring that the estimates are driven by sharp differences in pollution exposure around the treatment boundary; (ii) annual nameplate capacity of each power plant to ensure that identification relies solely on the timing of power plant openings; and (iii) the fraction of households with electricity in 1940 interacted with year fixed effects, to allow for differential trends based on initial electricity infrastructure.

average.[22]

All regressions are weighted by the number of live births. Robust standard errors are clustered at the county-level to adjust for heteroskedasticity and within-county serial correlation.

## 4.2 Analysis Based on Annual Variation in Power Plant Coal Consumption and Capacity

The second empirical strategy exploits spatial and temporal variation in annual coal consumption and coal-fired capacity of power plants. We regress outcome $Y$ – infant mortality, median rental rates, median housing values, and wages – in county $c$ in year $t$ on local power plant coal consumption or capacity, $Coal_{ct}$, county fixed effects, $\eta_c$, and state-by-year fixed effects, $\lambda_{st}$. The model includes a vector of time-varying covariates for geography, $X_{ct}$ (annual precipitation, temperature, degree days below 10 degrees Celsius, and degree days above 29 degrees Celsius), and time-invariant county controls, $Z_c$ (longitude and latitude, total population, total employment, and manufacturing employment in 1940), interacted with year fixed effects. The estimating equation is given by

$$Y_{ct} = \alpha + \beta \cdot Coal_{ct} \ + \psi X_{ct} + \theta_t Z_c + \eta_c + \lambda_{st} + \epsilon_{ct}. \tag{2}$$

The term $Coal_{ct}$ denotes either the total annual power plant coal consumption (in 100,000s of tons) or total capacity of coal-fired plants (in 100s of MWs) within 30 miles of the county-centroid. Because pollution abatement technologies were only first adopted in the late 1960s, there is a direct link between power plant coal consumption and emissions. Given the strong relationship between plant size and coal consumption, coal-fired capacity should also be related to annual plant emissions. The coefficient of interest, $\beta$, captures

---

[22] This interaction is defined on the basis of nameplate capacity rather than annual coal consumption to mitigate concerns that the categorization of power plant size is the result of potentially endogenous changes in local demand for electricity. See Figure 4 for trends in coal-fired capacity and coal consumption post-opening.

the change in health or property value outcome associated with a change in local coal-fired electricity production.

The identifying assumption requires that annual changes in local power plant capacity and coal consumption be unrelated to unobserved time-varying determinants of infant health and property values. Equation (2) allows for differential trends according to baseline economic activity to limit concerns that local economic conditions simultaneously affected health, property values, and the demand for electricity. Importantly, the model is estimated using annual variation in coal consumption or capacity. Although plant-level coal consumption may respond to short-term demand fluctuations, changes in capacity – from either the construction of a new plant or additions to existing capacity – required a multi-year planning process, and were typically made on the basis of 20 to 30 year forecasts of demand (EIA, 2010).

The parameter $\beta$ captures a combination of the health costs of power plant emissions and the economic benefits of increased electricity access. In an effort to disentangle these competing factors, and evaluate the tradeoffs associated with coal-fired power generation, we estimate a generalized version of the model in which the main effect is allowed to vary according to baseline electricity access. The term $Coal_{ct}$ is interacted with $H - Electricity_c$ and $L - Electricity_c$, indicators for counties above and below median electricity access in 1940. The interaction parameters, $\beta_L$ and $\beta_H$, identify the net effects at different levels of initial electricity access. In high electricity counties, however, 96 percent of households had electrical services in 1940. Thus, $\beta_H$ primarily captures the negative health effects due to pollution from increased coal-fired generation. These effects should be comparable to the estimates of $\delta$ in equation (1) rescaled by the average change in coal consumption (or capacity) post-power plant opening.

Regressions for infant mortality are weighted by the number of county live births to estimate the average effect for an infant in the sample. Regressions for median rental rates, median housing values, and wages are unweighted to estimate the local economic response for the average county in the sample. Robust standard errors are clustered at the county-level to adjust for heteroskedasticity and within-county serial correlation.

# 5 Results

This section reports (i) the impact of power plant openings on infant mortality, (ii) the effects of power plant coal consumption and capacity on infant mortality, (iii) the shape of the coal-infant mortality relationship, and (iv) the differential effects of power plant coal consumption and capacity on infant mortality, property values, and wages according to initial levels of electricity access.

## 5.1 Effects of Coal-Fired Power Plant Openings on Infant Mortality

To motivate the regression analysis, and evaluate the validity of the common trends assumption of the difference-in-differences strategy, we first present event study graphs based on the timing of power plant openings. These graphs are based on a generalized version of equation (1), that allows the coefficients $\delta^{Small}$ and $\delta^{Large}$ to vary with event time $t \in \{-6, 6\}$.

Although this type of analysis is appealing, two caveats should be mentioned. First, the opening of a coal-fired power plant is not an instantaneous, one-time shock to air quality. Coal-fired power plants are major construction projects, and a non-negligible amount of pollution is produced prior to opening.[23] Moreover, because power plants generally scale up production in the years after opening, the treatment effect may increase with event time.[24] Second, the Federal Power Commission volumes do not report the first month of

---

[23] According to the EPA, "construction operations can substantially impact local air quality from suspended dust, equipment exhaust, and burning emissions." (EPA, 1999, p1-1). The construction times cited by the Federal Power Commission ranged from one to four years. Unfortunately, the Federal Power Commission reports do not provide information on start dates of individual power plant construction, so the health affects driven by power plant construction cannot be directly tested.

[24] This is typically due to both the increased utilization of initial capacity and the staggered nature of power plant construction, which results in new generating units being brought online in the years after

plant operation. As a result, the estimates of $\delta^{t=0}$ will understate the impact of power plant operations on mortality, since most plants polluted for only a fraction of their first year of operation.

Figures 5a and 5b report the event study coefficients $\delta^t$ for $t \in \{-6, 6\}$ for large ($\geq 75$ MW) and small (<75 MW) power plants.[25] For large plants, infant mortality rises sharply in the first full year of power plant operation, and the gap widens with event time. The timing of these increases coincides with the annual changes in power plant coal consumption post opening (see Figure 4). For small power plants, there is no evidence of a systematic change in infant mortality post-opening, consistent with the modest rise in coal consumption post opening. There is a slight rise in infant mortality in the two years prior to opening, consistent with a rise in air pollution associated with power plant construction. Importantly, Figures 5a and 5b support the underlying assumptions of the research design: there is little evidence of differential pre-treatment trends in infant mortality.

Table 3 reports the estimates from the difference-in-differences estimation strategy based on new power plant openings. Column 1 includes county-plant pair fixed effects and year fixed effects. Column 2 adds state-by-year fixed effects. Column 3 adds controls for manufacturing employment in 1940 interacted with year fixed effects, and column 4 includes the additional geographic and economic covariates. The table reports the coefficient estimates of $1[LargePPOpen]_{pt} \times 1[Near]_{cp}$ and $1[SmallPPOpen]_{pt} \times 1[Near]_{cp}$, which allows the effect of a power plant opening to vary by size.[26]

The results suggest that large coal-fired power plants led to substantial increases in infant mortality. The point estimates in columns (1) and (2) imply that a plant opening is associated with roughly 2 additional infant deaths per 1,000 live births in counties within 30 miles relative to counties 30-90 miles away from the plant, a 5-7 percent increase in the infant mortality rate. The inclusion of the manufacturing covariates in column (3) decreases

---

opening (see Figure 4).

[25] The plotted coefficients are identified off of a nearly balanced panel in event time. The endpoints ($t = -7$, $t = 7$) are not reported in the figures (see Kline, 2012).

[26] Table A.4 reports the results for the combined interaction effect, $1[PPOpen]_{pt} \times 1[Near]_{cp}$.

the point estimates by 40 percent, suggesting that power plant openings indirectly affected health by stimulating local manufacturing activity.[27] The point estimates decrease slightly when the additional economic, population, and geographic covariates are included. The results in column (4) suggest that a large power plant opening led to 0.8 additional infant deaths per 1,000 live births, a 3 percent increase in the infant mortality rate. For reference, the infant mortality rate from all causes was 6.1 deaths per 1,000 live births in 2010 (CDC, 2013). On the other hand, there is no evidence that the opening of a small power plant had any impact on local health. The point estimates in the second row are small and statistically insignificant, consistent with the differences in coal consumption across large and small power plants (see Figure 4).

The estimated effects on infant mortality are quantitatively important. Given the number of infants born in treatment counties post-opening, the preferred estimates (column 4 of Table 3) imply that pollution from the 213 large power plants led to 22,015 additional infant deaths during the sample period. On average, each large plant was responsible for 12 infant deaths per year of operation.

The difference-in-differences estimates can be rescaled by the typical capacity and annual coal consumption of a power plant post-opening. The estimates imply that a 100,000 ton increase in coal consumption is associated with a 0.155 increase in the infant mortality rate, and that a 100 MW increase in coal-fired capacity is associated with a 0.215 in the infant mortality rate in the counties most likely affected by the power plant emissions.[28] These

---

[27] If the opening of a power plant stimulated manufacturing activity, the estimates in column (2) capture both the direct impact of power plant pollution and the indirect impact of manufacturing emissions post-opening. The inclusion of baseline manufacturing employment interacted with year fixed effects allows for differential trends in infant mortality according to the manufacturing sector's importance in the baseline.

[28] To derive these calculations, we re-estimate equation (1) replacing the dependent variable with either total annual power plant coal consumption (in 100,000s of tons) or total capacity of coal-fired plants (in 100s of MWs) within 30 miles of the county-centroid. The point estimates (standard errors) of $\delta^{Large}$ are 5.08 (0.51) for coal consumption and 3.66 (0.34) for coal-fired capacity (the corresponding estimates for small plant openings are 1.91 (0.37) and 1.42 (0.22)). Rescaling the "intention to treat" effect of power plant openings on infant mortality in column (4) by these "first stage" effects, we calculate that a 100,000 ton increase in coal consumption is associated with a $0.7862/5.08 = 0.155$ increase in the infant mortality rate, and that a 100 MW increase in coal-fired capacity is associated with a $0.7862/3.66 = 0.215$ in the infant mortality rate in counties within 30 miles of a power plant opening. If power plant openings affected infant mortality primarily via their direct contribution to air pollution, these calculations can be interpreted as

calculations form a benchmark against which the parameter estimates of equation (2) can be compared.

## 5.2 Effects of Power Plant Coal Consumption and Coal-Fired Capacity on Infant Mortality

Table 4 reports the impact of annual variation in power plant coal consumption and capacity on infant mortality. Panel A reports the baseline specification based on annual variation on power plant coal consumption. The point estimates are all positive and statistically significant.[29] The inclusion of manufacturing covariates reduces the magnitude of the point estimates, although the decrease is somewhat smaller in these models than in Table 3. Panel B reports the effects of coal and hydroelectric capacity. Across all three specifications, coal-fired capacity is associated with large and statistically significant increases in infant mortality. Meanwhile, the point estimates for hydroelectric capacity are insignificant and typically smaller in magnitude. Given that hydroelectricity generation is emissions free, local air pollution appears to be the driving force behind these negative health effects.

The preferred estimates in column (3) of Panel A imply that a one standard deviation increase in power plant coal consumption is associated with a 1.4 additional infant deaths per 1,000 live births, a 4.6 percent increase in the infant mortality rate. This health impact is roughly half the size of the rescaled difference-in-differences estimate (0.085 versus 0.155). Given that the difference-in-differences strategy holds electricity access constant across treatment and control counties, it is not surprising that the fixed effects estimates are somewhat smaller in magnitude. If electricity access was beneficial to infant mortality, then the net health impact of an expansion in power plant coal consumption should be less negative than the effect driven solely by increased air pollution.

---

"IV" estimates.

[29] We also estimate positive and statistically significant effects for all-age mortality. These findings (available upon request) should be interpreted with caution, however, given that we are unable to control for prior pollution exposure in the adult population.

Figure 6a reports the total number of infant deaths in the sample counties that are attributable to coal consumption by electric utilities. The estimates are calculated separately based on the number of live births in 1938 and annual live births. Calculations based on the latter are substantially larger, given that the baby boom led to an increase in the number of infants potentially exposed to air pollution. In 1938, fewer than 500 infant deaths can be attributed to coal-fired electricity. As coal-fired generation ramped up in the 1950s, the health costs grew dramatically.[30] By the end of the sample period, the rise in coal consumption by electric utilities was responsible for an additional 3,500 infant deaths per year. Had coal-fired electricity generation remained at its 1938 level, we calculate that the infant mortality rate would have fallen by more than one infant death per 1,000 live births in 1962 (as shown in Figure 6b).

## 5.3 Nonlinearities in the Concentration-Response Function

The literature on the relationship between pollution and mortality suggests that the concentration-response function is nonlinear. In particular, a number of studies find the marginal effect of a change in air quality to be larger at lower levels of pollution (Goodkind, Coggins, and Marshall, 2014; Pope III et al., 2015). We examine nonlinearities in the effects of pollution on infant mortality, taking advantage of the wide variation in the quantity of coal being burned by power plants across locations in a period when emissions were unregulated and pollution levels were substantially higher.

To investigate nonlinearities in the relationship between coal consumption and infant mortality, we estimate a flexible specification of equation (2) that allows the effect of a marginal change in coal consumption to vary according to its level. The model is estimated using four bins of coal consumption: 0-3, 3-6, 6-9, and >9 (in 100,000s of tons per year).

Table 5 reports the estimated effects from these regressions. Panel A reveals strong empirical support for nonlinear effects that are relatively stable across specifications. The

---

[30] The decrease in predicted mortality in the late 1950s corresponds to the decline in power plant coal use associated with the 'Eisenhower recession'.

marginal effects are positive and statistically significant for all four bins, although the effects are much larger at lower levels of pollution. For example, the estimates imply that the marginal health impact of a 100,000 ton increase in coal consumption is 2.5 larger in the counties in the 3-6 bin compared to counties in the 6-9 bin (the p-value associated with the test of equality for these two effects is 0.019). Panel B shows a similar pattern based on annual variation in coal-fired capacity.

There are at least two possible explanations for the nonlinear relationship between coal consumption or coal-fired capacity and infant mortality. First, the pathophysiological effects of a change in air pollution on an individual infant may be nonlinear and vary according to baseline air quality. Second, the impact of a marginal change in coal consumption on local air quality could be nonlinear and depend on contemporaneous air pollution levels.[31] In principle, this hypothesis could be tested by examining the impact of changes in power plant coal consumption on TSP concentrations at varying pollution levels. Unfortunately, given the limited number of counties with monitor information, and the fact that monitors were placed almost exclusively in locations with high initial levels of pollution, the data contains too little variation to examine this question.[32]

## 5.4 Tradeoffs Associated with Coal-Fired Electricity Generation: Infant Mortality

The previous results demonstrate that expansions in coal-fired electricity generation were harmful to infant health. These findings are consistent with recent evidence on the negative health effects associated with coal consumption for home heating (Barreca, Clay and Tarr, 2014) and industrial coal consumption (Hanlon, 2015). Nevertheless, it is unclear whether

---

[31] The process through which primary pollutants such as nitrogen oxides and sulfur dioxides are converted into atmospheric suspended particulates is complicated and highly nonlinear. It depends on a variety of factors such as temperature, precipitation, humidity, and wind speed.

