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CANARY IN A COAL MINE:
INFANT MORTALITY, PROPERTY VALUES, AND TRADEOFFS ASSOCIATED WITH MID-20TH CENTURY AIR POLLUTION

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ABSTRACT

Investments in local development and infrastructure projects often generate negative externalities such as pollution. Previous work has either focused on the potential for these investments to stimulate local economic activity or the health costs associated with air pollution. This paper examines the tradeoffs associated with the historical expansion in coal-fired electricity generation in the United States, which fueled local development but produced large amounts of unregulated air pollution. We focus on a highly responsive measure of health tradeoffs: the infant mortality rate. Our analysis leverages newly digitized data on all major coal-fired power plants for the period 1938-1962, and two complementary difference-in-differences strategies based on the opening of power plants and new generating units at existing sites. We find that coal-fired power plants imposed large negative health externalities, which were partially offset by the benefits from local electricity generation. We uncover substantial heterogeneity in these tradeoffs, both across counties and over time. Expansions in coal capacity led to increases in infant mortality in counties with high base- line access to electricity, but had no effect in low-access counties. Initial expansions in coal capacity led to decreases in infant mortality, but subsequent additions led to increases in infant mortality. These evolving tradeoffs highlight the importance of accounting for both current and future payoffs when designing environmental regulation.

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1 Introduction

Societal investments in local development and infrastructure projects can attract industry, create jobs, and increase local economic activity. But these projects can also generate negative externalities such as local air pollution. Empirical studies have either focused on the potential for these investments to stimulate economic activity or the health costs associated with air pollution. A theoretically grounded assessment of net value includes not only the potential of a project to produce the desired economic outcomes relative to the up-front costs, but also the externalities that are created. Policy analysis in this context can entail complex tradeoffs, since economic beneficiaries will typically differ from those bearing the external costs, and the benefits and costs may accrue differentially across generations.

This paper examines the tradeoffs associated with the historical expansion in coal-fired electricity generation in the United States. The mid-twentieth century witnessed a sharp rise in electricity generated by coal-fired power plants, which fueled local industrial activity, created jobs, and brought electricity to American households, but also produced large amounts of unregulated air pollution. This context provides a unique opportunity to evaluate the negative externalities and local benefits associated with a large scale investment project. We combine newly digitized detailed data on the location, year of opening, and characteristics of all major coal-fired power plants with annual county-level infant mortality rates for the period 1938-1962. Infants are acutely sensitive to contemporaneous environmental air pollution and the benefits arising from electricity access. Thus the infant mortality rate provides a measure of these tradeoffs, with infants serving as the proverbial "canary in a coal mine".

Our study brings together the two distinct literatures on the effects of local economic development projects and on the health externalities from air pollution. We assess both the local costs and benefits of coal-fired electricity generation, an important driver of local development and a major source of pollution. On the one hand, empirical work has demonstrated the potential for these projects to create jobs, stimulate economic activity, and generate local economic spillovers, but has largely overlooked the adverse side effects (Greenstone, Hornbeck and Moretti, 2010; Kline and Moretti, 2014; Donaldson and Hornbeck, 2016).[1] On the other hand, previous studies have estimated large health costs associated with air pollution, but typically do not account for the potential benefits from polluting activities (Chay and Greenstone, 2003a; Currie and Neidell, 2005; Currie and Walker, 2011; Schlenker and Walker, 2016). The mid-twentieth century expansion in coal-fired generation allows us to contrast the benefits from local electricity access against the costs from unregulated pollution. Additionally, wide differences in initial county conditions and an extended 25-year horizon allow us to explore the sources of these tradeoffs and track their evolution over time.

Our empirical analysis relies on two complementary difference-in-differences estimation strategies. Our first strategy relies on the sharp change in local amenities resulting from new power plant openings in an event-study framework. We compare changes in infant mortality rates between exposed counties to changes in infant mortality rates in counties at slightly further distances that trended similarly along observable characteristics, but which were largely unaffected by either the increase in electricity generation or air pollution. Our second strategy relies on variation in local capacity from both new power plant openings and the openings of new generating units at existing sites. We compare relative changes in infant mortality rates across counties exposed to different capacity changes within the same state that trended similarly along a range of baseline observable characteristics.

We combine these research strategies with two additional sources of variation to shed light on the tradeoffs associated with coal-fired generation. First, we exploit differences in baseline generating capacity to investigate treatment heterogeneity according to initial county access to electricity. We also leverage the 25-year period to track the evolution of the health tradeoffs as local coal-fired generating capacity expanded.

The results reveal clear tradeoffs associated with coal-fired generation. In counties with low baseline access to electricity, infant mortality was *unaffected* by coal capacity changes,

[1] Other major infrastructure projects examined by previous studies include electricity Dinkelman (2011), Lipscomb, Mobarak and Barham (2013), and Allcott, Collard-Wexler and O'Connell (2016), railways (Haines and Margo, 2008; Atack et al., 2010; Donaldson, 2018), highways (Baum-Snow, 2007; Michaels, 2008; Faber, 2014), and dams (Duflo and Pande, 2007; Severnini, 2014).

consistent with the health benefits from increased access having offset the health costs from air pollution.[2] Similarly, we estimate that hydroelectric capacity – which expanded electricity access, but produced no emissions – led to *decreases* in infant mortality. In contrast, in high-access counties, coal capacity expansions *increased* infant mortality significantly. These patterns are consistent with Hanlon (2016), who shows that urban development during England's Industrial Revolution was significantly slowed by pollution externalities. At the same time, our findings highlight the potential for electricity infrastructure investments to spur growth in underdeveloped regions, and to expand household electricity access (Kline and Moretti, 2014; Lewis, 2018).

We show that the mid-twentieth century witnessed a remarkable reversal in the relationship between coal-fired generation and infant mortality. Prior to 1950, coal-fired generation was associated with net *decreases* in infant mortality; after 1950, coal-fired generation was associated with net *increases* in infant mortality. This shift could reflect national-level changes, such as the broad expansion of transmission infrastructure, which extended electricity services more broadly. Since plant emissions remained locally concentrated, a diffusion of benefits may have increased the net local costs of coal-fired generation.[3] Alternatively, the reversal could reflect decreasing marginal benefits from generating capacity as electricity infrastructure expanded locally. To explore the forces underlying the reversal, we exploit within-county heterogeneity according to the timing of capacity additions. We estimate models that allow the effects of new capacity additions to vary according to the vintage of the existing local stock, controlling for the national-level evolution in health tradeoffs. We find that within the first decade of a plant opening, capacity expansions led to *decreases* in

[2]The health benefits may have arisen through both household electricity access – improved sanitation from modern appliances, improved indoor air quality from the elimination of coal cookstoves – and broad-based local economic development. Meanwhile, the pollution costs per unit of generating capacity were largely similar across localities. Prior to the passage of the 1963 Clean Air Act, electric utilities took virtually no steps to limit emissions. Innovations in boiler efficiency did reduce the emissions produced per ton of coal burned, and a modest rise in smokestack heights further decreased local exposure. We explore these possibilities in the analysis.

[3]Notably, the evolving tradeoffs run counter to other innovations in power plants, such as improved efficiency and increased smokestack heights, which should have mitigated the local health costs of emissions.

infant mortality; beyond 10 years, subsequent capacity additions led to *increases* in infant mortality. These results suggest that the reversal in the coal capacity-infant mortality relationship can largely be attributed to a decline in the marginal benefits of capacity additions as the existing local stock expanded, rather than the broad-based expansion of the electricity grid.

The striking reversal in the coal capacity-infant mortality relationship highlights the challenges facing policymakers. While demand for intervention may arise only when the negative externalities exceed the perceived local benefits, efficient regulations must account for the discounted stream of future benefits and costs. Given the lifespan of power plants and the high cost to retrofit these facilities with emissions controls, contemporary regulatory decisions may have consequences for decades. These results are particularly relevant for energy and environmental policies in developing countries today, where pollution concentrations are elevated and continue to rise, and where new coal-fired power plants continue to open with little or no emissions controls (Alpert, Shvainshtein and Kishcha, 2012; Zhang, 2016).[4]

The findings lead us to examine a variety of alternative mechanisms that might account for the local tradeoffs associated with coal-fired generating capacity. We explore the benefits arising from two channels: the potential for coal capacity to increase household electricity access and to stimulate local economic activity. To shed light on the first channel, we focus on potential benefits from improvements in household hygiene that emerged from access to pumped water, refrigeration, and washing machines, and improvements in household air quality caused by the elimination of coal cookstoves. The evidence supports both these mechanisms: expansions in coal-fired capacity had differentially positive effects on infant health in locations that had higher incidence of sanitation-related mortality and where households

[4] A further contribution of this study is to provide comprehensive evidence on the impacts of air pollution on infant health in an era when air pollution was severe, unregulated, and comparable to the levels in modern developing countries. Much of the previous research has focused on the post-Clean Air Act U.S., when air pollution levels were substantially lower and less variable across locations (Currie and Walker, 2011; Currie et al., 2015; Schlenker and Walker, 2016; Severnini, 2017). Our analysis complements previous studies examining the consequences of historical air pollution in the U.S. and the U.K. (Clay and Troesken, 2011; Hanlon and Tian, 2015; Hanlon, 2018; Beach and Hanlon, forthcoming), and current pollution in developing countries (Jayachandran, 2009; Arceo-Gomez, Hanna and Oliva, 2012).

were more reliant on coal for cooking in the baseline.[5] To assess the second channel, we estimate the effects of coal capacity on a range of local economic outcomes. We find little evidence of a broad expansion in the local economy, as captured by employment, wages, or population demographics. Instead, the effects were concentrated in the manufacturing sector, where expansions in coal-fired capacity stimulated modest employment growth in low access counties, consistent with Kline and Moretti (2014). Taken together, the results suggest that both changes in household technology and local economic development may have contributed to improvements in infant health in low access areas.

The paper proceeds as follows: Section 2 discusses the tradeoffs from mid-twentieth century coal-fired generation. Section 3 describes our data. Section 4 presents our empirical framework. Section 5 reports our findings. Section 6 discusses the historical implications of the findings, and relevance for the developing world. Section 7 concludes.

2 Costs and Benefits of Coal-fired Generation

Coal-fired electricity generation rose substantially during the mid-twentieth century. 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 (Figure 1a). This expansion was associated with important local tradeoffs: the costs from exposure to unregulated power plant emissions, and the benefits from increased local generating capacity. In this section, we briefly discuss why infant health is a useful indicator of these tradeoffs, and then describe the costs and benefits associated with coal-fired generation in greater detail.

Our analysis of the tradeoffs associated with coal-fired electricity generation focuses on infant health as measured by the infant mortality rate. Infants are acutely sensitive to contemporaneous environmental conditions, and given their young age, concerns regarding unmeasured past exposure are largely mitigated. The infant mortality rate has been widely

[5] These findings support evidence on the effects of indoor air pollution both historically and in the current developing countries context (Barreca, Clay and Tarr, 2014; Hanna, Duflo and Greenstone, 2016).

used to measure the effects of air pollution (Chay and Greenstone, 2003a,b; Currie and Neidell, 2005; Currie et al., 2014).[6] There is also a growing literature that documents the numerous benefits of electricity access for infant health (Barron and Torero, 2017; Lewis, 2018). Although the costs and benefits of coal-fired generation may accrue to other age groups, the infant mortality rate provides a highly responsive summary measure of the local tradeoffs.[7]

Coal-fired power plants were an important contributor to air pollution.[8] From 1938 to 1962, the share of domestic coal consumption by electric utilities increased from 15 to 54 percent, as other uses such as coal for home heating and coal for railways declined (Figure 1b). Air pollution from coal-fired power plants was locally concentrated. Figure 2 plots the average density of PM2.5 by distance to the source, based on nine power plants in Illinois in 1988 (Levy et al., 2002). Virtually all exposure was concentrated within 30 miles of plant: the average resident within 30 miles was exposed to concentrations that were 11 times greater than the average resident located between 30 and 90 miles from a plant.[9] 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 considerably below current levels (see Figure A.1a).[10]

[6]Infant health is affected by air pollution through both prenatal exposure (Currie and Walker, 2011), and postnatal exposure (Woodruff, Darrow and Parker, 2008; Arceo-Gomez, Hanna and Oliva, 2012).