[32] It is also possible that the results reflect heterogeneous responses to a change in air pollution based on average population characteristics across counties. For example, if less-healthy individuals selected into low-coal counties, they might be more susceptible to the consequences of a marginal increase in pollution.

the benefits of increased electricity access offset the harmful effects of air pollution, and the extent to which these competing factors were traded-off by households.

To investigate the tradeoffs associated with coal-fired electricity generation, we estimate a generalized version of equation (2) in which the impact of power plant coal consumption (or capacity) is allowed to vary according to baseline electricity access. We calculate the median level of electricity access in 1940 in the sample (weighting counties by the number of births), and create two indicators, $H - Electricity_c$ and $L - Electricity_c$, that identify counties above and below median electricity access in 1940. The main variable of interest, $Coal_{ct}$, is interacted with the two variables.

Table 6 reports the parameter estimates of $\beta_L$ and $\beta_H$ for infant mortality. Panel A reports the estimates based on coal consumption within 30 miles and Panel B relies on variation in coal-fired capacity within 30 miles. The patterns are very similar across the two measures. In counties with high baseline electricity access, increases in coal consumption and coal-fired capacity are associated with increases in infant mortality, with effects that are larger in magnitude than those reported in Table 4. In contrast, in counties with low initial access to electricity, expansions in coal-fired generation reduce infant mortality.

Together these estimates suggest that there were clear tradeoffs associated with coal-fired electricity generation, and that the negative health impact of power plant pollution was mitigated by the benefits associated with increased electricity access. Because virtually all households in $H - Electricity_c$ counties had access to electricity in 1940, there was minimal scope for expansion in coal-fired generation to improve health through increased electricity access. As a result, the estimates of $\beta_H$ primarily capture the negative health effects attributable to increased plant emissions. Conversely, in $L - Electricity_c$ counties, almost one half of residents initally lacked access to electricity, so there was significant scope for expansions in electricity access to improve infant health.

Given almost univeral electricity access in $H - Electricity_c$ counties, the parameter estimates of $\beta_H$ can be compared to the rescaled difference-in-differences estimates of equation

(1). In both settings, the effects can be interpreted as the pollution cost of power plant coal consumption and coal-fired capacity. The preferred estimates of equation (1) imply that a 100,000 ton increase in power plant coal consumption results in 0.155 additional infant deaths per 1,000 live births. The preferred estimates in Table 6 imply that an equivalent increase in local coal consumption would cause an additional 0.136 infant deaths per 1,000 live births. The corresponding effects of a 100 MW increase in local coal-fired capacity are 0.215 and 0.201 for the two empirical strategies, respectively. The fact that two different estimation strategies – relying on different sources of variation – yield such similar effect sizes provides confidence in the main findings.

In order to compare these results to more recent studies of the effects of TSP exposure on infant mortality, coal-fired electricity generation must be linked to local air quality measures. Unfortunately, air pollution monitor data is only available for a sample of 75 counties in the last six years of the sample period. Nevertheless, Table 7 reports the relationship between coal consumption, coal-fired capacity, and TSP for this period. The specifications are similar to those reported in Table 4, although given the small sample size, we omit the county fixed effects in all but the last column. Although imprecise, the point estimates are stable across specifications, and imply that a 100,000 ton increase in local coal consumption raised TSP concentrations by $1.53/145 = 1$ percent. Comparing these effects with the mortality effects driven by power plant pollution, $\beta_H$, we calculate that a 1 percent increase in TSP is associated with a 0.26 percent increase in infant mortality. In comparison, Chay and Greenstone (2003a) estimate an elasticity of 0.35 between TSP and infant mortality for the early 1980s. Given the higher levels of pollution that prevailed in the mid-20th century, the difference in effect sizes is consistent with a concave (supralinear) concentration-response function that is consistent with the results found in Table 5.

## 5.5 Tradeoffs Associated with Coal-Fired Electricity Generation: Property Values and Wages

Next, we explore the extent to which the negative externalities and the benefits of increased electricity access were capitalized into property values. Table 8 reports the effects of coal consumption and coal-fired capacity on property values, estimated separately for counties with high and low baseline electricity access. For reference, columns 1 and 2 report the estimates for infant mortality based on the same sample used in the housing market regressions.[33] The results in the housing market mirror those found for infant mortality. At low levels of electricity access, coal-fired generation has positive effects on housing values. At high levels of baseline access, the effects become negative. The results are stronger for rental values than for housing values. One explanation is that rental values are more likely to reflect contemporaneous conditions rather than the anticipated future discounted flow of benefits and costs (Banzhaf and Farooque, 2013).[34] The housing market response to coal-fired electricity was substantial: at low levels of baseline electricity access, a one standard deviation increase in coal consumption led to a 4.8 percent increase in local housing values, whereas at high levels of access it led to a decrease of 10.4 percent.[35]

These findings suggest that the benefits of local electricity access were traded off against power plant emissions. In the standard spatial equilibrium model, local coal-fired generation can affect housing values through either residential amenities or worker productivity (Roback, 1982; Moretti, 2011). For example, the negative relationship between coal consumption and housing prices in high electricity access counties could reflect either a residential disamenity or a decrease in worker productivity associated with exposure to higher levels of local air pol-

---

[33] The specifications reported in this table do not include state-by-year fixed effects, given that property values are only available in decennial years. Results from unreported regressions that include the full vector of state-by-year covariates are similar in magnitude, albeit somewhat less precisely estimated.

[34] Alternatively, the results could reflect heteregenous effects of coal-fired electricity generation across geographically distinct segments of the local population, given that the median county owner-occupied household and rental household may have had different levels electricity access and been exposed to different levels of plant emissions.

[35] At high levels of electricity access, the implied elasticity of housing values with respect to TSP is -0.32, comparable to Chay and Greenstone (2005).

lution. To separate these channels, we examine the effects of power plant coal consumption on local wages. Intuitively, if air pollution is a local disamenity, workers must be compensated with cheaper housing or higher local wages. Alternatively, if air pollution decreases worker productivity, firms will offer lower local wages or must be compensated with less expensive industrial land.

Table 9 reports the estimates for two measures of local wages: the log of manufacturing payroll per worker and the log of retail payroll per worker. At low levels of baseline electricity access, the effects on local wages are positive but very small and statistically insignificant. Combined with the positive effects on property values, these results imply that expansions coal-fired electricity infrastructure improved household amenities and increased worker productivity in areas with low initial access to electricity. Conversely, in counties with high baseline electricity access, coal consumption is associated with modest decreases in local wages, suggesting that the decline in property values was primarily driven by the negative effects of air pollution on worker productivity.[36]

Coal-fired generation may have also affected infant health and property values through residential sorting (Banzhaf and Walsh, 2008; Davis, 2011). Table 9 reports the estimates of equation (2) for local population characteristics. Columns (5) shows little evidence of sorting based on education levels. On the other hand, column (6) shows small but statistically significant effects on racial composition that mirror the responses in the housing market. In counties with low baseline electricity access, coal-fired generation is associated with increases in the fraction of whites. In counties with high electricity access, these effects are reversed. Given the magnitude, however, these results suggest that residential sorting played a limited role in the housing market response to coal-fired generation. Similarly, back-of-the-envelope calculations indicate that less than 6 percent of the estimated impact of power plant coal consumption on infant mortality can be attributed to race-based sorting.[37]

---

[36] Hanlon (2016) also finds that air pollution during the Industrial Revolution had substantial negative effects on worker productivity. Evidence on the impact of air pollution on labor productivity in recent years is provided by Graff Zivin and Neidell (2012), Chang et al. (2014), and Li, Liu and Salvo (2015).

[37] Given the average number of live births throughout the sample period, the estimates imply that at

# 6 Policy Implications

In this section, we use the previous estimates to calculate infant mortality per unit of coal-fired electricity generation. We then compute the cost per infant life saved of two historically feasible interventions to reduce population exposure to power plant emissions: (i) the adoption of baghouses to remove particulate matter, and (ii) the re-siting of power plants to less densely populated locations.

## 6.1 Health Costs of Unregulated Coal-Fired Generation

To assess the size of the health costs associated with power plant air pollution, we use the previous results to calculate infant mortality per terawatt-hour (TWh) of coal-fired electricity generation. The calculation is based on the difference-in-differences estimates for the 213 large power plants in operation in 1962. The preferred point estimates (column 4 of Table 3) imply that air pollution from these plants was responsible for 2,541 infant deaths in 1962; 12 infant deaths per plant.[38] These large power plants produced a total of 439.6 TWh of electricity in 1962, which implies that there were roughly 6 infant deaths per TWh of coal-fired electricity generation.[39] In comparison, Markandy and Wilkinson (2007) calculate 77 all-age deaths per TWh from coal-fired power plants in China.

Although total U.S. coal consumption remained roughly constant throughout the mid-20th century, there were substantial compositional shifts in its use. In particular, the rise in electric utility coal consumption coincided with the decline in residential coal use, as natural gas replaced coal for home heating. To assess the relative importance of these two secular

---

high levels of electricity access, a 100,000 ton increase in coal consumption is associated with 2 additional nonwhite births per year. During the sample period, the nonwhite infant mortality rate was roughly 22 points higher than the white infant mortality rate (Historical Statistics of the United States, 1976, p.57). Given this difference, we calculate that the average county infant mortality rate would have risen by 0.015 points due to the compositional change, 6 percent of the estimated coal consumption effect.

[38] This estimate is calculated as follows: $\delta^{Large}/1000\times$ N(infants in counties $<$ 30 miles in 1962) = $(0.0007862) \times (3,232,040) = 2,541$.

[39] Infant deaths acounted for 6 percent of all-age deaths in 1962. Under the strong assumption that the mortality effect is constant across all age groups, our estimates would imply that there were 100 all-age deaths per TWh of electricity generation.

trends, we contrast our results with recent research on the effects of coal consumption for home heating. Barreca, Clay, and Tarr (2014) find that the decline in coal consumption for home heating between 1945 and 1960 resulted in a nationwide reduction of one infant death per 1,000 live births. Thus, it appears that the health consequences of the rise in electric utility coal use and the decline in residential coal use were roughly offset.

## 6.2 Two Feasible Interventions to Reduce Pollution Exposure

Emissions from coal-fired electricity generation had substantial negative effects on health. Were there cost-effective policy options that could have mitigated these health costs while maintaining the benefits of local electricity infrastructure? We use historical cost estimates of abatement technologies to examine this question.

Although experimentation with scrubbing did not begin until the mid-1960s, effective pollution abatement technologies were available by mid-century. In particular, fabric filtration systems had already been shown to be effective at removing substantial amounts of particulate matter as small as 0.01 microns (Silverman, 1950).[40] These systems were expensive, involving both significant upfront capital investment and ongoing maintenance and disposal costs. Given these high costs and limited enforcement of clean air legislation in this period, it is not surprising that electric utilities did not voluntarily adopt these systems.

We rely on historical industry calculations of baghouse fabric filtration system costs to assss the cost-effectiveness of this pollution abatement technology. There were two primary costs: First, the upfront costs included both the purchase price of abatement equipment and installation costs, which ranged from 75 to 100 percent of the purchase price. For a typical large power plant, these annualized costs could range from \$110,000 to \$750,000 (1990 USD) (U.S. Department of Health, Education, and Welfare, 1969).[41] Second, the costs associated

---

[40] In these systems, exhaust is passed through a series of fabric filter (known as bags). Particulates are removed from the air as they adhere to these fibers. Periodically the accumulation of these particulates, known as fly ash, is then removed from the system.

[41] The upfront equipment costs depend critically on the desired air flow. These cost estimates are derived based on the assumption of 100-500 acfm (actual cubic feet per minute), a standard emissions output for a

with fly ash disposal. Each ton of coal burned produces between 250 and 300 kg of fly ash, so the average large plant in our sample would have produced between 208,000 and 250,000 tons of fly ash per year. Historically, the cost of ash disposal for electric utilities was $3.70 cents per ton, resulting in an average annual cost of $770,000 -$925,000. Together, these calculations imply a total annual cost of pollution abatement ranging from $880,000 to $1.675 million per plant.

Combined with the previous calculations, these results imply a cost per infant life saved of $73,000 to $140,000 (1990 USD). These costs fall well below the estimated $1 million (1990 USD) value of a statistical life (VSL) for this period (Costa and Kahn, 2004). Given that the pollution externality extended beyond infants, these cost estimates understate the true benefits of pollution abatement. Thus, it appears that the social benefits of pollution abatement dramatically exceeded the direct costs to electric utilities. Prior to the passage of the 1970 Clean Air Act Amendments (CAAA), however, private companies were not required to internalize these health costs, and electric utilities were unwilling to undertake the large capital investments associated with abatement technology. It appears that federal intervention under the 1970 CAAA was necessary to mitigate the externality imposed on the local population.

A second feasible intervention was the re-siting of power plants to less populous areas. We consider a scenario in which each of the 213 large power plants was relocated to the centroid of the least densely populated county within a 60-mile radius of its initial placement. This intervention would have reduced the total number of exposed infants – within 30 miles of a power plant – by two-thirds, and resulted in 14,961 fewer infant deaths over the sample period.

In order for electricity access to remain unchanged under this policy, transmission lines would need to be built back to the original power plant site. This involves two primary costs. First, the direct cost of constructing 8,542 miles of high voltage transmission lines at

---

large power plant. Capital costs are annualized over the expected 15 year lifespan of the equipment and are added to standard recurring maintenance and operational costs.

a typical construction cost that ranged from \$300,000 to \$500,000 per mile depending on line voltage, topography and input costs (Brown and Sedano, 2004). Second, the annual transmission losses associated with shipping electricity over a longer distance. Assuming an additional loss of 2 to 3 percent, we calculate annual cost of transmission loss to range from \$500,000 to \$800,000 per plant.[42] Annualizing the upfront transmission line capital costs over a 20-year time horizon, we calculate that the annual cost to range from \$1.4 to \$2.4 million per plant. These calculations imply a cost per infant life saved ranging from \$117,000 to \$200,000 (1990 USD). Although somewhat less cost effective than the baghouse abatement technology, the social savings associated with relocating plants to less densely populated areas far exceeded the direct infrastructure costs to electric utilities.