[7]Unlike effects on all-age mortality, which may be concentrated among individuals who were very ill (Spix et al., 1993; Lipfert and Wyzga, 1995), results found for infant mortality are also likely to represent meaningful impacts for life expectancy, which has been another outcome of interest in recent studies (Chen et al., 2013; Ebenstein et al., 2017).

[8]Monitoring of air pollution was rare before the 1950s, but sporadic readings during the first half of the twentieth century suggest that air pollution was severe and comparable to levels found in cities in developing countries today (see Table A.1). Data for a sample of 85 counties from 1957-1962 also show a strong relationship between local coal-fired capacity and TSP concentrations (Table A.4).

[9]This dispersion pattern is similar to more recent estimates conducted by the EPA (EPA, 2011).

[10]The sole mitigation of pollution came from siting larger plants farther from population centers, as advances in transmission technology allowed electricity to be shipped over longer distances (see Figure A.1b for the changes in power plant size over time). As transmission constraints eased, cost factors – such as local availability of fuel and water sources – played an increasingly important role in power plant site selection. Similarly, the desire to integrate the grid across markets led to the siting of plants in locations accessible to

Proximity to power plants played a critical role in determining whether households electrified, which brought direct benefits to infant health (Lewis, 2018).[11] Electric lights replaced kerosene lamps, which were highly polluting (Lam et al., 2012; Barron and Torero, 2017). The substitution of electric ranges for coal cookstoves also contributed to a better household air quality.[12] Although less harmful than open hearth cooking, as is common in many developing countries today, properly ventilated coal stoves still produce substantial amounts of residential air pollution (Evans et al., 2002; Hanna, Duflo and Greenstone, 2016).

Electricity also brought access to a range of new household technologies that indirectly benefited infant health. Modern appliances, such as vacuum cleaners, electric ranges, and washing machines, reduced the time required for basic housework, which allowed women to reallocate time to activities that promoted child health (Mokyr, 2000).[13] Without electricity, clothes washing and ironing alone required 9 to 11 hours of work per week (USDA, 1944). In rural areas, electric pumps brought access to indoor water, greatly reducing the time-cost and physical ardor of housework.[14] Many modern technologies also brought improvements to home sanitation. The diffusion of washing machines led to more frequent laundering, including of diapers (Wilson, 1929). Access to pumped water allowed for hygienic food preparation, increased hand washing, and sterilization of bottles. Refrigerators reduced exposure to food-borne bacteria (Meckel, 1990).

Expansions in coal-fired electricity generation may have improved infant health indirectly through their impact on local economic conditions (Hoynes, Miller and Simon, 2015). Increased local electricity infrastructure may have stimulated growth in the manufacturing

multiple markets. However, there is little evidence that concerns over public health played a significant role in this trend.

[11] In 1940, less than three-quarters of U.S. households had access to electricity.

[12] In 1940, only 5.4 percent of the households had electric ranges. That percentage increased considerably to 15 in 1950 and 30.8 in 1960 (USBC, 1963, p. XL, Table U). This increase mirrored the decline of coal cookstoves, which decreased from 11.5 percent in 1940 to 7.8 percent in 1950 to 1.1 percent in 1960 (USBC, 1963, p. XL, Table U).

[13] Messages that encouraged mothers to improve household health and hygiene were common in popular magazines and promoted by federally funded publicity campaigns (Ewbank and Preston, 1989; Moehling and Thomasson, 2012).

[14] A study of a half-million farm households found that without electricity, the average family used 1,400 gallons of well-drawn water per week, and spent more than 10 hours in water collection (Luff, 1940, p.9).

industry (Lipscomb, Mobarak and Barham, 2013; Kline and Moretti, 2014). Rural electrifiaction may have also increased higher agricultural revenue (Rud, 2012; Fishback and Kitchens, 2015; Lewis and Severnini, 2017).

Figure 3 illustrates the benefit-cost tradeoffs of increased coal-fired electricity generation as a function of current generating capacity.[15] In the absence of pollution abatement, expansions in coal-fired capacity should have similar effects on local air quality, independent of pre-existing generating capacity. In contrast, as local generating capacity increases, the marginal benefits from further capacity additions should decrease as the scope to expand electricity access diminishes. Together, the constant marginal cost and decreasing marginal benefit curve result in the inverted-U relationship between coal-fired capacity and infant mortality: at low levels of local access, expansions in capacity should tend to decrease infant mortality; at high levels of access, expansions in capacity should tend to increase infant mortality.

This simple framework highlights two ways in which the effects of coal-fired capacity are expected to vary. First, comparing across localities, expansions in coal-fired capacity should have more negative or less positive effects on infant health in places that had more generating capacity in the baseline period. Second, comparing within localities, expansions in coal-fired capacity should have more negative or less positive effects on infant health over time, since the diminishing marginal benefits from continued expansion is more likely to be overwhelmed by the constant marginal pollution costs. We explore these two predictions in the empirical analysis.

3 Data

To study the effects of coal-fired power plants on infant mortality, we digitized annual information on location, nameplate capacity, electricity generation, fuel consumption, first year of operation, and other characteristics of power plants that operated during the period

[15]In Appendix B.1, we present the microfoundations for this tradeoff.

1938 to 1962 (see Appendix B.2). In 1938, the Federal Power Commission began collecting detailed annual information on roughly 500 of the largest steam-electric power plants, representing over 90 percent of all coal-fired electricity generation nationwide (FPC, 1947, 1948-62, 1963). These data allow us to identify 270 coal-fired power plants that opened between 1938 and 1962, and more than 1,000 new generating unit openings at existing sites.

Our main outcome variable is the infant mortality rate per 1,000 live births. These data are drawn from annual volumes of the *Vital Statistics of the United States*.[16] Figure 4 displays trends in infant mortality, which decreased substantially from 1938 to 1962, particularly prior to 1950. Other outcome variables of interest are obtained from the Census of Housing and Population and the Census of Manufactures (Haines and ICPSR, 2010; USDOC and ICPSR, 2012). We obtain county-level data for decadal years 1940, 1950, and 1960 for the following outcomes: median dwelling rent, total and manufacturing employment, manufacturing and retail payroll per worker, percentage of whites, and percentage of population aged at least 25 years with a high school degree. Summary statistics are reported in Tables A.2 and A.3.

We compile information on baseline county-level characteristics including total population, total employment, manufacturing employment, an indicator for whether a county was recommended to receive a highway from the 1944 Interstate Highway System Plan (Baum-Snow, 2007; Michaels, 2008), and the total mileage of rail tracks in 1911 (Atack, 2016). Additionally, we assemble information on annual county climatic conditions from the National Oceanic and Atmospheric Administration (NOAA) including annual precipitation, average temperature, degree days below 10 degrees Celsius, and degree days above 29 degrees Celsius.

[16]Fishback et al. (n.d.) generously provided the data from 1938-1951. We digitized additional data for the period 1952-1958 (USHEW, 1952-1958*b*), and assembled the available microdata at the county level for the period 1959-1962 from the NBER Public Use Data Archive. These data are now available at ICPSR (Bailey et al., 2016).

4 Empirical Strategy

4.1 Analysis based on Coal-fired Power Plant Openings

The first research strategy is based on estimating average changes in infant mortality in counties 'near' a coal-fired power plant relative to changes in infant mortality in counties located slightly farther away before and after the plant opening. We define counties within 30 miles of a power plant as treatment counties, and counties 30 to 90 miles from a plant as control counties, based on the dispersion of particulate matter around coal-fired power plants (see Figure 2).[17] Figure A.2 depicts the 1,969 counties that form the basis of the analysis, with the dark grey shade identifying treatment counties and white representing control counties.[18]

We estimate the following regression model:

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

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).[19]

The variable $1[PPOperating]_{pt}$ 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, η_{cp}, to control for time-invariant determinants of infant mortality at a given distance from each plant.[20] It also includes a vector of

[17] In the empirical analysis, we explore the sensitivity of the results to these cutoffs.

[18] The treatment sample excludes counties exposed to multiple plant openings, while the control sample excludes counties ever treated by a plant opening.

[19] In the robustness checks, we exclude counties located 30 to 60 miles from a plant to alleviate concerns regarding spatial spillovers.

[20] In practice, the treatment indicator, $1[Near]_{cp}$, is collinear the county-plant pair fixed effects, η_{cp}, so it is suppressed from equation (1).

state-by-year fixed effects, λ_{st}, to control for state-level trends in infant mortality. The term $(Z_{cp} \times t)$ denotes a vector of time trends based on geographic characteristics (county-centroid longitude and latitude), baseline economic conditions (log of population, employment, and manufacturing employment, all measured in 1940), transportation infrastructure (an indicator for whether a county was recommended to receive a highway from the 1944 Interstate Highway System Plan, the total mileage of rail tracks in 1911), and the fraction of households with electric lighting in 1940. X_{cpt} denotes a vector of time-varying controls for hydroelectric capacity, and climatic covariates that may have influenced the dispersion of pollutants including annual precipitation, average temperature, degree days below 10 degrees Celsius, and degree days above 29 degrees Celsius. Equation (1) includes two additional research design covariates: (i) A time trend based on the distance between the county centroid and power plant. This variable ensures that identification is based on sharp changes in infant mortality following a power plant opening, rather than differential trends in outcomes based on power plant distance. (ii) Annual nameplate capacity of each coal-fired power plant. This variable ensures that all estimates capture the impact of an average sized power plant opening, so that treatment heterogeneity cannot be attributed to differences in the size of plants that opened in different locations or at different points in times.

The coefficient of interest, δ, captures the average change in the infant mortality rate following a coal-fired power plant opening in counties within 30 miles, relative to the average change in counties 30 to 90 miles away. The inclusion of the county-plant pair fixed effects, η_{cp}, ensures that δ is identified solely by the timing of the opening of power plants. Our identifying assumption is that infant mortality would have trended similarly in counties nearer and farther from a particular plant site in the absence of opening. In practice, this assumption must hold after allowing for differential trends according to baseline characteristics. We assess the validity of the approach in the next section.

The average treatment effect captured by δ may mask substantial treatment heterogeneity. Given the absence of abatement efforts, the local costs of coal-fired power plant emissions were likely to have been similar across localities. Nevertheless, the benefits from increased coal-fired generation may have differed based on pre-existing electricity infrastructure. To explore this potential treatment heterogeneity, we classify counties according to two measures of baseline electricity access: total baseline (coal and hydro) generating capacity within 30 miles in 1940, and the fraction of households with electricity in the baseline (reported in the 1940 census of population). We classify counties as either low (L) or high (H) access according to whether they had below- or above-median values. We then estimate generalized versions of equation (1), in which the effects of power plant openings (δ_L and δ_H) are allowed to differ across the two groups. These models allow us to explore underlying heterogeneity in the treatment effects according to pre-existing electricity infrastructure.

Two additional estimation details are worth nothing. First, all regressions are weighted by the number of live births. Second, robust standard errors are clustered at the county-level to adjust for heteroskedasticity and within-county serial correlation.[21]

4.2 Analysis Based on Local Variation in Coal-fired Capacity

Our second empirical strategy relies on local variation in coal-fired capacity driven by both new power plant openings and the opening of new generating units at existing facilities. This research approach offers several advantages over the 'event-study' design. Because the analysis relies on changes in coal-fired capacity due to both new power plant openings and openings of generating units at existing facilities, there is substantially more variation. The opening of new generating units at existing sites accounted for more than 80 percent of the nationwide expansion in coal-fired generating capacity from 1938 to 1962 (Figure 7a), and there were 10 times more capacity upgrades than new plant openings (Figure 7b). This additional variation allows us to identify effects over a larger sample of counties, rather than just those exposed to a plant opening. The richer variation in coal capacity also enables us to explore treatment dynamics over an extended 25-year time horizon. Figure A.3 displays the

[21] Similar results are found when standard errors are clustered at the plant level.