## 7 Concluding Remarks

This paper uses the expansion in U.S. fossil fuel powered electricity during the mid-20th century to study the tradeoffs associated with coal-fired power generation. Drawing on newly digitized power plant level data on plant openings and coal consumption, we show that effects on infant mortality were quantitatively important and nonlinear. By the end of the period of analysis, coal burning by power plants was responsible for over one infant death per thousand live births, a large effect relative to modern day infant mortality rates. The effects are shown to be even higher for lower levels of coal consumption. We find that benefits of increased electricity access mitigated the negative health effects, and that expansion in coal-fired generation actually led to improvements in infant health in counties with low initial electricity access. The housing market response mirrors this relationship, suggesting that households traded off the costs of air pollution against the benefits of increased local electricity access.

Our analysis has a number of implications for policymakers in developed and developing

---

[42] The loss rate is derived based on a transmission calculator assuming an average transmission distance of 40 miles with a 138 kilovolt line. The annualized costs depend on an assumption of mean power plant capacity of 147 MW, a 0.7 capacity factor, and a sale price of 3 cents per KWh.

countries. First, the nonlinear relationship between coal consumption and infant mortality suggests that initial efforts at pollution abatement may yield modest health improvements but are necessary to move further down the concentration-response function. The presence of these nonlinearities also implies that a flat Pigouvian tax is unlikely to provide incentives for polluting firms to reduce emissions to the socially optimal level.

Second, demand for policy intervention – regulation or taxation – may only emerge when the negative externalities are significantly larger than the perceived benefits. In our setting, there were significant pollution externalities related to coal-fired electricity generation, yet demand for corrective policies may have been limited by the fact that communities that gained access to electricity enjoyed sizeable benefits. In developed and developing countries today, industrial firms often use losses in local economic activity as a justification for limiting environmental regulation. As the initial benefits from industrialization diminish, governments in developing countries may be more willing to implement policies aimed at curbing emissions.

Lastly, the siting decisions of industrial plants should account for the stream of current and future costs and benefits of these long-lived infrastructure projects. Our analysis suggests that there would have been significant benefits had heavily polluting plants been sited in less densely populated locations or had pollution abatement technologies been adopted earlier. Today in developed and developing countries, regulators do not typically require estimation of current and future costs and benefits before issuing permits, and short-term political incentives may lead the longer-term costs to be undervalued.

# References

Allcott, Hunt, Allan Collard-Wexler, and Stephen D. O'Connell. 2016. "How Do Electricity Shortages Affect Industry? Evidence from India," *American Economic Review*, 106(3): 587-624.

Almond, Douglas, Yuyu Chen, Michael Greenstone, and Hongbin Li. 2009. "Winter Heating or Clean Air? Unintended Impacts of China's Huai River Policy?" *American Economic Review*, 99(2): 184-90.

Arceo-Gomez, Eva, Rema Hanna, and Paulina Oliva. 2012. "Does the Effect of Pollution on Infant Mortality Differ Between Developing and Developed Countries? Evidence from Mexico City," *NBER Working Paper #18349.*

Banzhaf, H. Spencer, and Omar Farooque. 2013. "Interjurisdictional Housing Prices and Spatial Amenities: Which Measures of Housing Prices Reflect Local Public Goods?" *Regional Science and Urban Economics*, 43(4): 635-648.

Banzhaf, H. Spencer, and Randall P. Walsh. 2008. "Do People Vote with Their Feet? An Empirical Test of Tiebout," *American Economic Review*, 98(3): 843-863.

Barreca, Alan, Karen Clay, and Joel Tarr. 2014. "Coal, Smoke, and Death: Bituminous Coal and American Home Heating," *NBER Working Paper #19881.*

Biondo, S. J., and J. C. Marten. 1977. "A History of Flue Gas Desulphurization Systems Since 1850." *Journal of the Air Pollution Control Association* 27(10): 948-961.

Brown, Matthew H., and Richard P. Sedano. 2004. *Electricity Transmission: A Primer.* National Council on Electricity Policy (NCEL). Denver, CO.

Chay, Kenneth Y. and Michael Greenstone. 2003a. "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession," *Quarterly Journal of Economics*, 118(3): 1121-1167.

Chay, Kenneth Y. and Michael Greenstone. 2003b. "Air Quality, Infant Mortality, and the Clean Air Act of 1970," *NBER Working Paper #10053.*

Chay, Kenneth Y., and Michael Greenstone. 2005. "Does Air Quality Matter? Evidence from the Housing Market." *Journal of Political Economy*, 113(2): 376-424.

Clancy, Luke, Pat Goodman, Hamish Sinclair, and Douglas W Dockery. 2002. "Effect of Air-Pollution Control on Death Rates in Dublin, Ireland: An Intervention Study," *Lancet*, 360(9341): 1210-1214.

Clay, Karen, and Werner Troesken. 2011. "Did Frederick Brodie Discover the World's First Environmental Kuznets Curve? Coal Smoke and the Rise and Fall of the London Fog," In Libecap, Gary, and Richard H. Steckel (eds.) *The Economics of Climate Change: Adaptations Past and Present*, Chicago: University of Chicago Press, pp. 281-310.

Cohen, Aaron J., H. Ross Anderson, Bart Ostro, Kiran Dev Pandey, Michal Krzyzanowski, Nino Knzli, Kersten Gutschmidt, C. Arden Pope III, Isabelle Romieu, Jonathan M. Samet, and Kirk R. Smith. 2004. "Urban Air Pollution," In: Ezzati, Majid, Alan D. Lopez, Anthony Rodgers and Christopher J.L. Murray, eds. *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors,* Geneva, World Health Organization, Vol. 2.

Costa, Dora L., Matthew E. Kahn. 2004. "Changes in the Value of Life, 1940-1980," *Journal of Risk and Uncertainty*, 29(2): 159-180.

Currie, Janet and Matthew Neidell. 2005. "Air Pollution and Infant Health: What Can We Learn From California's Recent Experience?" *Quarterly Journal of Economics*, 120(3): 1003-1030.

Currie, Janet, and W. Reed Walker. 2011. "Traffic Congestion and Infant Health: Evidence from E-ZPass." *American Economic Journal: Applied Economics*, 3(1): 65-90.

Currie, Janet, Joshua Graff Zivin, Jamie Mullins, and Matthew Neidell. 2014. "What Do We Know About Short- and Long-Term Effects of Early-Life Exposure to Pollution?" *Annual Review of Resource Economics*, 6(1): 217-247.

Currie, Janet, Lucas W. Davis, Michael Greenstone, and W. Reed Walker. 2015. "Environmental Health Risks and Housing Values: Evidence from 1,600 Toxic Plant Openings and Closings," *American Economic Review*, 105(2): 678-709.

Davis, Lucas W. 2011. "The Effect of Power Plants on Local Housing Values and Rents," *Review of Economics and Statistics*, 93(4): 1391-1402.

Dinkelman, Taryn. 2011. "The Effects of Rural Electrification on Employment: New Evidence from South Africa", *American Economic Review*, 101(7): 3078-3108.

Eisenbud, Merril. 1978. Levels of Exposure to Sulfur Oxides and Particulates in New York City and their Sources. *Bulletin of the New York Academy of Medicine 1978*, 54:991-1011.

Fishback, Price, and Carl Kitchens. 2015. "Flip the Switch: The Impact of the Rural Electrification Administration 1935-1940," *Journal of Economic History*, 74:(4): 1161-1195.

Fishback, Price, Michael Haines, Shawn Kantor, and Joseph Cullen. (s.d.). County and City Mortality Data, 1921 to 1950, available at *econ.arizona.edu/faculty/fishback.asp*

Gartner, Scott Sigmund, et al. 2006. In Carter, Susan B., Scott Sigmund Gartner, Michael R. Haines, Alan L. Olmstead, Richard Sutch, and Gavin Wright (eds.) *Historical Statistics of the United States,* New York: Cambridge University Press.

Gohlke, Julia, M., Reuben Thomas, Alistair Woodward, Diarmid Campbell-Lendrum, Annette Prüssüstün, Simon Hales, and Christopher J. Portier. 2011. "Estimating the global public health implications of electricity and coal consumption." *Environmental Health Perspectives* 119(6): 821-826.

Goklany, Indur M. 1999. *Clearing the Air: The Real Story of the War on Air Pollution.* Cato Institute.

Goodkind, Andrew L., Jay S. Coggins, and Julian D. Marshall. 2014. "A Spatial Model of Air Pollution: The Impact of the Concentration-Response Function," *Journal of the Association of Environmental and Resource Economists*, 1(4): 451-479.

Graff Zivin, Joshua, and Matthew Neidell. 2012. "The Impact of Pollution on Worker Productivity," *American Economic Review*, 102(7): 3652-3673.

Greenstone, Michael, and B. Kelsey Jack. 2015. "Envirodevonomics: A Research Agenda for an Emerging Field," *Journal of Economic Literature*, 53(1): 5-42.

Haines, Michael R., and Inter-university Consortium for Political and Social Research (ICPSR). 2010. Historical, Demographic, Economic, and Social Data: The United States, 1790-2002. Ann Arbor, MI: Inter-university Consortium for Political and Social Research, icpsr.org.

Hales, Jeremy M. 1976. *Tall Stacks and the Atmospheric Environment. EPA Publication*, No. EPA-450/3-76-007.

Hanlon, W. Walker, and Yuan Tian. 2015. "Killer Cities: Past and Present," *American Economic Review Papers & Proceedings*, 105(5): 570-75.

Hanlon, W. Walker. 2015. "Pollution and Mortality in the 19th Century," *NBER Working Paper 21647.*

Hanlon, W. Walker. 2016. "Coal Smoke and the Costs of the Industrial Revolution," *Mimeo.*

Ives, James Edmund, Rollo H. Britten, David William Armstrong, Wirt Alvin Gill, and Frederick Herbert Goldman. 1936. *Atmospheric Pollution of American Cities for the Years 1931 to 1933 with Special Reference to the Solid Constituents of the Pollution.* U.S. Treasury Department, Public Health Bulletin No 224. Washington: Government Printing Office.

Kline, Patrick. 2012. "The Impact of Juvenile Curfew Laws on Arrests of Youth and Adults," *American Law and Economics Review*, 14(1): 44-67.

Lave, Lester, and Eugene Seskin. 1970. "Air Pollution and Human Health", *Science*, 169(3947): 723-733.

Lave, Lester and Eugene Seskin. 1972. "Air Pollution, Climate, and Home Heating: Their Effects on U.S. Mortality Rates." *American Journal of Public Health* 62: 909-916.

Levy, Jonathan I., John D. Spengler, Dennis Hlinka, David Sullivan, Dennis Moon. 2002. "Using CALPUFF to Evaluate the Impacts of Power Plant Emissions in Illinois: Model Sensitivity and Implications," *Atmospheric Environment* 36: 1063-1075.

Lewis, Joshua. 2015. "Fertility, Child Health, and the Diffusion of Electricity into the Home," *Mimeo.*

Lewis, Joshua. 2016. “Short-run and Long-run Effects of Household Electrification,” *Mimeo.*

Lewis, Joshua, and Edson R. Severnini. 2015. “The Value of Rural Electricity: Evidence from the Rollout of the U.S. Power Grid,” *Mimeo.*

Li, Teng, Haoming Liu, and Alberto Salvo. 2015. “Severe Air Pollution and Labor Productivity,” *IZA Discussion Paper 8916.*

Lipscomb, Molly, Mushfiq A. Mobarak, and Tania Barham. 2013. “Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil.” *American Economic Journal: Applied Economics*, 5(2): 200-231.

Medley, Anthony Johnson, Chit-Ming Wong, Thuan Quoc Thach, Stefan Ma, Tai-Hing Lam, and Hugh Ross Anderson. 2002. “Cardiorespiratory and All-cause Mortality after Restrictions on Sulphur Content of Fuel in Hong Kong: An Intervention Study,” *Lancet*, 360(9346): 1646-1652.

Moretti, Enrico. 2011. “Local Labor Markets,” In Card, David, and Orley Ashenfelter (eds.), *Handbook of Labor Economics*, Volume 4b. New York: Elsevier, Chapter 14, pp. 1237-1313.

Pope III, C. Arden, Joel Schwartz, and Michael R. Ransom. 1992. “Daily Mortality and PM10 Pollution in the Utah Valley,” *Archives of Environmental Health: An International Journal*, 47(3): 211-217.

Pope III, C. Arden, Richard T. Burnett, Michael J. Thun, Eugenia E. Calle, Daniel Krewski, Kazuhiko Ito, George D. Thurston. 2002. “Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution”, *Journal of the American Medical Association*, 287(9): 1132-1141.

Pope III, C. Arden, Richard T. Burnett, George D. Thurston, Michael J. Thun, Eugenia E. Calle, Daniel Krewski, and John J. Godleski. 2004. “Cardiovascular Mortality and Long-Term Exposure to Particulate Air Pollution: Epidemiological Evidence of General Pathophysiological Pathways of Disease,” *Circulation*, 109: 71-77.

Pope, C. Arden, III, Douglas L. Rodermund, and Matthew M. Gee. 2007. “Mortality Effects of a Copper Smelter Strike and Reduced Ambient Sulfate Particulate Matter Air Pollution.” *Environmental Health Perspectives*, 115(5): 679-683.

Pope III, C. Arden, Maureen Cropper, Jay Coggins, and Aaron Cohen. 2015. “Health Benefits of Air Pollution Abatement Policy: Role of the Shape of the Concentration-Response Function,” *Journal of the Air & Waste Management Association*, 65(5): 516-522.

Ridker, Ronald G., and John A. Henning. 1967. “The Determinants of Residential Property Values with Special Reference to Air Pollution,” *Review of Economics and Statistics*, 49(2): 246-257.

Roback, Jennifer. 1982. “Wages, Rents, and the Quality of Life,” *Journal of Political Economy*, 90(6): 1257-1278.

Rosen, Sherwin. 1974. “Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition,” *Journal of Political Economy*, 82(1): 34-55.

Samet, Jonathan M., Francesca Dominici, Frank C. Curriero, Ivan Coursac, and Scott L. Zeger. 2000. “Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987-1994,” *The New England Journal of Medicine*, 343(24): 1742-1749.

Schlenker, Wolfram, and W. Reed Walker. Forthcoming. “Airports, Air Pollution, and Contemporaneous Health,” *Review of Economic Studies*.

Severnini, Edson. 2014. “The Power of Hydroelectric Dams: Agglomeration Spillovers,” *IZA Discussion Paper 8082*.

Severnini, Edson. 2015. “Nuclear Shutdown, Coal Power Generation, and Infant Health: Evidence from the Tennessee Valley Authority (TVA) in the 1980s,” *Mimeo*.

Silverman, Leslie. 1950. “Filtration Through Porous Materials,” *American Industrial Hygiene Association Quarterly*: 11(1): 11-20.

Stern, Arthur C. “History of Air Pollution Legislation in the United States.” *Journal of the Air Pollution Control Association* 32.1 (1982): 44-61.

U.S. Bureau of the Census. 1976. *Historical Statistics of the United States, Colonial Times to 1970*. No. 93. US Department of Commerce, Bureau of the Census.