2,027 sample counties within 90 miles of a coal-fired power plant by the end of our sample period. Counties are shaded according to the change in coal-fired capacity from 1938 to 1962, darker shades indicating larger increases in capacity.

We adopt a continuous difference-in-differences framework, comparing changes in outcomes in counties 'near' a capacity change to changes in outcomes in counties not exposed to a capacity change. Formally, we estimate the following regression model:

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

where IMR_{ct} denotes the infant mortality rate in county c in year t. The model includes county fixed effects, η_c, and state-by-year fixed effects, λ_{st}, to account for state-level trends in infant health. Both the time varying covariates, X_{ct}, and the time trends based on the invariant covariates, Z_c, are the same as those described in equation (1). The main explanatory variable, $CoalCapacity_{ct}$, denotes coal-fired capacity within 30 miles of the county centroid.[22]

The coefficient of interest, β, captures the average change in the infant mortality rate in counties within 30 miles of a capacity change, relative to the average change in infant mortality in counties within the same state that did not experience a capacity change. We estimate both the average treatment effect, β, and the heterogenous treatment effects (β_L and β_H), based on generalized versions of equation (2) that allow for treatment heterogeneity according to baseline generating capacity, and baseline household electricity access. We also estimate the evolving treatment effects based on generalized versions of equation (2) that allow for heterogeneity according to the timing of the openings and expansions of electricity generating capacity.

The identifying assumption requires that counties within the same state with similar baseline characteristics would have experienced similar trends in infant mortality in the absence of coal capacity changes. The local exogeneity of coal-fired capacity is supported by the

[22]In the empirical analysis, we explore the sensitivity of the results to alternate distances.

conclusions of historians of the power industry, who emphasize that geographical constraints and the incentive to develop an interconnected grid were the primary determinants of power plant investment decisions, rather than local demand. For example, Hughes (1993) argues that electric utilities were "massing generating units near economic sources of energy and near cooling water, and transmitting electricity to load centers" (p. 270) using high voltage transmission lines. We explore this question in more detail in the next section.

5 Results

5.1 Coal-fired Power Plant Openings and 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 δ to vary with event time $t \in \{-10, 6\}$.[23] We distinguish three time periods: prior to power plant construction, $t \in \{-10, -5\}$, likely construction, $t \in \{-4, 0\}$, and post-opening, $t \in \{1, 6\}$.[24] To examine both the costs of air pollution and the benefits of increased generating capacity, we report the estimates separately across counties that had above- and below-median generating capacity in 1940.

Figures 6a and 6b report the event study graphs. The estimates support the underlying research design. In both high- and low-capacity counties, there is no evidence of differential pre-trends in infant mortality.[25] Throughout the five-year period prior to plant construction, infant mortality rates trended similarly in both treatment and control counties. From $t \in$

[23]Following Kline (2012), we estimate equation (1) for the period $t \in \{-11, 7\}$ but suppress the endpoint coefficients, which place unequal weight on power plants that opened early or late in the sample period. Results based on a shorter time horizon are similar in both magnitude and significance.

[24]The Federal Power Commission reports cite construction times ranging from two to four years, although they do not specify the construction period by plant. During construction, local air quality was substantially impacted by dust, equipment exhaust, and burning emissions (EPA, 1999, p1-1). Since we lack information on the exact month of opening, period $t = 0$ is assigned to the pre-opening period.

[25]Graphs for the overall effects, and by baseline household electricity access are reported in Figures A.4 and A.5, and show little evidence of pre-trends in infant mortality.

$\{-4, 0\}$, infant mortality rates rose modestly in treatment counties, consistent with increased air pollution from plant construction.

Figures 6a and 6b show striking differences in infant mortality rates post-opening. In counties with high baseline generation capacity, power plant openings are associated with increases in mortality. The relative infant mortality rate rose sharply in the first full year of power plant operation, and the gap widened with time. The timing of these increases coincides with the annual changes in power plant coal consumption post opening (Figure 4). These results are consistent with the health costs from increased pollution having outweighed the marginal benefits from increased generating capacity. In contrast, in counties with low baseline generating capacity, there was a sharp decrease in infant mortality beginning two years after a plant opening, suggesting that the benefits from increased electricity generation overwhelmed the pollution costs. Interestingly, the timing of the mortality decreases coincides with the typical lag in appliance adoption following household electrification.[26]

Table 1 presents the regression estimates from the difference-in-differences estimation strategy based on new power plant openings.[27] Column 1 includes county-plant pair fixed effects, state-by-year fixed effects, and geographic controls. Column 2 includes controls for 1940 manufacturing employment interacted with a time trend to allow for differential trends in mortality according to the initial size of the manufacturing sector, a competing source of air pollution. The last column includes the full set of controls in equation (1).

Power plant openings led to a net increase in infant mortality. Across all three specifications in Panel A, the point estimates are positive and statistically significant. The inclusion of county covariates reduces the estimates somewhat, consistent with trends in infant mortality according to initial manufacturing employment and local infrastructure over the 25-year period.[28] The preferred point estimates (col. 3) imply that an operating power plant is

[26] A 1939 survey of 72,000 farm households found that within a year of electrification, the median household had purchased just one major modern appliance (Beall, 1940, p.805).

[27] We conservatively set $t = -1$ as the reference year in all regressions. Given the modest rise in infant mortality during construction (Figures 6a and 6b), the coefficient estimates reflect a lower bound for the health damage attributable to power plant openings.

[28] The event study design exploits sharp changes in the immediate aftermath of a plant opening, rather

associated with an increase of 0.6 additional infant deaths per 1,000 live births in 'nearby' counties per year of operation, a 2.1 percent increase in the infant mortality rate.[29]

Next, we explore heterogeneity in the mortality tradeoffs according to initial county characteristics. We estimate generalized versions of equation (1) that allow the coefficient estimates to differ according to generating capacity in 1940 (Panel B), and the fraction of households with electricity in 1940 (Panel C).[30] The results show that the impact of coal-fired power plant openings on infant mortality was larger in places with more pre-existing electricity infrastructure. In low access counties, whether measured by baseline generating capacity or the fraction of households with electricity, power plant openings had no significant impact on mortality rates, and the point estimates are generally negative. These results are striking, given the sharp increase in coal-fired emissions post-opening and the strong link between air pollution and infant mortality. The findings are consistent with the health benefits from increased electricity generation having offset the pollution costs. In contrast, in counties with high baseline access, power plant openings are associated with large and significant increases in infant mortality, consistent with the pollution costs having overwhelmed the marginal health benefits from increased electricity generation. In all four specifications, the hypothesis that the coefficients are equal is rejected.

The results in Table 1 are robust to a range of alternative specifications (Table A.5). We first explore the sensitivity of the results to the 30-mile cutoff. Although pollution was locally concentrated, the benefits of increased electricity access likely extended beyond 30 miles. To explore this issue, column 2 reports estimates from regressions that exclude counties located 30 to 60 miles from a power plant. The results are similar, albeit somewhat less positive, suggesting that the benefits extended beyond the 30 mile radius. In columns 3-4, we further explore the sensitivity of the results to alternate distance cutoffs. The results

than these long-run secular trends (see Figure A.4).

[29]This result was found by dividing the estimated coefficient by the average infant mortality rate in the 'nearby' counties in our 'event-study' sample ($2.1 = 0.609/29.1$). For comparison, the current infant mortality rate in the United States is roughly 6 infant deaths per 1,000 live births.

[30]The cross-county correlation baseline generating capacity and the fraction of households with electricity in 1940 is 0.4.

are qualitatively similar. In column 5, we re-estimate models based on the logarithm of infant mortality. The results are similar in both magnitude and statistical significance. In the final two columns we further evaluate whether air pollution is the underlying determinant of the mortality increases. Columns 6-7 allow the estimated impacts of plant openings to vary according to power plant size. The results show that the negative effects on infant health were driven by large power plants.[31] In columns 8-9, we allow the effects of power plant openings to vary according to whether counties were downwind from plants. The estimated effects are systematically larger in downwind counties.

5.2 Coal Capacity and Infant Mortality

In this section, we use variation in both new plant openings and expansions at existing sites to identify the impact of coal-fired generation on infant mortality over a larger sample of counties, and to explore the evolving effects over an extended 25-year time horizon. Analogous to the 'event-study' design, the empirical approach compares changes in outcomes in counties 'near' a capacity change to changes in outcomes in counties not exposed to a capacity change.

The identifying assumption that infant mortality would have trended similarly in the absence of capacity additions is supported by two pieces of evidence. First, the size of new generating units at existing sites was comparable to initial capacity at plant openings (Figure 7b), an indication of the common features in the decision making process (Cirillo et al., 1977), that suggests that the parallel trends assumption underlying the 'event-study' analysis will continue to hold. Second, there is little evidence that pre-trends in county socioeconomic conditions predict subsequent capacity expansions. Table 2 reports the relationship between baseline county characteristics and within-state capacity changes from 1938 to 1962.[32] Although capacity expansions appear to be related to 1940 *levels* of county

[31]Large power plants may also have differentially benefited infant health through greater electricity generation post-opening, although the amount of electricity required to meet household demand could easily have been met by the smaller plants.

[32]This evaluation of pre-trends is similar to Bailey (2006) and Hornbeck and Naidu (2013).

socioeconomic conditions, *changes* in those socioeconomic conditions from 1930 to 1940 have very little predictive power for subsequent capacity changes.[33]

Table 3, Panel A, reports the net effects of coal capacity on infant mortality. Across all three specifications, the point estimates are positive and statistically significant. Our preferred estimates in column 3 imply that a one standard deviation increase in coal capacity is associated with roughly 2 additional infant deaths per 1,000 live births, a 6.5 percent increase in the infant mortality rate.[34]

The estimated effects in Table 3 are similar in magnitude to the results from the event study. Rescaling the 'event-study' estimates by the average amount of coal-fired capacity post-opening, we calculate that a 100 megawatt increase in coal capacity is associated with a 0.24 increase in infant mortality rate; an effect that compares similarly to the 0.188 average effect reported in Table 3.[35] The similarity across the two different estimation strategies, each based on different sources of variation, provides additional confidence in the finding.

Table 3, Panels B and C, show substantial heterogeneity in the health effects according to baseline electricity infrastructure. The broad patterns support the 'event-study' results. In counties with high baseline electricity access, increases in coal-fired capacity are associated with higher infant mortality rates. In low-access counties, where there was greater scope for expansions in electricity generation to benefit health, the point estimates are small and generally negative. These patterns are consistent with the converging overall trends in infant mortality (Figure 4).

The results in Table 3 are robust to a range of alternate specifications (Table A.6). The effects are similar when all counties within 150 miles of a power plant at the end of

[33]Consistent with the historical narrative of the power industry, coal-fired capacity expansions were concentrated in counties that were more urban, had larger manufacturing sectors, and higher wages and property values. Nevertheless, given the extended lifespan of these facilities, infrastructure investment decisions were largely unresponsive to contemporaneous trends in economic outcomes, consistent with the negligible R-squared values reported in columns 3 and 4.

[34]The first result was found by multiplying the estimated coefficient by the standard deviation of coal capacity ($1.98 = 0.188 \times 10.55$). The second result was found by dividing the 1.98 by the average infant mortality rate in our coal capacity sample ($6.5 = 1.98/30.4$).

[35]This result was found by dividing the estimated coefficient by the average increase in coal capacity after the power plant openings in our 'event-study' sample ($0.24 = 0.609/2.55$).

our sample period are included in the analysis (col. 1), and when we restrict the sample to counties within 30 miles of a power plant (col. 2). Notably, the latter set of results are based solely on within-county variation in the timing of capacity expansions, since all counties belong to the 'treatment' sample. Columns 3 and 4 show that the effects are similar, albeit smaller in magnitude, under alternate 50-mile and 100-mile treatment radii, consistent with the localized dispersion of pollutants around power plants. We also find qualitatively similar results based on the logarithm of infant mortality (col. 5). Finally, the last two columns report the results from regressions based on local hydroelectric capacity. Hydro capacity, which produced emissions-free electricity, is associated with net *decreases* in infant mortality.[36]

Next, we explore the evolving relationship between coal-fired capacity and infant mortality. Table 4, Panel A, reports the results from regressions that allow the effect of coal capacity to differ across the pre- and post-1950 periods. The results show a striking reversal in the coal capacity-infant mortality relationship: prior to 1950, coal-fired generation was associated with decreases in infant mortality; after 1950, coal-fired generation was associated with increases in infant mortality.

To shed light on this reversal, Panel B allows the evolving effects of coal capacity to vary according to baseline generating capacity. The pre-1950 point estimates for coal capacity are negative for both low-access and high-access counties. The magnitude and significance of the effects is larger in low-access counties, consistent with the increased ability to expand access in these areas relative to high-access counties. In high-access counties, the coal capacity-infant mortality relationship becomes positive and statistically significant in the post-1950 period. In low-access counties, the relationship remains negative but is statistically insignificant, and resembles the pre-1950 relationship in high-access counties. These results are consistent with the tradeoffs depicted in Figure 3: As the marginal benefits of additional capacity diminished, they were overwhelmed by the (constant) marginal health

[36]Given the limited number of hydroelectric power plant openings, there is not enough variation for us to estimate the results separately by baseline electricity access in Panels B and C.

damage from power plant emissions.[37] This shift appears to have occurred in both high- and low-access counties, albeit at different points along the cost-benefit curve.

The results in Table 4, Panels A and B, point to a broad decrease in net benefits from additional coal-fired capacity post-1950.[38] This shift could reflect national-level changes, such as the expansion in high voltage transmission in the 1950s, that reduced the reliance on local generating infrastructure (Brown and Sedano, 2004). Alternatively, it could reflect a decline in the marginal benefits from capacity additions as the stock of local electricity infrastructure increased.[39]

To separate the role of national-level changes from evolution in the local benefits, we estimate within-county models that allow the effects of coal capacity expansions to differ according to the vintage of pre-existing generating infrastructure. Specifically, we re-estimate equation (2), allowing the effects of coal capacity to differ according to whether a power plant had previously operated for at least ten years. These models also control for changes in the coal capacity-infant mortality relationship before and after 1950, implicitly allowing for national-level trends in the health tradeoffs.

Panel C shows that within the first ten years of power plant operations, coal capacity is associated with significant decreases in infant mortality, consistent with higher marginal benefits at lower levels of access.[40] After ten years, additional expansions in coal capacity led to significant increases in infant mortality. Together these results suggest that the post-1950 shift in the coal capacity-infant mortality relationship was primarily driven by local evolution in the tradeoffs: as access to electricity infrastructure became widespread, the marginal benefits from subsequent additions diminished.

[37] In fact, research on the relationship between ambient air pollution and mortality indicate that the concentration-response function is concave, so that the health damage from a marginal increase in power plant emissions was more severe pre-1950 (Goodkind, Coggins and Marshall, 2014; Pope III et al., 2015).

[38] It is unlikely that the shift was related to changes in health costs from power plant emissions. In fact, to the extent that newly built plants were more efficient, we would expect the coal capacity-infant mortality relationship to become *more* negative in the post-1950 period, exactly the opposite of these findings.

[39] By 1950, 94 percent of American homes were electrified (Lebergott, 1976, p.279), and industrial access was universal.

[40] These effects are derived from variation in capacity due both to the initial plant opening and any subsequent expansions in capacity within the first ten years of operation.

5.3 Coal-fired Capacity, Household Technology, and Infant Health

The previous results show that the health effects of coal-fired generation varied widely, both across counties and over time. Since efforts at pollution abatement were largely absent during this time period, this variation can largely be attributed to differences in the benefits associated with local coal-fired generation. In this section, we explore the extent to which electricity access and its effects on household technology can account for these heterogeneous benefits.

Expansions in local coal-fired generation may have benefited infant health through changes in household technology, which brought access to a range of modern technologies that may have benefited infant health. We focus on two broad categories of possible benefits: improvements in household hygiene and decreases in *household* air pollution.

The previous literature has emphasized the importance of sanitation improvements from access to pumped water, refrigeration, and washing machines for infant health. To explore the importance of this channel, we evaluate how the relationship between coal-fired capacity and infant mortality varied according to baseline sanitation conditions. Using state-level data on mortality by cause, we calculate the fraction of infant deaths due to diarrhea and enteritis in 1930.[41] These deaths are primary attributable to environmental factors, such as poor sanitation, poor hygiene, and unsafe drinking water (WHO, 2009, p.9). We use this measure to construct indicators for above- and below-median baseline hygiene-related mortality, and interact the main effects of coal capacity with these measures.[42]

Among low-access counties, there were large differences in the effects of coal capacity according to baseline hygiene conditions. Table 5 shows that in counties with below-median hygiene mortality, the net effect on mortality is positive and statistically significant. In contrast, the infant mortality effects are significantly *smaller* in counties that had above-

[41] We compiled data on infant mortality by cause from USBC (1930).

[42] By focusing on the fraction of infant deaths due to diarrhea-enteritis rather than the overall infant diarrhea-enteritis mortality rate, this analysis relies on heterogeneity based on cause-of-death given a particular mortality rate, rather than differences across counties in the baseline infant mortality rate.

median baseline hygiene mortality, where there was greater scope for modern technologies to improve health.

A second benefit may have occurred through reductions in *household* air pollution, as coal stoves were replaced by modern stoves. There were wide baseline cross-county differences in the use of coal for cooking: on average just 13 percent of households had coal stoves, but the gap between counties at 90th versus the 10th percentile was 36 percentage points.[43] We exploit these baseline differences in coal stove ownership to assess the importance of improvements in household air quality for infant health. We construct indicators for above- and below-median ownership rates of coal stoves in 1940, interact the main effects of coal capacity with these variables.[44]

Table 5 column 3 shows that for low-access counties, the infant mortality effects are significantly *smaller* in counties that were initially more reliant on coal for cooking, where there was more scope to improve household air quality. Among counties with low access to electricity that were also heavily reliant on coal for cooking, increases in coal-fired generating capacity led to reductions in infant mortality, despite having contributed to local air pollution through power plant emissions. Although the amount of coal burned for home cooking was substantially less than for electricity generation, the concentration of these emissions in residential neighborhoods increased exposure by a factor of ten (Smith, 1993; Evans et al., 2002).

5.4 Coal-fired Capacity, Property Values, and Economic Activity

Expansions in coal-fired generation may have influenced health indirectly through improvements in local economic conditions or changes in demographic composition. In this section, we explore the role of these non-household channels for infant mortality, and explore the extent to which the local tradeoffs were capitalized into property values (Chay and

[43]By 1960, coal stoves had been all but eliminated from American households, replaced by electric and gas stoves, with ownership rates were 30 and 64 percent, respectively.

[44]We compiled data on the share of households share of households reporting coal as the primary cooking fuel in 1940 from Bailey and Collins (2011).

Greenstone, 2005; Mendelsohn and Olmstead, 2009).

Table 6 reports the estimated effects of coal-fired capacity on various outcomes, estimated separately by baseline access and by baseline capacity. All results are estimated for decadal years 1940, 1950, and 1960.[45] For reference, column 1 reports the estimates for infant mortality based on the decennial sample. Column 2 shows that the effects in the housing market mirror those found for infant mortality. At low levels of access, coal-fired generation has positive effects on rental values. At high levels of baseline access, the effects are negative. Similarly, Panel C shows that initial expansions in coal-fired capacity led to increases in property values, while subsequent expansions led to decreases.[46] Together, these findings suggest that local residents traded off the benefits of local generation against power plant emissions.

We find some evidence of residential sorting consistent with the housing market response (Banzhaf and Walsh, 2008; Davis, 2011). In low-access counties, coal capacity expansions are associated with modest increases in the percent of white residents and the percent with a high school diploma, while in high-access counties the effects are insignificant (cols. 7-8). These demographic changes are too small to explain the heterogeneous patterns of mortality reported in Table 3. Combining the estimated changes in racial and educational composition with underlying group differences in mortality, we calculate that just 9 to 19 percent of the observed heterogeneity in mortality can be attributed to sorting.[47][48]

[45] All regressions are weighted by the number of live births to match the infant mortality analysis. Qualitatively similar results are found in unweighted regressions.

[46] We focus on rental values because they reflect contemporaneous conditions, whereas housing values also capture the anticipated future discounted flow of benefits and costs (Banzhaf and Farooque, 2013). Qualitatively similar results are found based on dwelling values.

[47] Changes in the racial composition account for 7 to 17 percent of the mortality gap, while sorting by education account for just 2 percent, consistent with the wide disparities in white/non-white infant mortality during this time period, gaps that dominated other socioeconomic indicator (Collins and Thomasson, 2005). To the extent that racial differences in mortality are partly attributable to educational differences, the sum of the two effects will overstate their combined influence.

[48] These estimates are derived by comparing the differential estimates in Table 3 (col. 3) to the differential estimates in Table 6 (col. 7 and 8) combined with overall differentials in infant mortality in 1950 by race and education. For example, the differential impact of coal capacity on the percent white is $-0.19 = (-0.051 - 0.139)$. Combined with a white versus non-white infant mortality rate differential of -17.7 in 1950, the implied mortality difference is $0.034 = (17.7 \times 0.0019)$, which accounts for $17\% = 0.034/(0.195 - 0.001)$ of the mortality differential. Following Collins and Thomasson (2005), and assuming that the individuals with

Coal capacity expansions stimulated employment growth in both low- and high-access counties (cols. 3 and 4). The effects on manufacturing employment were particularly low-access counties, consistent with electricity infrastructure fostering industrial activity in underdeveloped regions (Kline and Moretti, 2014). In contrast, we find no evidence that coal capacity expansions increased local wages (cols. 5 and 6). The effects are small and statistically insignificant in low access counties, and negative in counties with high access. These patterns are in line with Hanlon (2016), who finds that air pollution during the Industrial Revolution had negative effects on worker productivity.[49] Taken together, these results indicate that local economic development in low-access areas may also have contributed to improvements in infant health, in addition to the household channel.

6 Discussion

Our results show that there were important tradeoffs associated with coal-fired electricity generation in mid-twentieth century United States. On the one hand, unregulated power plant emissions had substantial negative effects on health. On the other hand, increases in local electricity generation appear to have improved health. These tradeoffs were not static. Instead, the marginal health benefits appear to have diminished as the stock of generating capacity increased, and by the mid-1950s, coal-fired generation was responsible for thousands of infant deaths per year.

Historically, there were technologies that could have mitigated the pollution from power plants. 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

a high school diploma obtained four more years of education than those without it, we calculate a mortality differential of 4.7 across individuals with and without a high school diploma. Together with the estimates in Table 6 (col. 8), we calculate that $2\% = (-0.014 - 0.099)/100 \times 4.7/(0.195 - 0.001)$ of the mortality gap can be attributed to sorting by education.

[49]Evidence on the impact of air pollution on labor productivity in recent years is provided by Graff Zivin and Neidell (2012), Chang et al. (2016), Chang et al. (forthcoming), and He, Liu and Salvo (forthcoming).

particulate matter (Silverman, 1950).[50] Given their high cost and the limited enforcement of clean air legislation in this period, it is not surprising that electric utilities did not voluntarily adopt these systems.[51] Nevertheless, comparing the cost of abatement to the estimated mortality effects, back-of-the-envelope calculations imply a cost per infant life saved of $102,000 to $210,000 (1990 USD), well below the estimated $1 million value of a statistical life (VSL) for the period (Costa and Kahn, 2004).

The historical U.S. context provides a point of comparison to the challenges in many developing countries today, where policymakers must balance the negative externalities associated with power plant pollution with their potential to stimulate local development. There were large potential gains from expansions in electricity infrastructure in both contexts (Dinkelman, 2011; Lipscomb, Mobarak and Barham, 2013; Lewis, 2018). In particular, given the ubiquity of open hearth cooking, the scope to improve *indoor* air quality may be substantially larger in developing countries today, since exposure from indoor sources of pollution may be more than 7 times greater than exposure from neighborhood sources (Smith, 1993).