U.S. Bureau of Mines. *Minerals Yearbook* (various years). Washington DC: Government Printing Office.

U.S. Center for Disease Control (CDC). 2013. “Infant Mortality Statistics from the 2010 Period Linked Birth/Infant Death Data Set,” *National Vital Statistics Reports*: 62(8): 1-27.

U.S. Department of Commerce (DOC) - Bureau of the Census, and Inter-university Consortium for Political and Social Research (ICPSR). 2012. *County and City Data Book (United States) Consolidated File: County Data, 1947-1977*, ICPSR07736-v2, Ann Arbor, MI: Inter-university Consortium for Political and Social Research.

U.S. Department of Health, Education and Welfare (HEW). 1952-1958. Marriage, Divorce, Natality, Fetal Mortality and Infant Mortality Data. *Vital Statistics of the United States (Volume I)*, Washington, DC: U.S. Government Printing Office.

U.S. Department of Health, Education and Welfare 1958. *Air Pollution Measurements of the National Air Sampling Network: Analyses of Suspended Particulates, 1953-1957*. Public Health Service Publication No 637. Washington DC: Government Printing Office.

U.S. Department of Health, Education and Welfare (HEW). 1969. *Control Techniques for Particulate Air Pollution*. Public Health Service Protection and Environmental Health Service. Washington DC: Government Printing Office.

U.S. Energy Information Administration (EIA). 2010. *Annual Electric Generator Report*, Form-EIA-860. Washington DC: U.S. Energy Information Administration.

U.S. Environmental Protection Agency (EPA). 1999. *Estimating Particulate Matter Emissions from Construction Operations: Final Report*, Available at nepis.epa.gov.

U.S. Environmental Protection Agency (EPA). 2011. “Final Response to Petition From New Jersey Regarding SO2 Emissions From the Portland Generating Station; Final Rule,” In: *Federal Register*, 76(215): 69051-69077. November 7, 2011.

U.S. Federal Power Commission (FPC). 1947. *Steam-Electric Plant Construction Cost and Annual Production Expenses, 1938-1947*. Washington DC: U.S. Federal Power Commission.

U.S. Federal Power Commission (FPC). 1948-62. *Steam-Electric Plant Construction Cost and Annual Production Expenses (Annual Supplements)*. Washington DC: U.S. Federal Power Commission.

U.S. Federal Power Commission (FPC). (1962). *Principal Electric Power Facilities in the United States* (map). Washington DC: U.S. Federal Power Commission.

Woodruff, Tracey, Lyndsey Darrow, and Jennifer Parker. 2008. “Air Pollution and Postneonatal Infant Mortality in the United States, 1999-2002.” *Environmental Health Perspectives* 116(1): 110-115.

# 8 Figures and Tables

Table 1: Summary Statistics: Power Plants Openings

| | **Treatment counties** <30 miles from a power plant | | | **Control counties** 30-90 miles from a power plant |
|---|---|---|---|---|
| | All PPs | Large PPs (≥75 MW) | Small PPs (<75 MW) | |
| **Power Plant Characteristics** | | | | |
| Initial Year of Operation | 1952.3 | 1952.5 | 1950.4 | - |
| Coal-Fired Capacity (MWs) | 137.6 | 146.9 | 14.8 | - |
| Annual Coal Consumption (100,000 Tons) | 6.7 | 7.1 | 0.9 | - |
| **County Characteristics** | | | | |
| Infant Mortality Rate | 28.9 | 28.8 | 30.3 | 32.5 |
| Number of Live Births | 2,639 | 3,036 | 973 | 815 |
| Distance to Power Plant | 18.0 | 18.0 | 18.5 | 64.5 |
| Coal Consumption within 30 miles (100,000 Tons) | 20.9 | 22.3 | 2.8 | 1.4 |
| Coal-Fired Capacity within 30 miles (100 MWs) | 12.1 | 12.9 | 1.4 | 0.8 |
| Hydroelectric Capacity within 30 miles (100 MWs) | 0.23 | 0.23 | 0.15 | 0.20 |
| **Baseline County Characteristics (1940)** | | | | |
| Population (1,000s) | 781 | 844 | 130 | 76 |
| Employment (1,000s) | 299 | 324 | 45 | 25 |
| Manufacturing Employment (1,000s) | 102 | 110 | 16 | 7 |
| Number of Plants | 272 | 213 | 59 | - |
| Number of Counties | 728 | 557 | 171 | 1,196 |
| Number of Plant-County Pairs | 1,028 | 830 | 198 | 4,173 |
| Observations | 25,700 | 20,750 | 4,950 | 104,325 |

Notes: The top panel describes the mean characteristics of the 272 coal-fired power plants that opened between 1938 and 1962. The bottom panels report the sample means for the treatment and control counties. Sample means are weighted by the number of live births.

Table 2: Summary Statistics: Annual Coal Consumption and Coal-Fired Capacity

| | All | High Electricity Access | Low Electricity Access |
|---|---|---|---|
| **Dependent Variables** | | | |
| Infant Mortality Rate | 31.4 | 27.9 | 34.7 |
| Median Monthly Dwelling Rent | 231.4 | 286.0 | 181.0 |
| Median Dwelling Value | 39,624 | 51,722 | 28,436 |
| Manufacturing Payroll Per Worker | 17.1 | 20.9 | 13.5 |
| Average Retail Payroll Per Worker | 12.2 | 13.5 | 11.0 |
| % Population White | 88.3 | 92.7 | 84.2 |
| % Population $\geq$25yr with High School | 33.0 | 38.3 | 28.1 |
| **Independent Variables** | | | |
| Coal Consumption within 30 miles (100,000 Tons) | 9.3 | 17.4 | 1.7 |
| Coal-Fired Capacity within 30 miles (100 MWs) | 5.1 | 9.5 | 0.9 |
| Hydroelectric Capacity within 30 miles (100 MWs) | 0.25 | 0.21 | 0.29 |
| **Baseline County Characteristics (1940)** | | | |
| % Households with Electricity | 71.6 | 95.5 | 54.7 |
| Population (1,000s) | 357 | 787 | 54 |
| Employment (1,000s) | 135 | 300 | 18 |
| Manufacturing Employment (1,000s) | 46 | 107 | 3 |
| Number of Counties | 1,983 | 223 | 1,760 |

Notes: This table reports the characteristics for the sample of 1,983 used to estimation equation (2). Sample means are weighted by the number of live births. 'High Electricity Access' and 'Low Electricity Access' identify counties that had above- and below-median electricity access in 1940, where median electricity access in the sample is calculated as the fraction of households with electricity in 1940, weighting counties by the number of live births. All dollar amounts are reported in 1990 dollars.

Table 3: Effects of Large and Small Power Plant Openings on Infant Mortality

| **Dependent Variable** | **Infant Mortality Rate** | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **Large Power Plants (>75 MW) vs. Small Power Plants (≤75 MW)** | | | | |
| 1(Large Plant Operating) × 1(County within 30 miles) | 2.1700** | 1.7577*** | 1.0093*** | 0.7862*** |
| | (1.0025) | (0.4321) | (0.3848) | (0.2643) |
| 1(Small Plant Operating) × 1(County within 30 miles) | 1.4292** | 0.2846 | -0.0972 | -0.2101 |
| | (0.6249) | (0.3902) | (0.3625) | (0.3084) |
| R-squared | 0.6441 | 0.6946 | 0.6961 | 0.7045 |
| F-statistic: $\delta^{Large} = \delta^{Small}$ | 1.42 | 15.13 | 9.04 | 9.19 |
| P-value | 0.2332 | 0.0001 | 0.0027 | 0.0025 |
| Observations | 130,025 | 130,025 | 130,025 | 130,025 |
| County-Plant Pair FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| State-by-Year FE | N | Y | Y | Y |
| 1940 Manufacturing Employment × Year FE | N | N | Y | Y |
| Additional Covariates | N | N | N | Y |

Notes: The table reports the difference-in-differences estimates of equation (1). Each column reports the point estimates from a different regression. The dependent variable in all regressions is the infant mortality rate per 1,000 live births. The variable 1(County within 30 miles) is an indicator for whether the distance between the county-centroid and the power plant is less than 30 miles. The indicators for 'Small' and 'Large' distinguish plants currently operating with $\lesseqgtr$ 75 MW of nameplate capacity. Additional covariates include geographic controls (time-varying controls for temperature, precipitation, degree days below $10^{o}$C and degree days above $29^{o}$C, and latitude and longitude interacted with year), demographic and economic controls (population and total employment in 1940) interacted with year, percent households with electricity in 1940 interacted with year, county-centroid distance to the power plant interacted with year, and annual nameplate power plant capacity. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 4: Effects of Coal Consumption and Coal-fired Capacity on Infant Mortality

| **Dependent Variable** | **Infant Mortality** | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| **Panel A. Coal Consumption within 30 Miles** | | | |
| Coal Consumption | 0.1418*** | 0.1082*** | 0.0850*** |
| | (0.0357) | (0.0194) | (0.0167) |
| R-squared | 0.6462 | 0.6944 | 0.6992 |
| **Panel B. Coal vs. Hydro Capacity within 30 Miles** | | | |
| Coal Capacity | 0.2189*** | 0.1873*** | 0.1643*** |
| | (0.0479) | (0.0263) | (0.0302) |
| Hydroelectric Capacity | -0.1295 | 0.0354 | -0.0251 |
| | (0.2611) | (0.1151) | (0.1378) |
| R-squared | 0.6463 | 0.6949 | 0.6996 |
| Observations | 49,575 | 49,575 | 49,575 |
| County & Year FE | Y | Y | Y |
| State-by-Year FE | N | Y | Y |
| All Controls | N | N | Y |

Notes: The table reports the fixed effects estimates of equation (2). The dependent variable in all regressions is the infant mortality rate per 1,000 live births. The variable 'Coal Consumption' denotes total power plant coal consumption within 30 miles of the county-centroid (in 100,000 tons). The variables 'Coal Capacity' and 'Hydroelectric Capacity' denote total coal-fired and hydroelectric capacity within 30 miles of the county-centroid (in 100 MWs). Additional controls include geographic controls (time-varying controls for temperature, precipitation, degree days below $10^o$C and degree days above $29^o$C, and latitude and longitude interacted with year), and economic covariates (population, total employment, and manufacturing employment in 1940, all interacted with year). Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 5: Nonlinear Effects of Coal Consumption and Coal-fired Capacity on Infant Mortality

| **Dependent Variable** | **Infant Mortality** | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| **Panel A. Coal Consumption within 30 Miles** | | | |
| Coal Consumption × $1(\text{Coal} < 3)$ | 0.3675* | 0.2929* | 0.3077** |
| | (0.2169) | (0.1511) | (0.1534) |
| Coal Consumption × $1(\text{Coal} \in [3,6))$ | 0.1742* | 0.2180*** | 0.2249*** |
| | (0.0979) | (0.0726) | (0.0697) |
| Coal Consumption × $1(\text{Coal} \in [6,9))$ | 0.1593** | 0.0972** | 0.0973** |
| | (0.0638) | (0.0459) | (0.0407) |
| Coal Consumption × $1(\text{Coal} \geq 9)$ | 0.1431*** | 0.1107*** | 0.0882*** |
| | (0.0354) | (0.0196) | (0.0168) |
| R-squared | 0.6462 | 0.6945 | 0.6993 |
| **Panel B. Coal-Fired Capacity within 30 Miles** | | | |
| Coal Capacity × $1(\text{Capacity} < 1)$ | 1.0336 | 0.2947 | 0.4049 |
| | (0.6355) | (0.4779) | (0.4619) |
| Coal Capacity × $1(\text{Capacity} \in [1,2))$ | 0.2695 | 0.3630* | 0.4484** |
| | (0.2568) | (0.2202) | (0.2023) |
| Coal Capacity × $1(\text{Capacity} \in [2,3))$ | 0.1445 | 0.2300 | 0.2399 |
| | (0.1903) | (0.1593) | (0.1581) |
| Coal Capacity × $1(\text{Capacity} \geq 3)$ | 0.2189*** | 0.1889*** | 0.1656*** |
| | (0.0480) | (0.0264) | (0.0306) |
| R-squared | 0.6464 | 0.6950 | 0.6996 |
| Observations | 49,575 | 49,575 | 49,575 |
| County & Year FE | Y | Y | Y |
| State-by-Year FE | N | Y | Y |
| All Controls | N | N | Y |

Notes: The table reports the fixed effects estimates of equation (2). The dependent variable in all regressions is the infant mortality rate per 1,000 live births. The variable 'Coal Consumption' denotes total power plant coal consumption within 30 miles of the county-centroid (in 100,000 tons). The variables 'Coal Capacity' denotes total coal-fired and hydroelectric capacity within 30 miles of the county-centroid (in 100 MWs). Indicators $1(\text{Coal} \in (\text{x,y}))$ and $1(\text{Capacity} \in (\text{x,y}))$ denote whether consumption or capacity was within the specified range $(x, y)$ in year $t$. Additional controls include geographic controls (time-varying controls for temperature, precipitation, degree days below 10$^o$C and degree days above 29$^o$C, and latitude and longitude interacted with year), and economic covariates (population, total employment, and manufacturing employment in 1940, all interacted with year). Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 6: Effects of Coal Consumption and Coal-fired Capacity by Baseline Electricity Access

| **Dependent Variable** | **Infant Mortality** | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| **Panel A. Coal Consumption within 30 Miles** | | | |
| Coal Consumption × 1(L-Electricity) | -0.1414*** | -0.0629** | -0.0503** |
| | (0.0303) | (0.0246) | (0.0240) |
| Coal Consumption × 1(H-Electricity) | 0.1767*** | 0.1483*** | 0.1359*** |
| | (0.0196) | (0.0180) | (0.0198) |
| R-squared | 0.6496 | 0.6956 | 0.7000 |
| **Panel B. Coal-Fired Capacity within 30 Miles** | | | |
| Coal Capacity × 1(L-Electricity) | -0.3350*** | -0.1260* | -0.0962 |
| | (0.0885) | (0.0720) | (0.0674) |
| Coal Capacity × 1(H-Electricity) | 0.2309*** | 0.2094*** | 0.2014*** |
| | (0.0416) | (0.0272) | (0.0343) |
| R-squared | 0.6488 | 0.6957 | 0.7001 |
| Observations | 49,575 | 49,575 | 49,575 |
| County & Year FE | Y | Y | Y |
| State-by-Year FE | N | Y | Y |
| All Controls | N | N | Y |