In the intervening half century, there have been major advances in emission control that could be used to mitigate the local health impacts of coal-fired generation.[52] These new systems are both more effective at pollution mitigation and less costly. Moreover, significant improvements in the transmission and distribution of electricity have allowed plants to operate in more remote areas farther from population centers. Despite these advances, however,

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

[51] There were two primary costs associated with these systems: installation costs and fly ash disposal. For a typical large power plant the installation costs, annualized over the expected 15-year lifespan, could range from $110,000 to $750,000 (1990 USD) per year depending on the desired airflow (USHEW, 1969). The cost of fly ash disposal for electric utilities was $3.70 per ton, and the typical power plant in the sample produced between 165,000 and 198,000 tons of fly ash per year. Thus the annual cost of pollution abatement ranged from $720,000 to $1.48 million per plant.

[52] These include advances in SO2 control technologies that absorb pollutants (e.g., wet and dry flue gas desulfurization systems); advances in NOx control technologies such as combustion modification that reduce oxidation of nitrogen in the fuel (e.g. low-NOx burners, flue gas recirculation) and post-combustion processes that capture NOx after it has been produced (e.g., selective and nonselective catalytic reduction processes); and modern electrostatic precipitators that remove more than 99.9 percent of particulate matter.

coal-fired power plants continue to be opened in India and China with little or no control of emissions.

Our results highlight the challenges facing regulators in modern developing countries. Prior to the adoption of the 1970 Clean Air Act Amendments, new power plants continued to open with virtually no emissions controls, even as the health benefits from electricity generation were overwhelmed by the pollution costs. Whereas optimal regulation requires a consideration of both the current and future stream of benefits and costs, the American experience highlights how environmental regulation can be slow to respond to these evolving tradeoffs. Short-term political incentives that promote economic development over environmental concerns may heighten these challenges. Given the longevity of power plants, and the high costs of retrofitting abatement technology, our findings highlight how current decision-making of energy mix can have long-lasting health effects. In fact, many of the power plants built before 1970 were exempted from legislation, and continued to produce unregulated emissions for decades (Ackerman et al., 1999).

7 Conclusion

Economic development is often powered by polluting industries. While it is imperative to understand how the health externalities should be weighed against the benefits of the polluting activity along the process of development, empirical evidence on the subject is scarce. This paper represents a first step toward understanding these issues, focusing on the local tradeoffs associated with coal-fired power plants in mid-twentieth century America, large scale investment projects that stimulated local development and produced massive amounts of pollution. We combine a research design that leverages new power plant openings and upgrades at existing facilities with a newly digitized dataset on all major coal-fired power plants.

Expansions in coal-fired generating capacity are estimated to have imposed substantial health costs through local emissions, but also brought significant benefits through increased local electricity infrastructure. The benefits appear to have arisen primarily through household access to a range of new technologies that improved hygiene and eliminated the use of coal cookstoves. Although coal-fired generation initially improved infant health, as the stock of local generating capacity expanded the marginal benefits from subsequent installations diminished, and by the 1950s the pollution costs outweighed the benefits of increased electricity access. Despite the negative impact on health, it took several decades for restrictions on power plant emissions to emerge, with thousands of infant lives lost in the interim.

This paper raises broader questions about the role of air pollution in the process of economic development. In many contexts, the demand for policy intervention may only emerge when the negative externalities are significantly larger than the perceived benefits, and industrial firms often use losses in local economic activity as a justification for limiting environmental regulation. As developing countries such as China and India industrialize, with its corresponding effects on both income levels and air quality, these challenges become ever more urgent. Understanding how best to implement environmental policies that limit emissions without unduly inhibiting development is a critical area for future research.

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Tables and Figures

Table 1: The Effect of Coal-fired Power Plant Openings on Infant Mortality, 1938-1962

	Dependent variable: Infant Mortality Rate		
	(1)	(2)	(3)
Panel A: Overall effects			
1(Plant Operating) × Near	0.877***	0.780***	0.609***
	(0.215)	(0.215)	(0.192)
R-squared	0.673	0.673	0.679
Panel B: Effects by Generating Capacity in 1940: Below vs. Above median			
1(Plant Operating) × Near	-0.620*	-0.540	-0.194
× Below	(0.366)	(0.354)	(0.319)
1(Plant Operating) × Near	1.303***	1.197***	0.870***
× Above	(0.252)	(0.266)	(0.236)
P-value: Test $\beta_{Below} = \beta_{Above}$	0.000	0.001	0.007
R-squared	0.673	0.673	0.679
Panel C: Effects by Household Electricity Access in 1940: Below vs. Above median			
1(Plant Operating) × Near	-0.437	-0.396	0.018
× Below	(0.325)	(0.315)	(0.291)
1(Plant Operating) × Near	1.525***	1.419***	0.936***
× Above	(0.268)	(0.292)	(0.265)
P-value: Test $\beta_{Below} = \beta_{Above}$	0.000	0.000	0.021
R-squared	0.673	0.673	0.679
Observations	132,000	132,000	132,000
County-plant pairs	5,280	5,280	5,280
Counties	1,969	1,969	1,969
County-Plant FE	Y	Y	Y
State-by-Year FE	Y	Y	Y
Research Design Variables	Y	Y	Y
Geographic Variables	Y	Y	Y
1940 Mfg Emp x Year		Y	Y
All Other Controls			Y

Notes: This table reports the 'event-study' estimates from equation (1). Each column in each panel reports the point estimates from a different regression. The infant mortality rate is per 1,000 live births. *Near* is an indicator equal to one if the county-centroid distance to the power plant is less than 30 miles, and zero if the county-centroid is from 30 to 90 miles from the plant. 'Research Design Variables' include a time trend based on county-centroid distance to the coal-fired power plant, and annual nameplate capacity of the plant to ensure that identification relies solely on the timing of power plant openings. 'Geographic Variables' include time trends based on county longitude and latitude, annual precipitation, average temperature, degree days below 10^oC and degree days above 29^oC. 'All Other Controls' include annual hydropower capacity within 30 miles of a county-centroid, and time trends based on a variety of baseline county characteristics – log population, log employment, and proportion of households with electricity access in 1940, mileage of rail tracks in the beginning of the twentieth century (1911), and an indicator for whether a county was recommended to receive a highway from the 1944 Interstate Highway Plan. All regressions are weighted by live births. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 2: Predictors of Coal Capacity Changes, 1938-1962

	Dependent variable: Δ Coal Capacity, 1938-1962			
	Explanatory variables measured in			
	Levels, 1940		Changes, 1930-1940	
	(1)	(2)	(3)	(4)
Above vs. below median capacity, 1940	Above	Below	Above	Below
Panel A: Economic variables				
Log(total employment)	2.7652***	0.3061***	3.0965	0.5720*
	(0.6994)	(0.0997)	(1.9710)	(0.2892)
R-squared	0.153	0.0069	0.0090	0.0019
Manufacturing employment share	0.0996**	0.0136	0.1054	0.0071
	(0.0469)	(0.0131)	(0.0729)	(0.0125)
R-squared	0.0264	0.0020	0.0051	0.0002
Manufacturing payroll per worker	0.4318**	-0.0001	0.0664	-0.0004
	(0.1970)	(0.0011)	(0.2295)	(0.0010)
R-squared	0.0306	0.0000	0.0005	0.0000
Retail payroll per worker	2.5954***	0.0032	-0.1216	0.0028
	(0.7333)	(0.0024)	(0.3157)	(0.0025)
R-squared	0.1490	0.0001	0.0002	0.0000
Railroad miles, 1911	0.0151	0.0007		
	(0.0098)	(0.0021)		
R-squared	0.0158	0.000190		
Predicted interstate highway, 1944	3.0331***	0.1947		
	(0.8033)	(0.2020)		
R-squared	0.0357	0.0012		
Panel B: Demographic variables				
Infant mortality rate	-0.0461	-0.0003	-0.0223	-0.0052*
	(0.0304)	(0.0053)	(0.0232)	(0.0028)
R-squared	0.0066	0.0000	0.0024	0.0017
Percent urban	0.0757***	0.0077**	0.0643	-0.0174**
	(0.0245)	(0.0031)	(0.0543)	(0.0083)
R-squared	0.0671	0.0037	0.0025	0.0015
Percent white	-0.0687	-0.0019	0.0660	0.0016
	(0.0647)	(0.0030)	(0.0543)	(0.0030)
R-squared	0.0046	0.0001	0.0008	0.0000
Log(median dwelling rent)	8.1441***	0.4132	0.7269	0.5472
	(1.9627)	(0.3698)	(3.4226)	(0.4772)
R-squared	0.1590	0.0028	0.0002	0.0015

Notes: This table reports estimates from the analysis exploring the predictive power of levels and pre-trends of baseline county characteristics in explaining changes in coal-fired electricity generating capacity over the period 1938-1962. Each cell reports the estimates from a single regression of the change in coal capacity from 1938 to 1962 on the indicated county characteristic, conditional on state fixed effects and weighted by live births. Standard errors are clustered at the county-level; ***,**,* denote significance at 1%, 5%, and 10%, respectively.

Table 3: The Effect of Coal Capacity on Infant Mortality, 1938-1962

	Dependent variable: Infant Mortality Rate		
	(1)	(2)	(3)
Panel A: Overall effects			
Coal capacity	0.213***	0.222***	0.188***
	(0.030)	(0.025)	(0.027)
R-squared	0.639	0.675	0.679
Panel B: Effects by Generating Capacity in 1940: Below vs. Above median			
Coal capacity × Below	-0.146***	-0.094*	-0.040
	(0.051)	(0.049)	(0.058)
Coal capacity × Above	0.215***	0.229***	0.203***
	(0.027)	(0.025)	(0.028)
P-value: Test $\beta_{Below} = \beta_{Above}$	0.000	0.000	0.000
R-squared	0.640	0.676	0.680
Panel C: Effects by Household Electricity Access in 1940: Below vs. Above median			
Coal capacity × Below	-0.145***	-0.036	0.001
	(0.043)	(0.041)	(0.043)
Coal capacity × Above	0.214***	0.233***	0.195***
	(0.026)	(0.025)	(0.030)
P-value: Test $\beta_{Below} = \beta_{Above}$	0.000	0.000	0.000
R-squared	0.640	0.676	0.680
Observations	50,675	50,675	50,675
Counties	2,027	2,027	2,027
County and Year FE	Y	Y	Y
State-by-Year FE		Y	Y
All controls			Y

Notes: This table reports the difference-in-differences estimates from equation (2). Each column in each panel reports the point estimates from a different regression. The infant mortality rate is per 1,000 live births. The variable *Coal capacity* denotes total coal-fired capacity within 30 miles of the county-centroid (measured in 100s of megawatts). 'All Controls' include time trends based on county longitude and latitude, annual precipitation, average temperature, degree days below 10^{o}C and degree days above 29^{o}C, annual hydropower capacity within 30 miles of a county-centroid, and time trends based on a variety of baseline county characteristics – log population, log employment, and log manufacturing employment in 1940, mileage of rail tracks in the beginning of the twentieth century (1911), and an indicator for whether a county was recommended to receive a highway from the 1944 Interstate Highway Plan. All regressions are weighted by live births. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 4: Evolution in the Coal Capacity-Infant Mortality Relationship, 1938-1962

	Dependent variable: Infant Mortality Rate		
	(1)	(2)	(3)
Panel A: Pre-1950 vs. Post-1950			
Coal capacity × Pre-1950	-0.016	-0.099**	-0.087*
	(0.063)	(0.046)	(0.045)
Coal capacity × Post-1950	0.143***	0.134***	0.121***
	(0.032)	(0.024)	(0.026)
Panel B: Dynamics by Generating Capacity in 1940: Below vs. Above median			
Pre-1950 ×			
Coal capacity × Below	-0.477***	-0.611***	-0.745***
	(0.150)	(0.195)	(0.190)
Coal capacity × Above	0.015	-0.059	-0.054
	(0.061)	(0.043)	(0.044)
Post-1950 ×			
Coal capacity × Below	-0.162***	-0.115**	-0.061
	(0.050)	(0.050)	(0.059)
Coal capacity × Above	0.154***	0.149***	0.140***
	(0.029)	(0.024)	(0.027)
Panel C: Dynamics by years since power plant first opened			
Coal capacity	-0.160***	-0.101**	-0.122***
× 1(< 10 years operating)	(0.050)	(0.046)	(0.046)
Coal capacity	0.217***	0.231***	0.209***
× 1(≥ 10 years operating)	(0.028)	(0.024)	(0.027)
Observations	50,675	50,675	50,675
Counties	2,027	2,027	2,027
County and Year FE	Y	Y	Y
State-by-Year FE		Y	Y
All controls			Y

Notes: This table reports the difference-in-differences estimates from equation (2). Each column in each panel reports the point estimates from a different regression. The infant mortality rate is per 1,000 live births. The variable *Coal capacity* denotes total coal-fired capacity within 30 miles of the county-centroid (measured in 100s of megawatts). The variables 1(< 10 years operating) and 1(≥ 10 years operating) are indicators for the length of time over which the power plant has been in operation. See Table 3 notes for a description of the control variables in column (3). All regressions are weighted by live births. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 5: Coal Capacity and Household Electricity Access: Heterogeneity by Baseline Sanitation, and Coal Stoves

	Dependent variable: Infant Mortality Rate		
	(1)	(2)	(3)
Panel A: Heterogeneity by Baseline Sanitation-Related Mortality			
Above median electricity access			
× Coal Capacity	0.214***	0.233***	0.200***
	(0.026)	(0.024)	(0.030)
Below median electricity access			
× Coal Capacity	-0.048	0.073	0.138**
	(0.056)	(0.055)	(0.054)
× Coal Capacity × 1(High mortality)	-0.180**	-0.190**	-0.231***
	(0.075)	(0.075)	(0.071)
Panel B: Heterogeneity by Baseline Coal Stove Use			
Above median electricity access			
× Coal Capacity	0.214***	0.232***	0.195***
	(0.026)	(0.024)	(0.030)
Below median electricity access			
× Coal Capacity	-0.062	0.019	0.079
	(0.049)	(0.056)	(0.059)
× Coal Capacity × 1(High stoves)	-0.171**	-0.104	-0.143*
	(0.074)	(0.082)	(0.081)
Observations	50,675	50,675	50,675
Counties	2,027	2,027	2,027
County and Year FE	Y	Y	Y
State-by-Year FE		Y	Y
All controls			Y

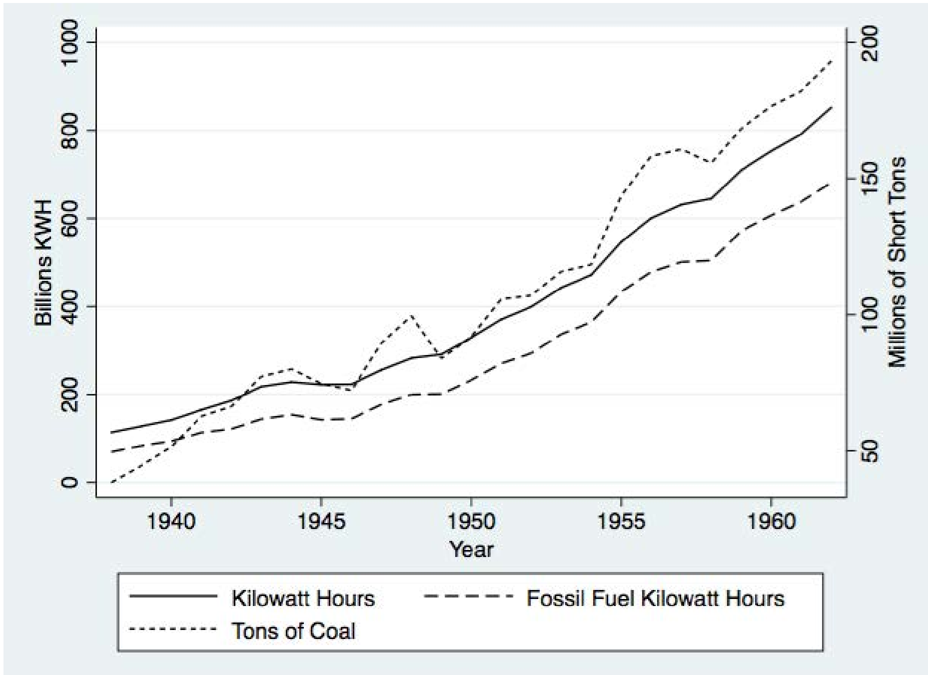
Notes: This table reports the difference-in-differences estimates from equation (2). Each column in each panel reports the point estimates from a different regression. The infant mortality rate is per 1,000 live births. The variable *Coal capacity* denotes total coal-fired capacity within 30 miles of the county-centroid (measured in 100s of megawatts). The variable 1(High mortality) indicates whether the county belonged to a state with above-median share of infant deaths due to diarrhea-enteritis in 1930. The variable 1(High stoves) indicates whether the county had above-median use of coal cookstoves in 1940. See Table 3 notes for a description of the control variables in column (3). All regressions are weighted by live births. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 6: The Effect of Coal Capacity on Economic and Demographic Outcomes

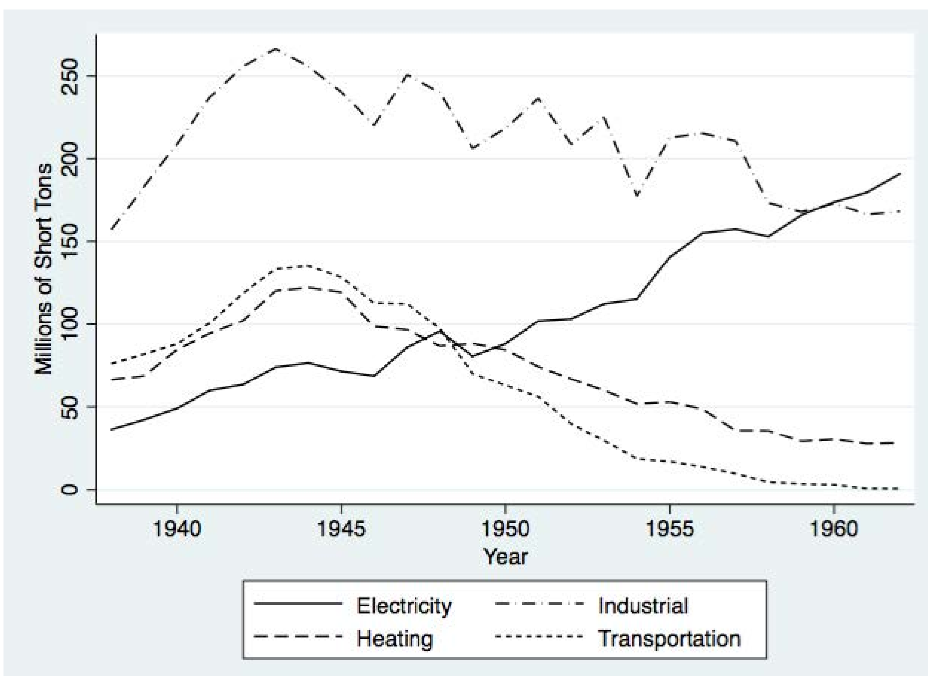
	Dependent variables:							
	Infant mortality rate	Median dwelling rent	Employment		Wages		Demographic composition	
			Total	Mfg	Mfg payroll per worker	Retail payroll per worker	% white	% with high school diploma
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Effects by Generating Capacity in 1940: Below vs. Above median								
Coal capacity × Below	-0.188*	0.002	0.016*	0.021**	0.002	-0.001	0.065	0.088*
	(0.098)	(0.002)	(0.008)	(0.010)	(0.002)	(0.001)	(0.058)	(0.047)
Coal capacity × Above	0.284***	-0.006***	0.012***	0.010**	-0.003***	-0.003***	-0.040	0.028
	(0.035)	(0.001)	(0.004)	(0.004)	(0.000)	(0.000)	(0.045)	(0.024)
Panel B: Effects by Household Electricity Access in 1940: Below vs. Above median								
Coal capacity × Below	-0.170*	0.005***	0.016***	0.019***	-0.001	0.001	0.139***	0.099***
	(0.094)	(0.002)	(0.004)	(0.006)	(0.001)	(0.001)	(0.049)	(0.038)
Coal capacity × Above	0.307***	-0.006***	0.012***	0.010**	-0.002***	-0.003***	-0.051	0.014
	(0.036)	(0.001)	(0.004)	(0.004)	(0.001)	(0.000)	(0.045)	(0.026)
Panel C: Dynamic Effects by Years Since Power Plant First Opened								
Coal capacity	-0.283***	0.004**	0.015	0.025**	0.002	-0.001	0.056	0.050
× I(< 10 years operating)	(0.091)	(0.002)	(0.009)	(0.011)	(0.002)	(0.001)	(0.060)	(0.056)
Coal capacity	0.302***	-0.006***	0.012***	0.010**	-0.003***	-0.003***	-0.042	0.030
× I(≥ 10 years operating)	(0.035)	(0.001)	(0.004)	(0.004)	(0.000)	(0.000)	(0.046)	(0.025)
Full controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table reports the difference-in-differences estimates from equation (2). Each column in each panel reports the point estimates from a different regression. The variable *Coal capacity* denotes total coal-fired capacity within 30 miles of the county-centroid (measured in 100s of megawatts). Median dwelling rent, employment, and wage outcomes are all measured in logs. See Table 3 notes for a description of the control variables. All regressions are weighted by live births. 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



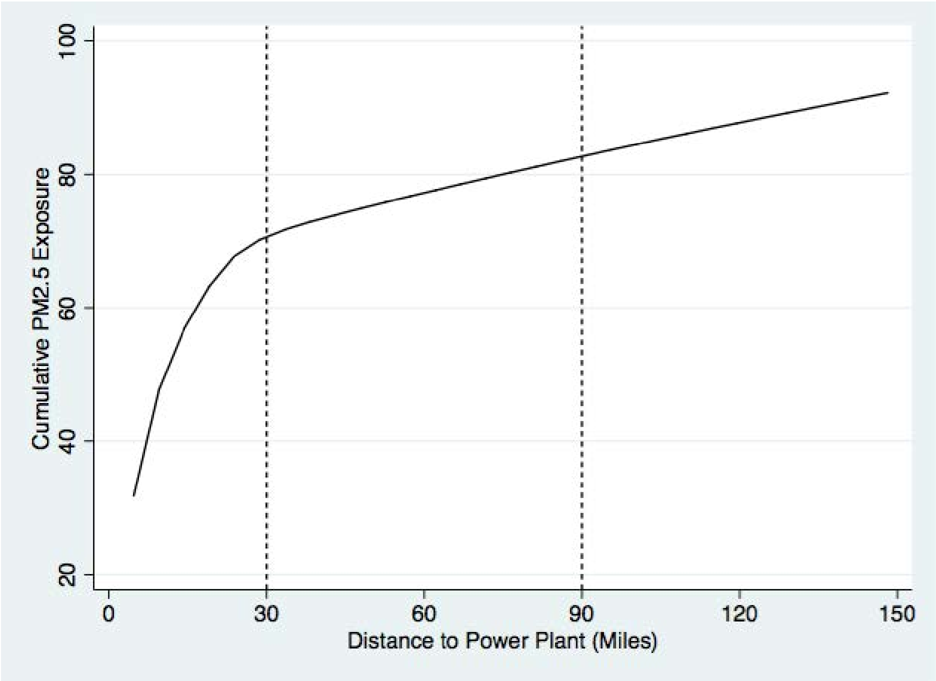
(a) Trends in Electricity Generation



(b) Coal Consumption, by Source

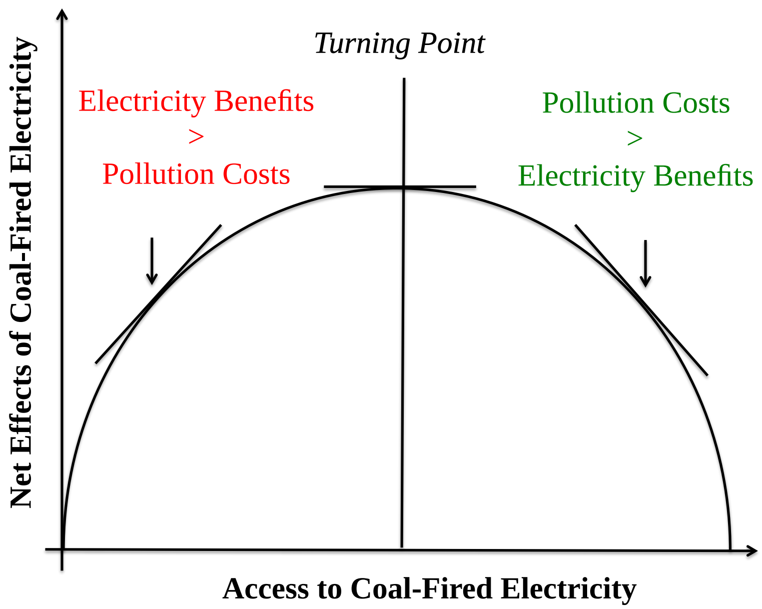
Notes: (a) Data from Gartner (2006), *Historical Statistics of the United States*, Table Db218-227. Electric utilities-power generation and fossil fuel consumption by energy source: 1920-2000. (b) Data from United States Bureau of Mines, *Minerals Yearbook* (various years).