Notes: The table reports the fixed effects estimates of equation (2). The dependent variable in all regressions is the infant mortality rate per 1,000 live births. The variable ‘Coal Consumption’ denotes total power plant coal consumption within 30 miles of the county-centroid (in 100,000 tons). The variables ‘Coal Capacity’ denotes total coal-fired and hydroelectric capacity within 30 miles of the county-centroid (in 100 MWs). Indicators 1(L-Electricity) and 1(H-Electricity) identify counties with low and high electricity access in 1940. Additional controls include geographic controls (time-varying controls for temperature, precipitation, degree days below $10^{o}$C and degree days above $29^{o}$C, and latitude and longitude interacted with year), and economic covariates (population, total employment, and manufacturing employment in 1940, all interacted with year). Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 7: Effects of Coal Consumption and Coal-fired Capacity on TSP Levels (1957-1962)

| **Dependent Variable** | **TSP Concentration** | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| **Panel A. Coal Consumption within 30 Miles** | | | |
| Coal Consumption | 1.3865*** | 1.5623*** | 1.5355 |
| | (0.3388) | (0.5365) | (1.4142) |
| R-squared | 0.6294 | 0.7164 | 0.9664 |
| | (0.0303) | (0.0246) | (0.0240) |
| **Panel B. Coal-Fired Capacity within 30 Miles** | | | |
| Coal Capacity | 0.0117*** | 0.0127*** | 0.0193 |
| | (0.0029) | (0.0043) | (0.0144) |
| R-squared | 0.6069 | 0.6921 | 0.9661 |
| Observations | 379 | 379 | 379 |
| Number of Counties | 75 | 75 | 75 |
| State & Year FE | Y | Y | Y |
| State-by-Year FE | N | Y | Y |
| County FE | N | N | Y |
| All Controls | N | N | Y |
| *Sample Means* | | | |
| TSP Concentration (1957) | | 145.0 | |
| TSP Concentration (1962) | | 100.5 | |
| Δ Coal Consumption (1962 − 1957) | | 2.64 | |
| Δ Coal Capacity (1962 − 1957) | | 2.22 | |

Notes: The table reports the fixed effects estimates of equation (2) estimated for the years 1957-1962. The dependent variable in all regressions is the TSP concentration in counties with monitoring stations. The variable 'Coal Consumption' denotes total power plant coal consumption within 30 miles of the county-centroid (in 100,000 tons). The variables 'Coal Capacity' and 'Hydroelectric Capacity' denote total coal-fired and hydroelectric capacity within 30 miles of the county-centroid (in 100 MWs). Additional controls include geographic controls (time-varying controls for temperature, precipitation, degree days below $10^{o}$C and degree days above $29^{o}$C, and latitude and longitude interacted with year), and economic covariates (population, total employment, and manufacturing employment in 1940, all interacted with year). Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 8: Effects of Coal Consumption and Coal-fired Capacity on Property Values, by Baseline Electricity Access

| **Dependent Variable** | **Infant Mortality** | | **Log Median Rent** | | **Log Median Housing Value** | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A. Coal Consumption within 30 Miles** | | | | | | |
| Coal Consumption × 1(L-Electricity) | -0.2169*** | -0.1760*** | 0.0032*** | 0.0028*** | 0.0007 | 0.0018 |
| | (0.0678) | (0.0610) | (0.0009) | (0.0008) | (0.0013) | (0.0011) |
| Coal Consumption × 1(H-Electricity) | 0.2411*** | 0.2487*** | -0.0204*** | -0.0061** | -0.0147*** | -0.0032** |
| | (0.0709) | (0.0546) | (0.0042) | (0.0024) | (0.0027) | (0.0013) |
| R-squared | 0.7411 | 0.7613 | 0.9305 | 0.9551 | 0.9248 | 0.9422 |
| **Panel B. Coal-Fired Capacity within 30 Miles** | | | | | | |
| Coal Capacity × 1(L-Electricity) | -0.5817*** | -0.4108** | 0.0085*** | 0.0064*** | 0.0023 | 0.0039 |
| | (0.1893) | (0.1634) | (0.0024) | (0.0022) | (0.0029) | (0.0027) |
| Coal Capacity × 1(H-Electricity) | 0.2976*** | 0.3701*** | -0.0247*** | -0.0086*** | -0.0184*** | -0.0019 |
| | (0.0652) | (0.0768) | (0.0043) | (0.0028) | (0.0036) | (0.0024) |
| R-squared | 0.7437 | 0.7640 | 0.9302 | 0.9551 | 0.9247 | 0.9421 |
| Observations | 3,708 | 3,708 | 3,708 | 3,708 | 3,707 | 3,707 |
| County & Year FE | Y | Y | Y | Y | Y | Y |
| All Controls | N | Y | N | Y | N | Y |

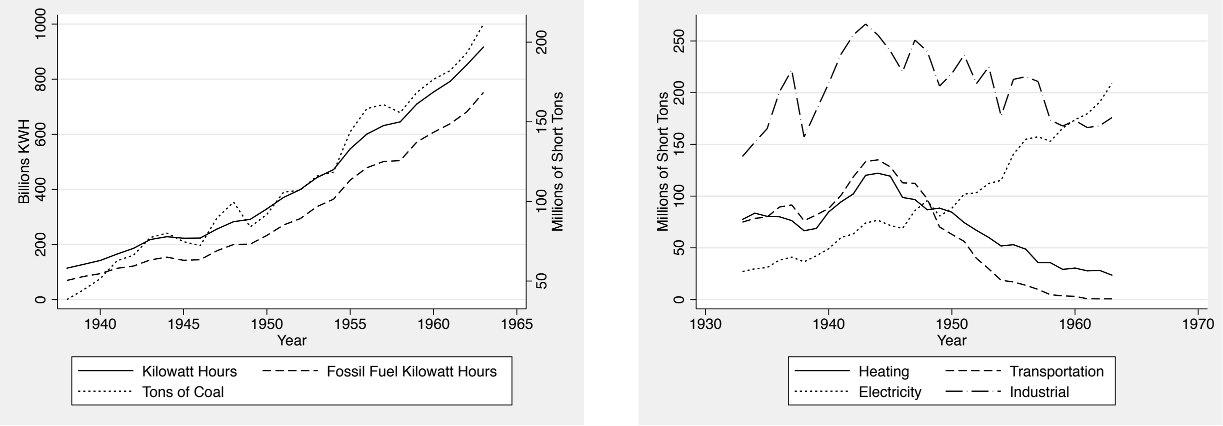
Notes: The table reports the fixed effects estimates of equation (2) estimated for decadal census years 1940, 1950, and 1960. The dependent variables are infant mortality rate, median monthly rental rate (in logs), and median housing value (in logs). The variable 'Coal Consumption' denotes total power plant coal consumption within 30 miles of the county-centroid (in 100,000 tons). The variables 'Coal Capacity' denotes total coal-fired capacity within 30 miles of the county-centroid (in 100 MWs). Indicators 1(L-Electricity) and 1(H-Electricity) identify counties with low and high electricity access in 1940. Additional controls include geographic controls (time-varying controls for temperature, precipitation, degree days below 10$^o$C and degree days above 29$^o$C, and latitude and longitude interacted with year), and economic covariates (population, total employment, and manufacturing employment in 1940, all interacted with year). Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 9: Effects of Coal Consumption and Coal-Fired Capacity on Wages and Sorting, by Baseline Electricity Access

| **Dependent Variable** | **Infant Mortality Rate** | **Log Median Rent** | **Log Manufacturing Payroll per Worker** | **Log Retail Payroll per Worker** | **% Individuals ≥25 years with HS** | **% Population White** |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A. Coal Consumption within 30 Miles** | | | | | | |
| Coal Consumption × 1(L-Electricity) | -0.1760*** | 0.0028*** | 0.0009 | 0.0009 | 0.0249 | 0.0177* |
| | (0.0610) | (0.0008) | (0.0014) | (0.0007) | (0.0184) | (0.0102) |
| Coal Consumption × 1(H-Electricity) | 0.2487*** | -0.0061** | -0.0019* | -0.0026*** | 0.0271 | -0.0723** |
| | (0.0546) | (0.0024) | (0.0011) | (0.0007) | (0.0271) | (0.0321) |
| R-squared | 0.7613 | 0.9551 | 0.9011 | 0.9283 | 0.9672 | 0.9896 |
| **Panel B. Coal-Fired Capacity within 30 Miles** | | | | | | |
| Coal Capacity × 1(L-Electricity) | -0.4108** | 0.0064*** | 0.0006 | 0.0013 | 0.1357*** | 0.0801** |
| | (0.1634) | (0.0022) | (0.0030) | (0.0015) | (0.0472) | (0.0342) |
| Coal Capacity × 1(H-Electricity) | 0.3701*** | -0.0086*** | -0.0020 | -0.0043*** | 0.0814 | -0.1050*** |
| | (0.0768) | (0.0028) | (0.0013) | (0.0014) | (0.0534) | (0.0377) |
| R-squared | 0.7640 | 0.9551 | 0.9011 | 0.9284 | 0.9674 | 0.9896 |
| Observations | 3,708 | 3,708 | 3,352 | 3,707 | 3,708 | 3,708 |
| All Controls | Y | Y | Y | Y | Y | Y |

Notes: The table reports the fixed effects estimates of equation (2) estimated for decadal census years 1940, 1950, and 1960. The dependent variables are infant mortality rate, median monthly rental rate (in logs), manufacturing payroll per worker (in logs), retail payroll per worker (in logs), percent of individuals 25 years and older with a high school diploma, and the white share of the population. The variable 'Coal Consumption' denotes total power plant coal consumption within 30 miles of the county-centroid (in 100,000 tons). The variables 'Coal Capacity' denotes total coal-fired capacity within 30 miles of the county-centroid (in 100 MWs). Indicators 1(L-Electricity) and 1(H-Electricity) identify counties with low and high electricity access in 1940. Additional controls include geographic controls (time-varying controls for temperature, precipitation, degree days below 10$^{o}$C and degree days above 29$^{o}$C, and latitude and longitude interacted with year), and economic covariates (population, total employment, and manufacturing employment in 1940, all interacted with year). Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

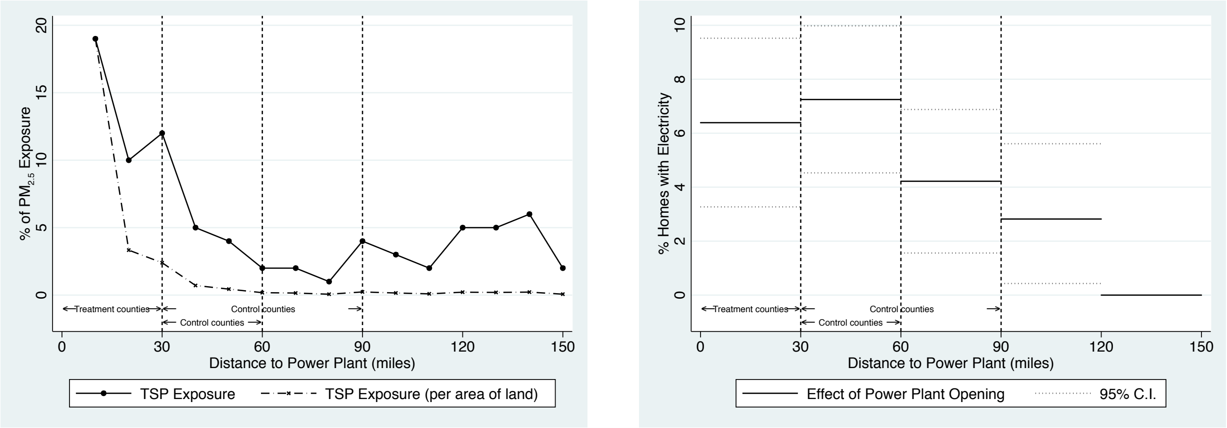
Figure 1: Trends in U.S. Electricity Generation and Coal Consumption



(a) Trends in Electricity Generation (b) Coal Consumption, by Source

Notes: (a) Data from Gartner et al., *Historical Statistics of the United States* (2006). Table Db218-227. Electric utilities-power generation and fossil fuel consumption by energy source: 1920-2000. (b) Data from United States Bureau of Mines, *Minerals Yearbook* (various years).

Figure 2: Impact of Large Coal-Fired Power Plants on $PM_{2.5}$ Exposure and Electricity Access



(a) Dispersion of $PM_{2.5}$ (b) Electricity Access

Notes: (a) Based on a study of 12 large coal-fired power plants in Illinois (Levy et al., 2002). (b) This figure plots the regression estimates from fixed effects models relating the fraction of households with electricity to the opening of large power plants (>30 MW) for the census years 1940, 1950, and 1960.