Figure 2: Cumulative Dispersion of $PM_{2.5}$ Around Large Coal-Fired Power Plants



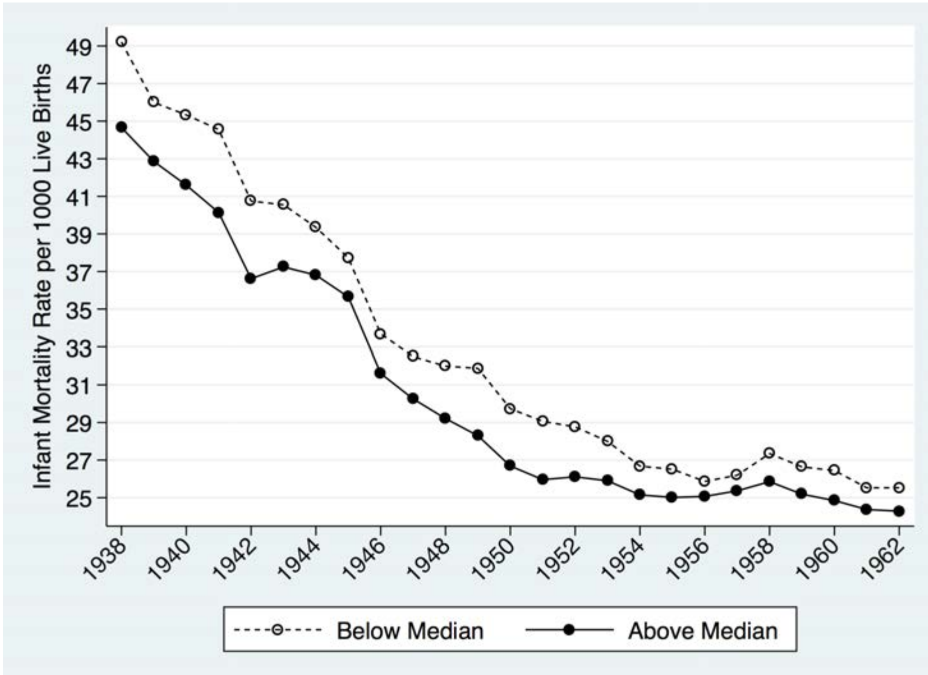
Notes: This figure shows the cumulative exposure to particulate matter by distance to large coal-fired power plants (Levy et al., 2002).

Figure 3: Tradeoffs Associated with Coal-fired Electricity Generation



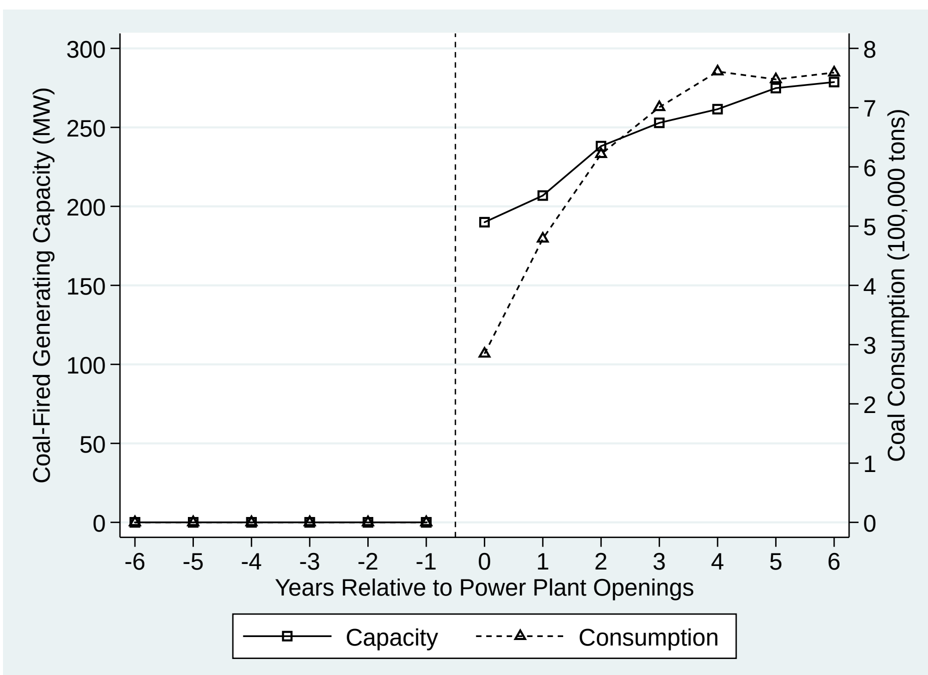
Notes: This figure illustrates the tradeoffs associated with the expansion of coal-fired electricity access. Appendix B.1 provides a microfoundation for this inverted-U shape.

Figure 4: Trends in Infant Mortality by Baseline Coal Capacity, 1938-1962



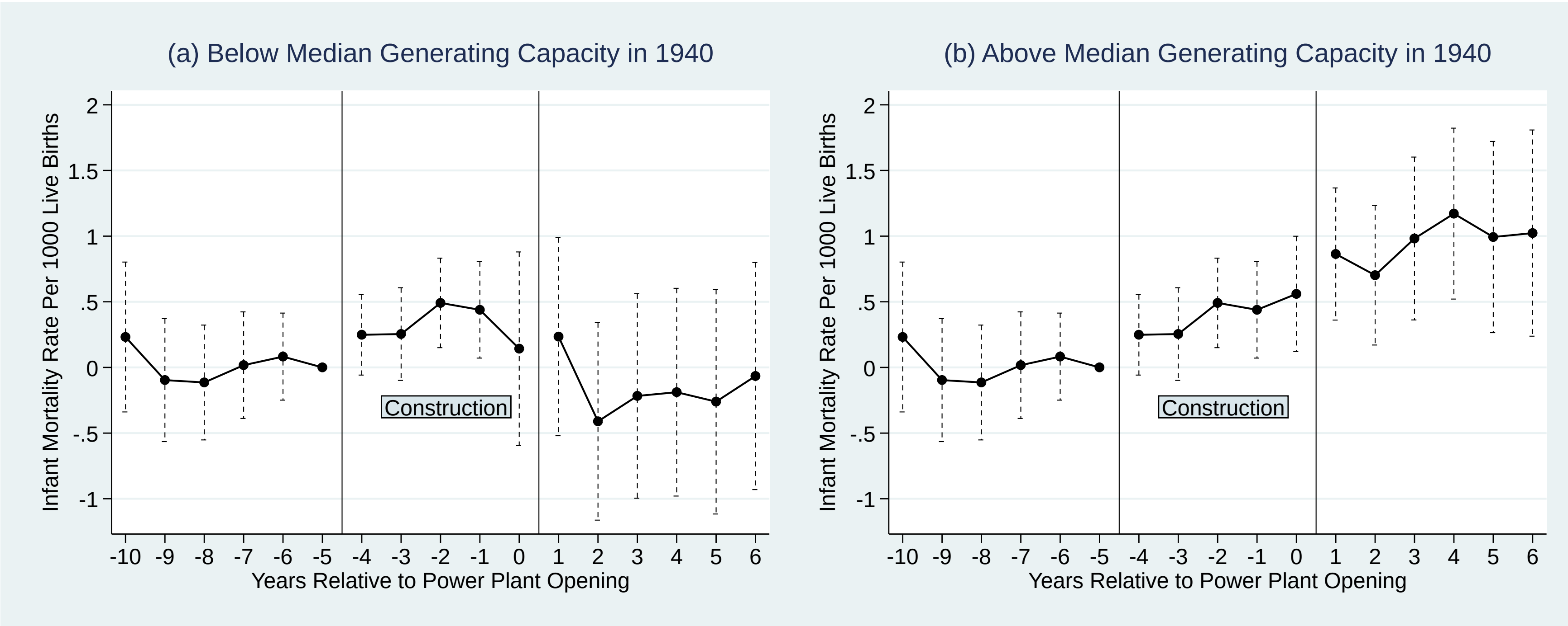
Notes: This figure plots the mean infant mortality rate from 1938 to 1962, separately for counties above and below the 1940 median coal-fired electricity generating capacity. Sample means are weighted by live births.

Figure 5: Power Plant Openings, Generating Capacity, and Coal Consumption



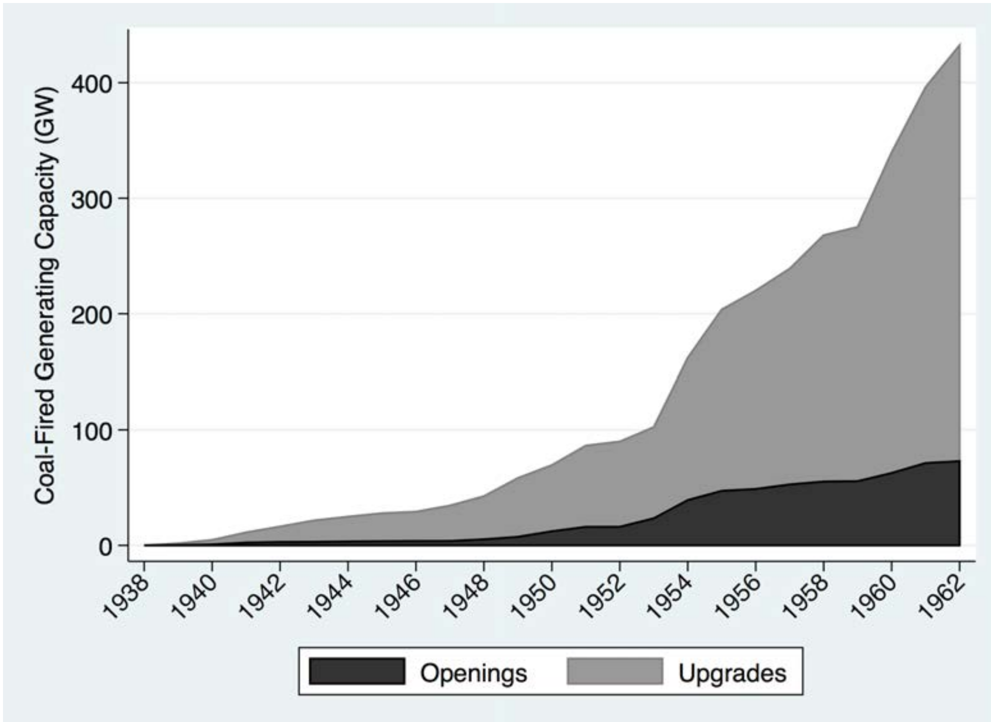
Notes: This figure reports coal-fired electricity generating capacity (in MWs) and coal consumption (in 100,000s of tons) for the 270 power plants that opened between 1938 and 1962.