Figure 3: Tradeoffs Associated with Coal-fired Electricity Generation

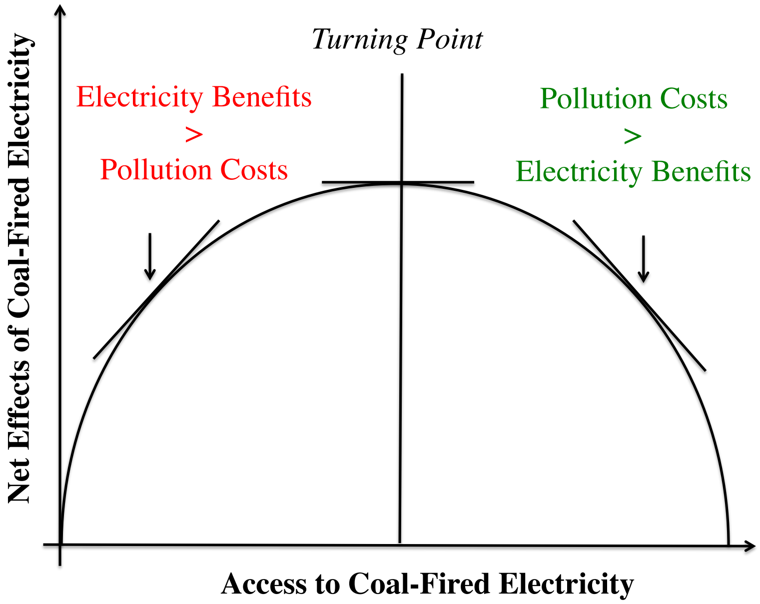
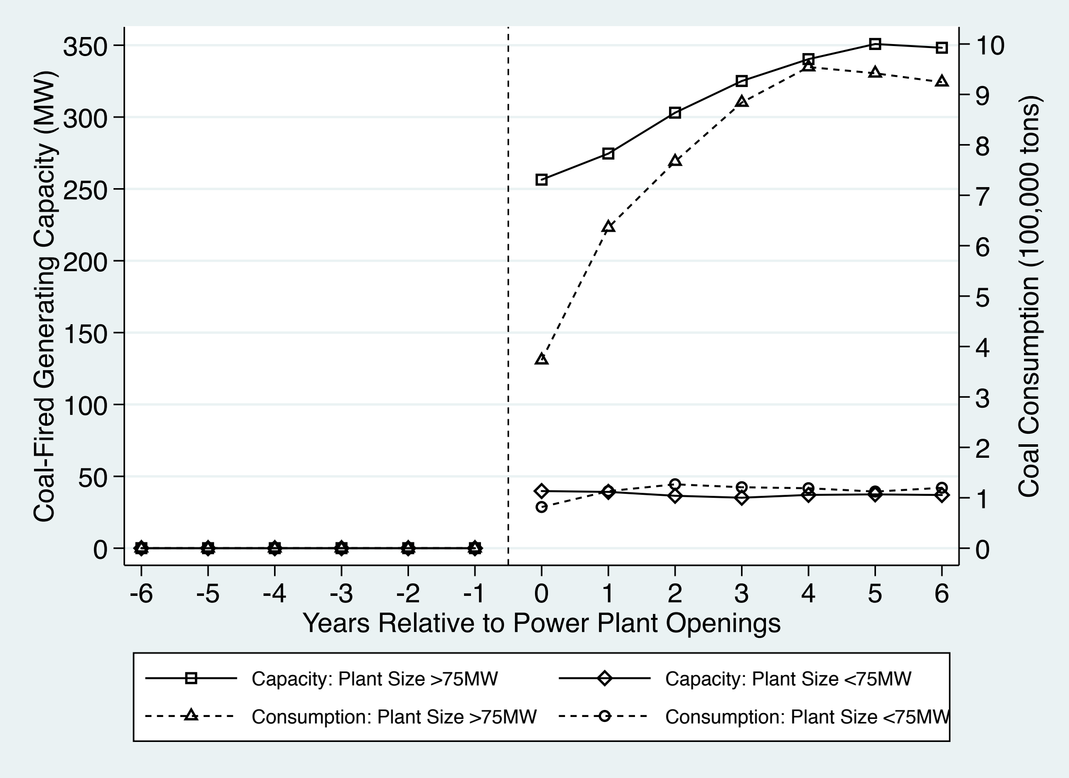
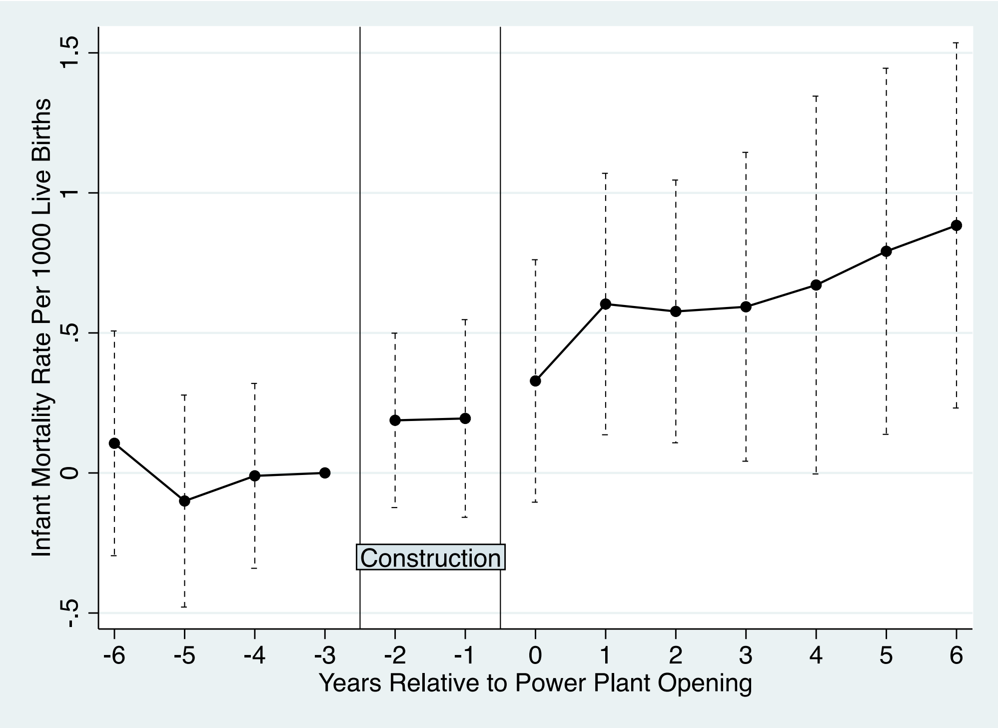


Figure 4: Generating Capacity and Coal Consumption for Large and Small Power Plants

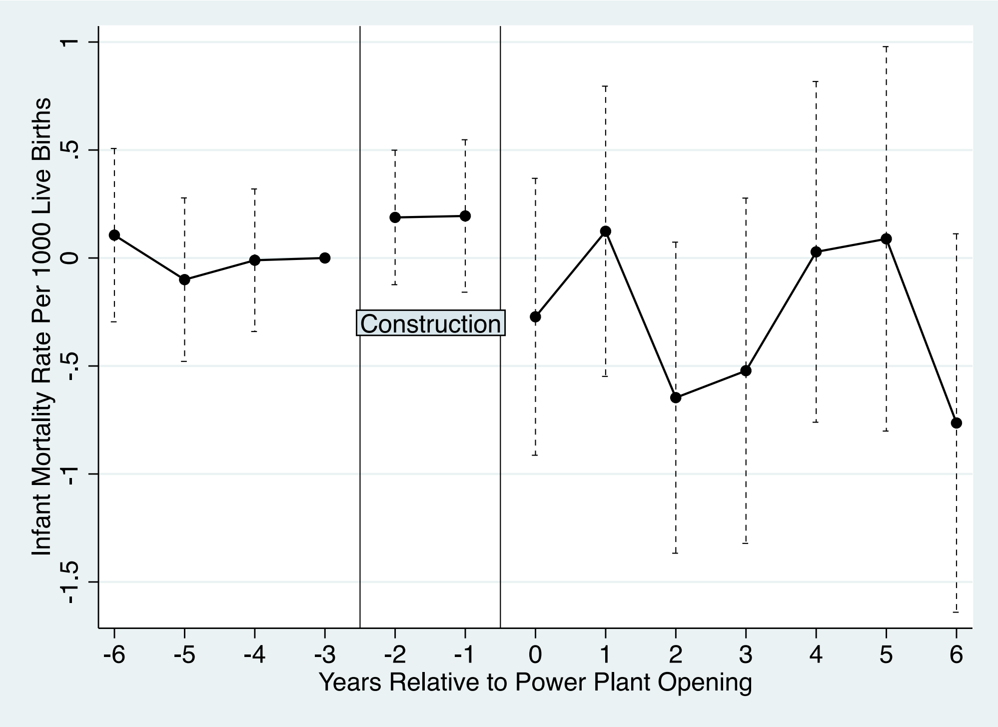


Notes: This figure reports coal-fired generating capacity (in MWs) and coal consumption (in 100,000s of tons) for the 272 large and small power plants (≷75 MW) that opened between 1938 and 1962.

Figure 5: Event Study: The Effect of Coal-Fired Power Plant Openings on Infant Mortality



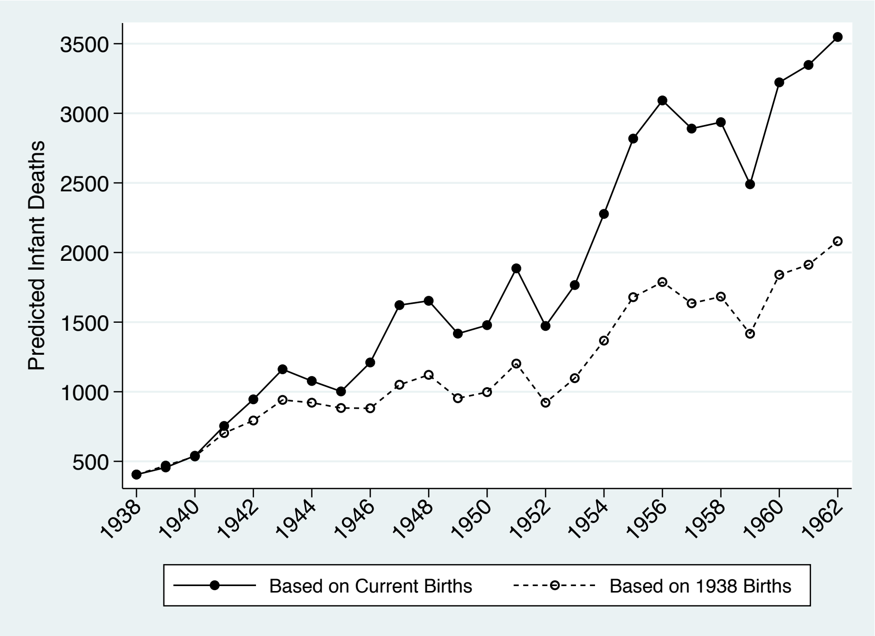
(a) Large Power Plants (>75 MW)



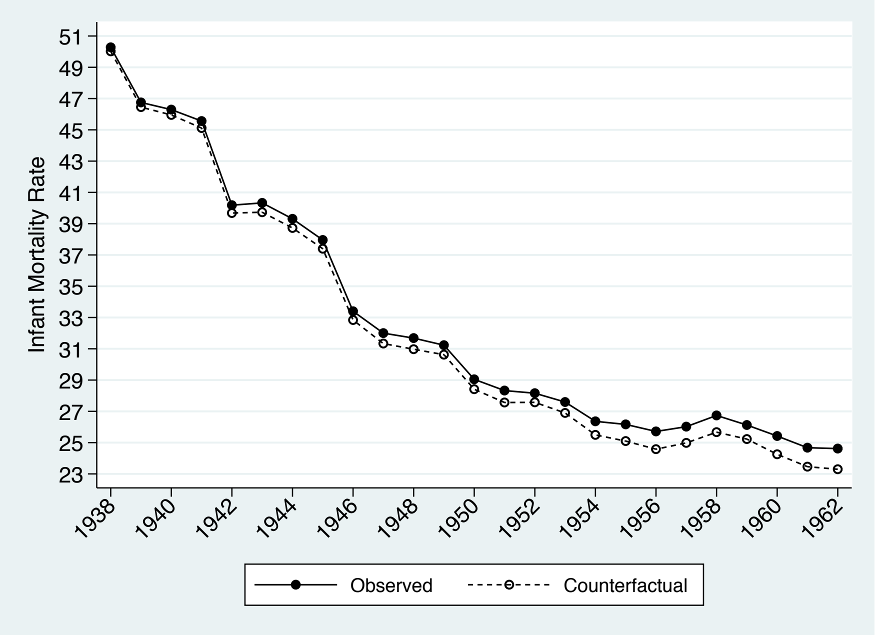
(b) Small Power Plants (<75 MW)

Notes: These figures report the event study estimates based on equation (1), separately for large and small power plant size. The coefficients plot the time path of infant mortality in 'treatment' counties (<30 miles from a power plant) relative to 'control' counties (30-90 miles from a power plant) before and after a plant opening. Vertical dashed lines denote the 95% confidence intervals based on standard errors that are clustered at the county-level.

Figure 6: Power Plants Coal Consumption and Infant Mortality



(a) Number of Infant Deaths Attributable to Power Plant Coal Consumption



(b) Effect of Power Plant Coal Consumption on the Infant Mortality Rate

Notes: (a) This figure reports number of infant deaths in the sample that are attributable to coal consumption by power plants, based on the preferred estimates in Table 4 (column 3). The number is calculated separately based on annual live births, and live births in 1938. (b) This figure reports the observed trend in the infant mortality rate in the sample and the predicted trend in infant mortality assuming coal consumption by power plants had been equal to zero. The predicted trend is derived based on the preferred estimates for coal consumption in Table 4 (column 3).

# A Appendix

## A.1 Additional Figures and Tables

Table A.1: TSP Concentration in Various Years

| Location | Time | TSP | Source |
|---|---|---|---|
| Chicago | 1912-1913 | 760 | Eisenbud (1978) |
| 14 Large US Cities | 1931-1933, Winter | 510 | Ives et al. (1936) |
| US Urban Stations | 1953-1957 | 163 | U.S. Department of Health, Education and Welfare (1958) |
| 8 of 14 Large US Cities | 1954 | 214 | U.S. Department of Health, Education and Welfare (1958) |
| US Urban Stations | 1960 | 118 | Lave and Seskin (1972) |
| 14 Large US Cities | 1960 | 143 | EPA data |
| | | | |
| US National Average | 1990 | 60 | Chay and Greenstone (2003a) |
| 58 Chinese Cities | 1980-1993 | 538 | Almond et al. (2009) |
| Worldwide | 1999 | 18% of urban pop > 240 | Cohen et al. (2004) |

Notes: The original measurements were in TSP for all of the sources except for Cohen et al. (2004). Cohen et al., Figure 17.3 (World), indicates that 18% of the urban population lived in locations where the PM10 was greater than 100. We translated the PM10 values to TSP using the following formula: PM10/0.417, where 0.417 is the empirical ratio of PM10 to TSP in their world data (Table 17.4). The estimate for 1990 is from Chay and Greenstone (2003a), Figure 1. EPA data are authors calculations based on EPA dataset for 1960.

Table A.2: Municipal Smoke Abatement Legislation Prior to 1930

| Decade | Cities Passing Legislation |
|---|---|
| 1880-1890 | Chicago, Cincinnati |
| 1890-1900 | Cleveland, Pittsburgh, St. Paul |
| 1900-1910 | Akron, Baltimore, Boston, Buffalo, Dayton, Detroit, Indianapolis, Los Angeles, Milwaukee, Minneapolis, New York, Newark, Philadelphia, Rochester, St. Louis, Springfield (MA), Syracuse, Washington |
| 1910-1920 | Albany County (NY), Atlanta, Birmingham, Columbus, Denver, Des Moines, Duluth, Flint, Hartford, Jersey City, Kansas City, Louisville, Lowell, Nashville, Portland (OR), Providence, Richmond, Toledo |
| 1920-1930 | Cedar Rapids, East Cleveland, Erie County (NY), Harrisburg, Grand Rapids, Lansing, Omaha, Salt Lake City, San Francisco, Seattle, Sioux City, Wheeling |

Notes: Stern (1982), Table III, p. 45.

Table A.3: Effects of Large and Small Power Plant Openings: Sample Counties $\leq$ 60 Miles from a Plant

| **Dependent Variable** | **Infant Mortality Rate** | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **Large Power Plants (>75 MW) vs. Small Power Plants ($\leq$75 MW)** | | | | |
| 1(Large Plant Operating) × 1(County within 30 miles) | 2.2674** | 1.6291*** | 0.9225** | 0.7669** |
| | (1.1218) | (0.4428) | (0.4170) | (0.3244) |
| 1(Small Plant Operating) × 1(County within 30 miles) | 1.4849** | 0.3288 | -0.0766 | -0.1724 |
| | (0.6994) | (0.4461) | (0.4238) | (0.3834) |
| R-squared | 0.6520 | 0.7158 | 0.7178 | 0.7261 |
| F-statistic: $\delta^{Large} = \delta^{Small}$ | 1.25 | 12.89 | 7.85 | 7.81 |
| P-value | 0.2636 | 0.0003 | 0.0051 | 0.0053 |
| Observations | 64,225 | 64,225 | 64,225 | 64,225 |
| County-Plant Pair FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| State-by-Year FE | N | Y | Y | Y |
| 1940 Manufacturing Employment × Year FE | N | N | Y | Y |
| Additional Covariates | N | N | N | Y |

Notes: The table reports the difference-in-differences estimates of equation (1). The sample is restricted to counties within 60 miles of a plant that opened between 1938 and 1962. Each column reports the point estimates from a different regression. The dependent variable in all regressions is the infant mortality rate per 1,000 live births. The variable 1(County within 30 miles) is an indicator for whether the distance between the county-centroid and the power plant is less than 30 miles. The indicators for 'Small' and 'Large' distinguish plants currently operating with $\lesseqgtr$ 75 MW of nameplate capacity. Additional covariates include geographic controls (time-varying controls for temperature, precipitation, degree days below 10$^o$C and degree days above 29$^o$C, and latitude and longitude interacted with year), demographic and economic controls (population and total employment in 1940) interacted with year, percent households with electricity in 1940 interacted with year, county-centroid distance to the power plant interacted with year, and annual nameplate power plant capacity. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table A.4: Average Effects of Power Plant Openings: Sample Counties ≤ 90 Miles from a Plant and Sample Counties ≤ 60 from a Plant

| **Dependent Variable** | **Infant Mortality Rate** | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **Sample: Counties within 90 Miles of a Power Plant** | | | | |
| 1(Any Plant Operating) × 1(County within 30 miles) | 2.0564** | 1.5073*** | 0.7738** | 0.5201** |
| | (0.9386) | (0.4120) | (0.3493) | (0.2359) |
| R-squared | 0.6441 | 0.6943 | 0.6960 | 0.7044 |
| Observations | 130,025 | 130,025 | 130,025 | 130,025 |
| **Sample: Counties within 60 Miles of a Power Plant** | | | | |
| 1(Any Plant Operating) × 1(County within 30 miles) | 2.1385** | 1.3978*** | 0.7011* | 0.5320* |
| | (1.0450) | (0.4279) | (0.3910) | (0.3079) |
| R-squared | 0.6519 | 0.7155 | 0.7176 | 0.7259 |
| Observations | 64,225 | 64,225 | 64,225 | 64,225 |
| Observations | 64,225 | 64,225 | 64,225 | 64,225 |
| County-Plant Pair FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| State-by-Year FE | N | Y | Y | Y |
| 1940 Manufacturing Employment × Year FE | N | N | Y | Y |
| Additional Covariates | N | N | N | Y |

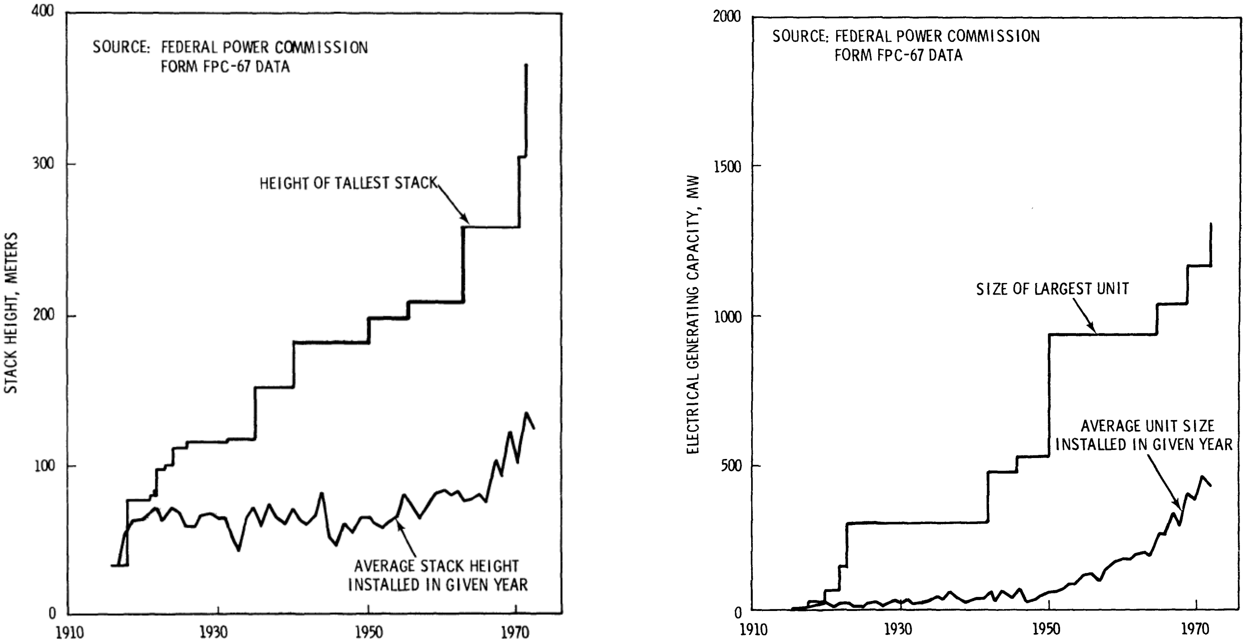
Notes: The table reports the difference-in-differences estimates of equation (1). In the top panel the sample includes counties within 90 miles of a plant that opened between 1938 and 1962, in the bottom panel the sample is restricted to counties within 60 miles of a plant. Each column reports the point estimate from a different regression. The dependent variable in all regressions is the infant mortality rate per 1,000 live births. The variable 1(County within 30 miles) is an indicator for whether the distance between the county-centroid and the power plant is less than 30 miles. Additional covariates include geographic controls (time-varying controls for temperature, precipitation, degree days below $10^{o}$C and degree days above $29^{o}$C, and latitude and longitude interacted with year), demographic and economic controls (population and total employment in 1940) interacted with year, percent households with electricity in 1940 interacted with year, county-centroid distance to the power plant interacted with year, and annual nameplate power plant capacity. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table A.5: Effects of Coal Consumption and Coal-fired Capacity: Counties within 90 Miles of a Power Plant

| **Dependent Variable** | **Infant Mortality** | | **Log Median Rent** | | **Log Median Housing Value** | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Panel A. Coal Consumption within 30 Miles** | | | | | | |
| Coal Consumption × 1(L-Electricity) | -0.2152*** | -0.1764*** | 0.0030*** | 0.0029*** | 0.0006 | 0.0019* |
| | (0.0680) | (0.0609) | (0.0009) | (0.0008) | (0.0013) | (0.0011) |
| Coal Consumption × 1(H-Electricity) | 0.2439*** | 0.2484*** | -0.0206*** | -0.0058** | -0.0148*** | -0.0029** |
| | (0.0710) | (0.0549) | (0.0042) | (0.0023) | (0.0027) | (0.0013) |
| R-squared | 0.7437 | 0.7641 | 0.9308 | 0.9570 | 0.9256 | 0.9435 |
| **Panel B. Coal Capacity within 30 Miles** | | | | | | |
| Coal Capacity × 1(L-Electricity) | -0.5794*** | -0.4122** | 0.0078*** | 0.0065*** | 0.0019 | 0.0041 |
| | (0.1897) | (0.1630) | (0.0024) | (0.0022) | (0.0029) | (0.0027) |
| Coal Capacity × 1(H-Electricity) | 0.2991*** | 0.3692*** | -0.0251*** | -0.0083*** | -0.0186*** | -0.0016 |
| | (0.0655) | (0.0773) | (0.0043) | (0.0027) | (0.0036) | (0.0023) |
| R-squared | 0.7464 | 0.7668 | 0.9306 | 0.9570 | 0.9256 | 0.9434 |
| Observations | 3,519 | 3,519 | 3,519 | 3,519 | 3,518 | 3,518 |
| County & Year FE | Y | Y | Y | Y | Y | Y |
| All Controls | N | Y | N | Y | N | Y |

Notes: The table reports the fixed effects estimates of equation (2) estimated for decadal census years 1940, 1950, and 1960. The sample is restricted to counties within 90 miles of an operational power plant at some point between 1938 and 1962. The dependent variables are infant mortality rate, median monthly rental rate (in logs), and median housing value (in logs). The variable 'Coal Consumption' denotes total power plant coal consumption within 30 miles of the county-centroid (in 100,000 tons). The variables 'Coal Capacity' denotes total coal-fired capacity within 30 miles of the county-centroid (in 100 MWs). Indicators 1(L-Electricity) and 1(H-Electricity) identify counties with low and high electricity access in 1940. Additional controls include geographic controls (time-varying controls for temperature, precipitation, degree days below 10°C and degree days above 29°C, and latitude and longitude interacted with year), and economic covariates (population, total employment, and manufacturing employment in 1940, all interacted with year). Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Figure A.1: Trends in Power Plant Smoke Stack Height and Electrical Generating Capacity

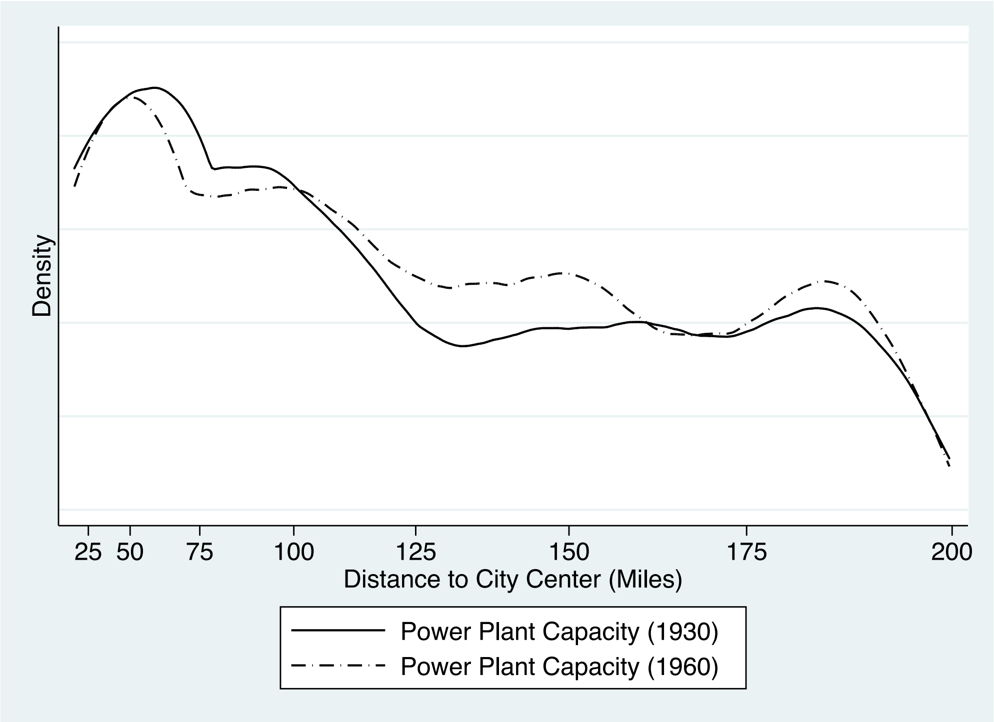


(a) Stack Height of Newly Installed Power Plants

(b) Capacity of Newly Installed Power Plants

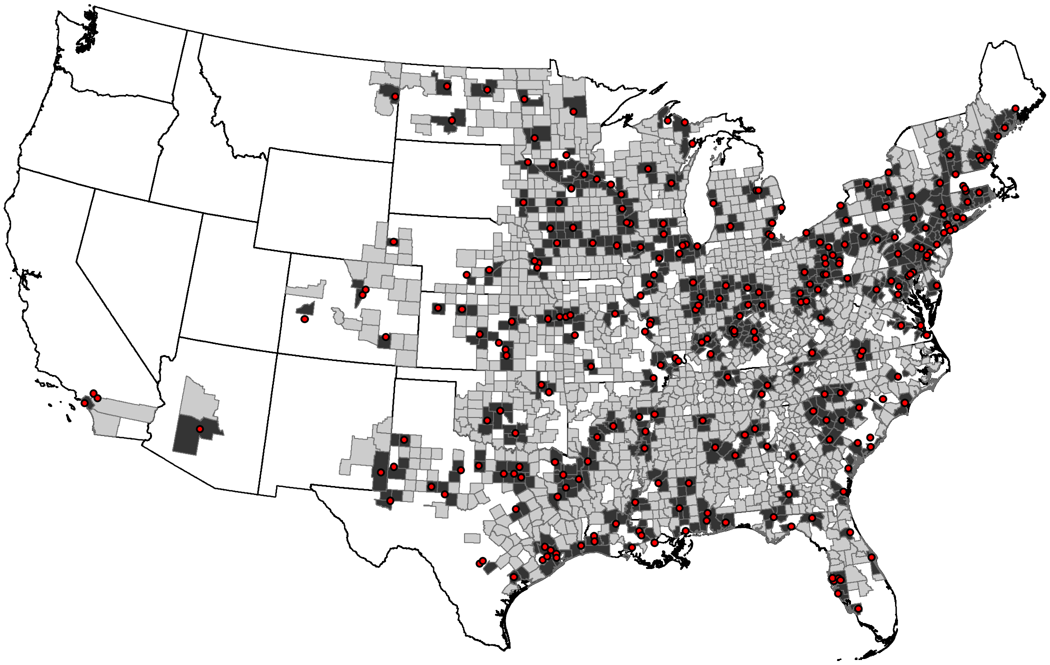
Notes: Hales (1976).

Figure A.2: Density of Coal-Fired Capacity Around 50 Largest U.S. Cities in 1930 and 1960



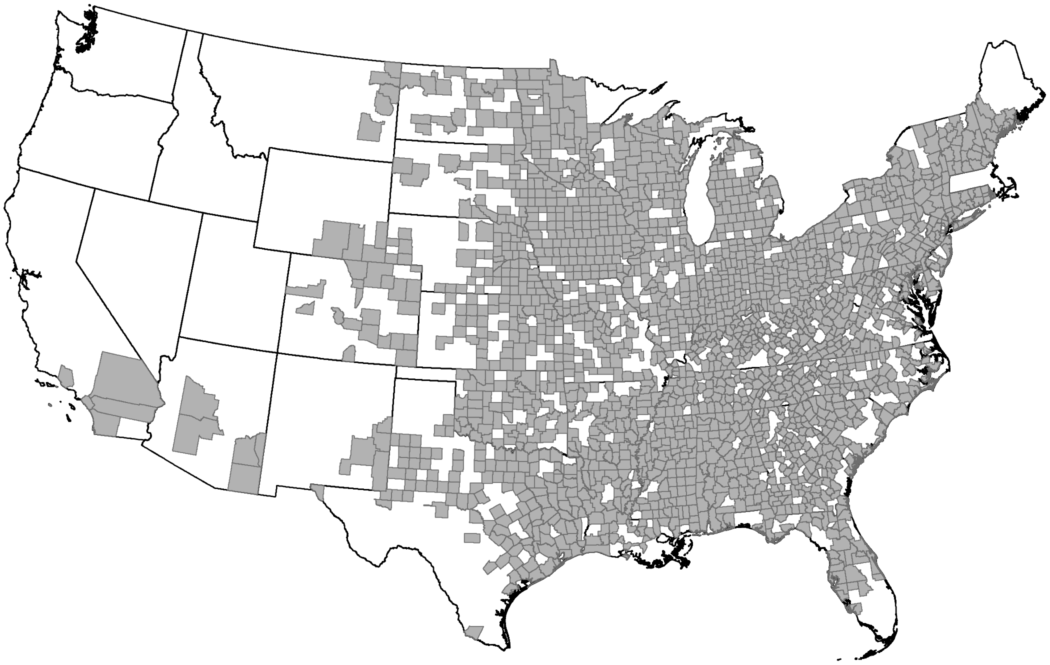
Notes: This figure reports the distribution of coal-fired capacity around the 50 largest U.S. cities in 1930 and 1960. For ease of interpretation, the x-axis is scaled such that a uniform density will appear as a horizontal line in the figure.

Figure A.3: Sample Counties for Power Plants Openings Analysis



Notes: This figure reports the sample of 1,924 counties used in the difference-in-differences. Red dots identify the 272 power plants that opened between 1938 and 1962. Black identifies 'treatment' counties (≤ 30 miles of a power plant), grey identifies 'control' counties (30-90 from a power plant).

Figure A.4: Sample Counties for Coal Consumption and Coal-Fired Capacity Analysis



Notes: This figure reports the sample of 1,983 counties used in the coal consumption and coal-fired capacity regressions.

## A.2 Conceptual Framework

In order to examine the welfare consequences of an expansion in coal-fired power generation, we develop a simple partial equilibrium model. We assume that a representative consumer of a U.S. county has a concave utility function over electricity ($E$), health ($H$), and a composite good that we call shelter ($S$). We also assume that health is a function of air quality ($A$) and access to electricity ($E$), and that there is a market for electricity and shelter, but not for air quality. Finally, we assume that air quality is directly affected by coal-fired power generation. The consumer's problem is:

$$\text{Max}_{E,S\in\mathbb{R}^2_+}\, U(E,H,S) \quad \text{s.t.} \quad dE + rS = Y, \quad H \equiv H(A,E), \quad A \equiv A(E),$$

where $d$ and $r$ represent prices of electricity and shelter, respectively, $Y$ income, $H_A \geq 0$ the slope of the pollution-mortality concentration-response function, $H_E \geq 0$ the marginal impact of electricity access on health, $A_E \leq 0$ the effect of a marginal increase in coal-fired power generation on air quality. To simplify, we define $E$ as the share of hours of the day that the representative consumer uses electricity. An expansion of coal-fired power generation allows the consumer to increase her use of electricity during the day.

The first order conditions to the consumer's problem are given by:

$$U_E + U_H \cdot \big(H_A A_E + H_E\big) = \frac{dU_S}{r}.$$

Since $U_E$, $U_H$, and $U_S$ are all positive, a tradeoff between electricity access and air pollution exists only if $A_E$ and $H_A$ are both non-zero.[43] That is, the tradeoff exists only if air pollution increases with electricity generation ($A_E < 0$), and health outcomes deteriorate with polluion ($H_A > 0$). When both conditions are met, the impact of welfare consequences of coal-fired generation will depend on the level of electricity access. At low levels of access, the marginal benefit of an increase in generation will tend to outweigh the pollution costs. As a result of concavity, the marginal benefit will decrease as electricity production increases, and eventually be outweighed by the pollution costs. This simple setup provides a microfoundation for the relationship depicted in Figure 3.

---

[43] Notice that this setup is a variation of Greenstone and Jack (2015) framework used to evaluate why developing countries have a low marginal willingness to pay for environmental quality. One of their leading explanation is that, due to low income levels, citizens of those countries value increases in income more than marginal improvements in environmental quality.

## A.3 Data Appendix

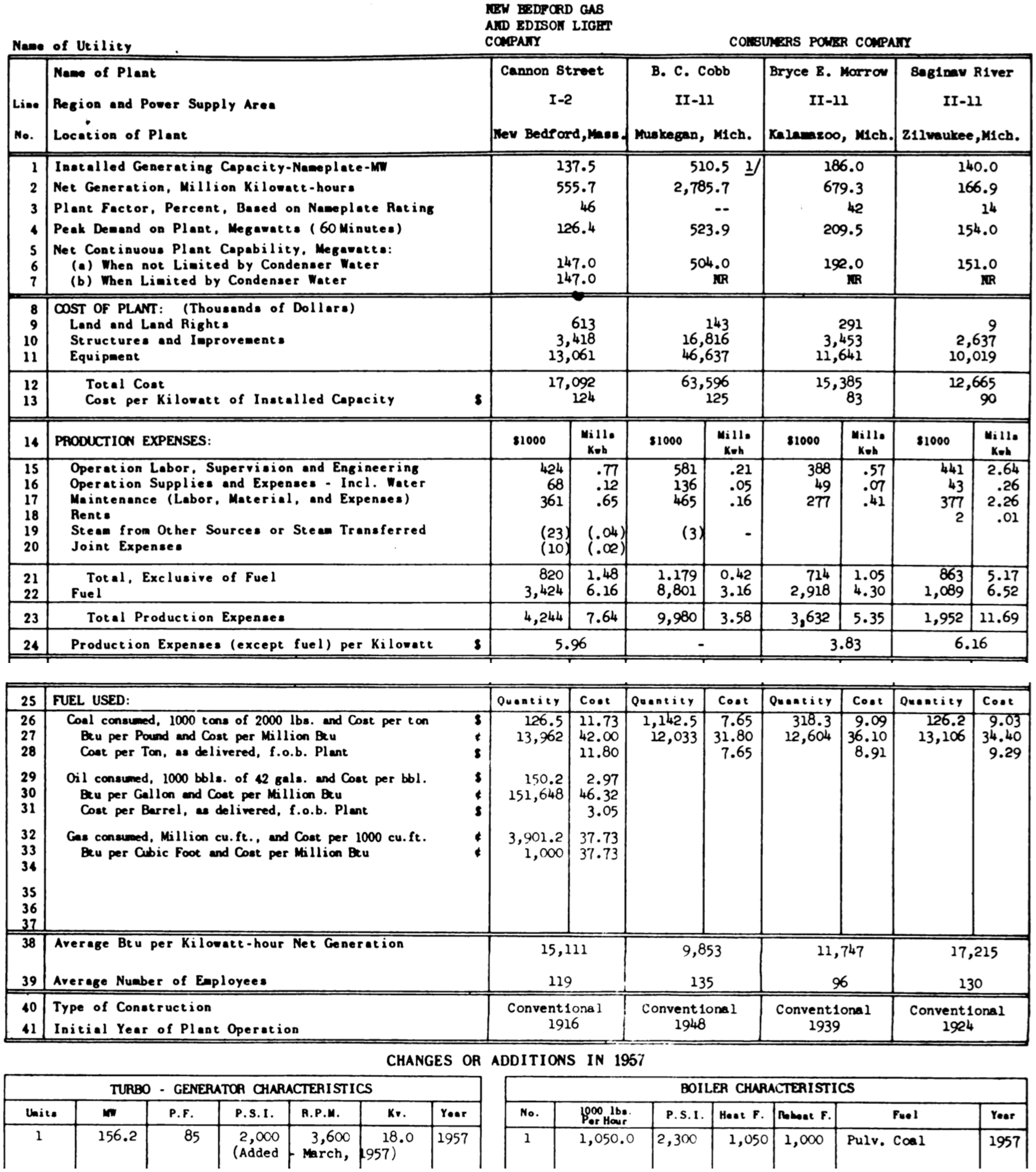
### A.3.1 Power Plant Data

We have digitized power plant level data from the Federal Power Commission reports for the years 1938-1962. These are the titles of the reports:

1938-1947: *Steam-Electric Plant Construction Cost and Annual Production Expenses, 1938-1947*

1948-1962: *Steam-Electric Plant Construction Cost and Annual Production Expenses* (Annual Supplements)

As an example, we present a page from the 1957 report:



| Line No. | Name of Utility | | NEW BEDFORD GAS AND EDISON LIGHT COMPANY | | CONSUMERS POWER COMPANY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Name of Plant | | Cannon Street | | B. C. Cobb | | Bryce E. Morrow | | Saginaw River | |
| | Region and Power Supply Area | | I-2 | | II-11 | | II-11 | | II-11 | |
| | Location of Plant | | New Bedford,Mass. | | Muskegan, Mich. | | Kalamazoo, Mich. | | Zilwaukee,Mich. | |
| 1 | Installed Generating Capacity-Nameplate-MW | | 137.5 | | 510.5 1/ | | 186.0 | | 140.0 | |
| 2 | Net Generation, Million Kilowatt-hours | | 555.7 | | 2,785.7 | | 679.3 | | 166.9 | |
| 3 | Plant Factor, Percent, Based on Nameplate Rating | | 46 | | -- | | 42 | | 14 | |
| 4 | Peak Demand on Plant, Megawatts (60 Minutes) | | 126.4 | | 523.9 | | 209.5 | | 154.0 | |
| 5 | Net Continuous Plant Capability, Megawatts: | | | | | | | | | |
| 6 | (a) When not Limited by Condenser Water | | 147.0 | | 504.0 | | 192.0 | | 151.0 | |
| 7 | (b) When Limited by Condenser Water | | 147.0 | | NR | | NR | | NR | |
| 8 | COST OF PLANT: (Thousands of Dollars) | | | | | | | | | |
| 9 | Land and Land Rights | | 613 | | 143 | | 291 | | 9 | |
| 10 | Structures and Improvements | | 3,418 | | 16,816 | | 3,453 | | 2,637 | |
| 11 | Equipment | | 13,061 | | 46,637 | | 11,641 | | 10,019 | |
| 12 | Total Cost | | 17,092 | | 63,596 | | 15,385 | | 12,665 | |
| 13 | Cost per Kilowatt of Installed Capacity | $ | 124 | | 125 | | 83 | | 90 | |
| 14 | PRODUCTION EXPENSES: | | $1000 | Mills Kwh | $1000 | Mills Kwh | $1000 | Mills Kwh | $1000 | Mills Kwh |
| 15 | Operation Labor, Supervision and Engineering | | 424 | .77 | 581 | .21 | 388 | .57 | 441 | 2.64 |
| 16 | Operation Supplies and Expenses - Incl. Water | | 68 | .12 | 136 | .05 | 49 | .07 | 43 | .26 |
| 17 | Maintenance (Labor, Material, and Expenses) | | 361 | .65 | 465 | .16 | 277 | .41 | 377 | 2.26 |
| 18 | Rents | | | | | | | | 2 | .01 |
| 19 | Steam from Other Sources or Steam Transferred | | (23) | (.04) | (3) | - | | | | |
| 20 | Joint Expenses | | (10) | (.02) | | | | | | |
| 21 | Total, Exclusive of Fuel | | 820 | 1.48 | 1.179 | 0.42 | 714 | 1.05 | 863 | 5.17 |
| 22 | Fuel | | 3,424 | 6.16 | 8,801 | 3.16 | 2,918 | 4.30 | 1,089 | 6.52 |
| 23 | Total Production Expenses | | 4,244 | 7.64 | 9,980 | 3.58 | 3,632 | 5.35 | 1,952 | 11.69 |
| 24 | Production Expenses (except fuel) per Kilowatt | $ | 5.96 | | - | | 3.83 | | 6.16 | |
| 25 | FUEL USED: | | Quantity | Cost | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| 26 | Coal consumed, 1000 tons of 2000 lbs. and Cost per ton | $ | 126.5 | 11.73 | 1,142.5 | 7.65 | 318.3 | 9.09 | 126.2 | 9.03 |
| 27 | Btu per Pound and Cost per Million Btu | ¢ | 13,962 | 42.00 | 12,033 | 31.80 | 12,604 | 36.10 | 13,106 | 34.40 |
| 28 | Cost per Ton, as delivered, f.o.b. Plant | $ | | 11.80 | | 7.65 | | 8.91 | | 9.29 |
| 29 | Oil consumed, 1000 bbls. of 42 gals. and Cost per bbl. | $ | 150.2 | 2.97 | | | | | | |
| 30 | Btu per Gallon and Cost per Million Btu | ¢ | 151,648 | 46.32 | | | | | | |
| 31 | Cost per Barrel, as delivered, f.o.b. Plant | $ | | 3.05 | | | | | | |
| 32 | Gas consumed, Million cu.ft., and Cost per 1000 cu.ft. | ¢ | 3,901.2 | 37.73 | | | | | | |
| 33 | Btu per Cubic Foot and Cost per Million Btu | ¢ | 1,000 | 37.73 | | | | | | |
| 34 | | | | | | | | | | |
| 35 | | | | | | | | | | |
| 36 | | | | | | | | | | |
| 37 | | | | | | | | | | |
| 38 | Average Btu per Kilowatt-hour Net Generation | | 15,111 | | 9,853 | | 11,747 | | 17,215 | |
| 39 | Average Number of Employees | | 119 | | 135 | | 96 | | 130 | |
| 40 | Type of Construction | | Conventional | | Conventional | | Conventional | | Conventional | |
| 41 | Initial Year of Plant Operation | | 1916 | | 1948 | | 1939 | | 1924 | |

CHANGES OR ADDITIONS IN 1957

TURBO - GENERATOR CHARACTERISTICS

| Units | MW | P.F. | P.S.I. | R.P.M. | Kv. | Year |
|---|---|---|---|---|---|---|
| 1 | 156.2 | 85 | 2,000<br>(Added | 3,600<br>- March, | 18.0<br>1957) | 1957 |

BOILER CHARACTERISTICS

| No. | 1000 lbs. Per Hour | P.S.I. | Heat F. | Reheat F. | Fuel | Year |
|---|---|---|---|---|---|---|
| 1 | 1,050.0 | 2,300 | 1,050 | 1,000 | Pulv. Coal | 1957 |

### A.3.2 Infant Mortality Data

We have digitized the following tables of the Vital Statistics of the United States for the years 1952-1958:

1952-1954: Table 18
1955-1956: Table 19
1957: Table 24
1958: Table 25

*Reference*: U.S. Department of Health, Education, and Welfare (HEW). (Various Years). Marriage, Divorce, Natality, Fetal Mortality and Infant Mortality Data. *Vital Statistics of the United States (Volume I)*. Washington, DC: U.S. Government Printing Office.

Data for the state of Massachusetts are only available at the state level for years 1953 and 1954. This is the explanation given in the introduction of Volume I of the *Vital Statistics of the United States*: "Errors in the transcription of birth and death certificates in the Massachusetts State office made it undesirable to tabulate data by place of residence for the individual urban places and counties in that State. Figures for 1953 [1954] are shown only for the State as a whole" (U.S. HEW, 1955 [1956], page XIII). Because our analysis is based on a balanced panel of U.S. counties for the period 1938-1962, Massachusetts counties are excluded.