Figure 6: Event Study: The Effect of Coal-Fired Power Plant Openings on Infant Mortality

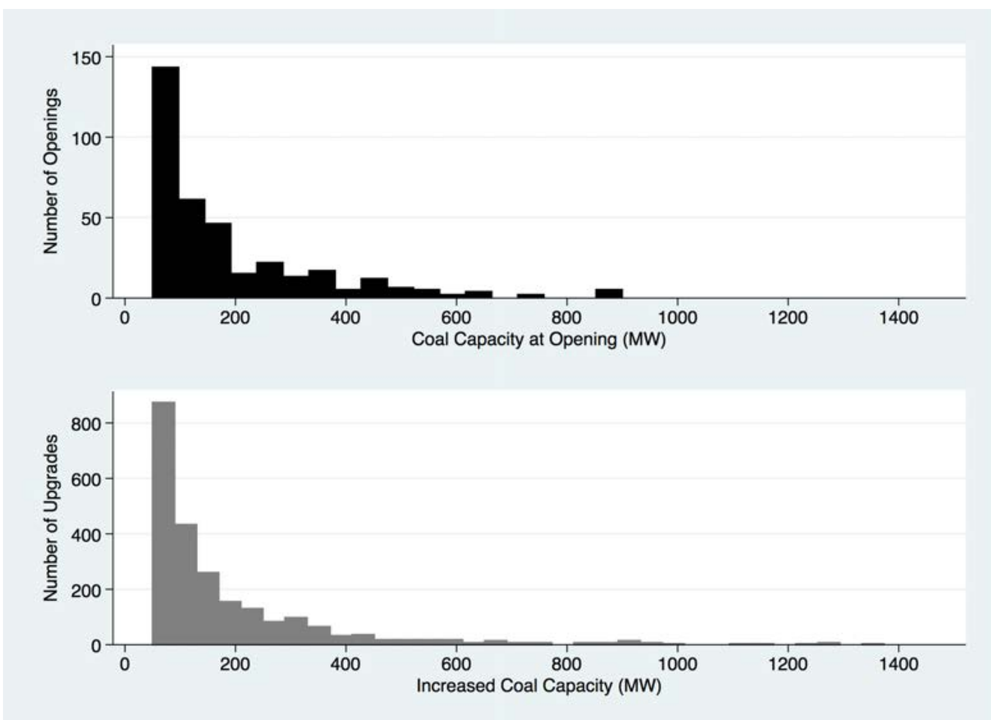


Notes: These figures report the event study estimates based on equation (1), separately for counties with below and above median generating capacity in 1940. The coefficients plot the time path of infant mortality in 'treatment' counties (<30 miles from a power plant) relative to 'control' counties (30-90 miles from a power plant). The period $t \in \{-10, -5\}$ identifies pre-construction, $t \in \{-4, 0\}$ identifies likely construction, and $t \in \{1, 6\}$ identifies post-opening. Following (Kline, 2012), we estimate the regression for the period $t \in \{-11, 7\}$ and suppress the endpoint coefficients. Vertical dashed lines denote the 95% confidence intervals based on standard errors that are clustered at the county-level.

Figure 7: Power Plant Openings and Installation at Existing Sites



(a) Changes in generating capacity due to new openings and upgrades, 1938-1962



(b) Frequency of power plant openings and upgrades at existing sites, by size

Notes: These figures depict the changes in coal-fired electricity generating capacity in our sample over the period 1938-1962, as well as the size distribution of new plant openings and upgrades at existing sites starting at 50MW.

A Appendix: Tables and Figures

Table A.1: TSP Concentration in Various Years

Location	Time	TSP	Source
14 Large US Cities	1931-1933, Winter	510	Ives et al. (1936)
US Urban Stations	1953-1957	163	USHEW (1958*a*)
8 of 14 Large US Cities	1954	214	USHEW (1958*a*)
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 total suspended particulates (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 particulate matter (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: Characteristics of Power Plants and Surrounding Counties

	Counties <30 miles from power plant			Counties 30-90 miles from power plant
	All	Above vs. below median capacity, 1940		
		Above	Below	
	(1)	(2)	(3)	(4)
Panel A: Coal-fired power plant characteristics				
Number	270	96	174	-
Initial year of operation	1952	1952	1952	-
Capacity (MWs)	140.9	151.9	90.7	-
Annual coal consumption (100,000 tons)	6.8	7.2	4.2	-
Panel B: County characteristics				
Infant mortality rate	29.1	28.6	31.4	31.1
Distance to power plant	18.1	18.0	18.6	64.6
Hydroelectric capacity <30 miles (MWs)	19	22	8	22
Baseline characteristics, 1940				
Employment (1,000s)	320	395	26	34
% Manufacturing employment	29.1	32.0	18.0	19.6
Population (1,000s)	842	1,037	76	102
% Urban	70.3	78.2	39.2	38.4
% Households with electricity	88.4	94.1	66.3	66.9
Railroad mileage, 1911	198.7	219.4	117.7	112.4
Predicted interstate highway, 1944	0.80	0.87	0.49	0.50
Counties	734	251	483	1,235
N(plant-county pairs)	1,056	469	587	4,224
Observations	26,400	11,725	14,675	105,600

Notes: This table reports summary statistics for the event-study sample. Panel A describes the mean characteristics of the 270 coal-fired power plants that opened between 1938 and 1962. Panel B describes the sample means for the treatment and control counties. All means are weighted by the number of live births.

Table A.3: Summary Statistics, Coal Capacity Analysis

	All counties	Above vs. below median capacity, 1940: Above	Below
	(1)	(2)	(3)
Panel A: Outcome variables			
Infant mortality rate			
Mean	30.4	29.1	32.0
Change, 1962-1938	-19.82	-20.86	-19.54
Median dwelling rent per month, 1990$	240.6	272.3	200.3
Manufacturing payroll per worker	17.7	19.8	14.9
Retail payroll per worker	12.5	13.3	11.3
% White	89.1	89.9	88.2
% High School (age 25+)	34.0	36.9	30.3
Panel A: Coal and hydro generation			
Coal capacity <30 miles (100 MWs)			
Mean	5.94	10.00	0.70
Change, 1962-1938	3.33	9.38	1.69
Coal consumption <30 miles (100K Tons)			
Mean	10.24	17.35	1.05
Change, 1962-1938	2.27	6.84	1.04
Hydro capacity <30 miles (100 MWs)			
Mean	0.28	0.40	0.12
Change, 1962-1938	0.15	0.21	0.14
Panel A: Baseline Characteristics, 1940			
Population (1,000s)	456	835	69
% Urban	52.0	70.5	33.1
Employment (1,000s)	171	316	23
% Manufacturing Employment	23.0	30.0	15.8
% Households with Electricity	74.8	89.2	60.3
Mileage of Railroads, 1911	155.7	201.0	109.5
Predicted Interstate Highway, 1944	0.63	0.83	0.42
Number of Counties	2,027	431	1,596

Notes: This table reports the characteristics for the sample of 2,027 counties used to estimate equation (2). Sample means are reported separately according to whether counties had above or below median generating capacity in 1940. All means are weighted by the number of live births. All dollar amounts are reported in 1990 dollars.

Table A.4: Total Suspended Particulates (TSP) Concentration and Coal Capacity, 1957-1962

	Dependent variable: Total Suspended Particulates	
	(1)	(2)
Coal capacity ($\leq$ 30 miles)	2.3245**	
	(1.0228)	
Coal capacity ($\leq$ 50 miles)		2.2378***
		(0.6451)
Observations	433	433
Counties	85	85
R-squared	0.723	0.753
Mean dep var in 1957	141	
Mean dep var in 1962	100	
State-by-Year FE	Y	Y
Geographic Controls	Y	Y

Notes: This table reports the relationship between coal-fired electricity generating capacity and total suspended particulates (TSP), a measure of particulate matter collected by the EPA for the period 1957-1962.

Table A.5: The Effect of Coal-fired Power Plant Openings on Infant Mortality, Robustness Tests

	Dependent variable: Infant Mortality Rate						
			Alternate treatment radii				
	Baseline estimates	Omit counties 30-60 miles from power plant	< 20 miles from power plant	< 40 miles from power plant	Log infant mortality rate	Effects by power plant size	Effects by wind direction
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Overall effects							
1(Plant Operating) × Near	0.609***	0.482***	0.334*	0.398**	0.016***		
	(0.192)	(0.186)	(0.196)	(0.167)	(0.006)		
× Large (≥ 75MW)						0.754***	
						(0.213)	
× Small (< 75MW)						0.121	
						(0.253)	
× Downwind (90°arc from plant centroid)							0.945***
							(0.327)
× Upwind (270°arc from plant centroid)							0.492**
							(0.204)
Panel B: Effects by Generating Capacity in 1940: Below vs. Above median							
1(Plant Operating) × Near × Below	-0.194	-0.284	-0.646	-0.305	-0.003		
	(0.319)	(0.366)	(0.4044)	(0.284)	(0.009)		
1(Plant Operating) × Near × Above	0.870***	0.694***	0.557**	0.729***	0.022***		
	(0.236)	(0.205)	(0.237)	(0.197)	(0.007)		
Panel C: Effects by Household Electricity Access in 1940: Below vs. Above median							
1(Plant Operating) × Near × Below	0.018	-0.037	-0.387	-0.209	0.003		
	(0.291)	(0.333)	(0.337)	(0.279)	(0.009)		
1(Plant Operating) × Near × Above	0.936***	0.734***	0.607**	0.797***	0.023***		
	(0.265)	(0.231)	(0.261)	(0.220)	(0.008)		
Full controls	Y	Y	Y	Y	Y	Y	Y

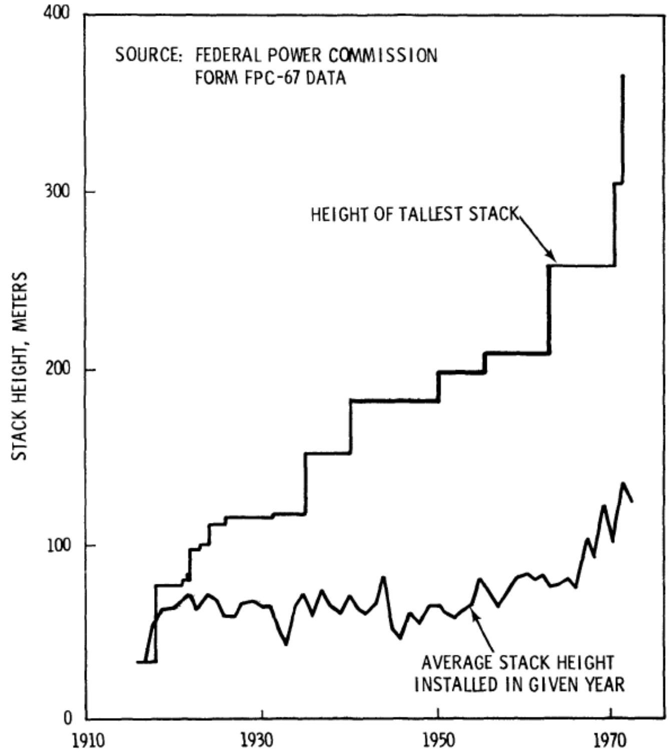
Notes: This table reports robustness tests from the 'event-study' estimates from equation (1). Each column in each panel reports the point estimates from a different regression. All models include the full set of controls from Table 1. The variables 'Large' and 'Small' indicate whether the initial capacity of power plants was above or below 75MW. All regressions are weighted by live births. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table A.6: The Effect of Coal Capacity on Infant Mortality, Robustness Tests

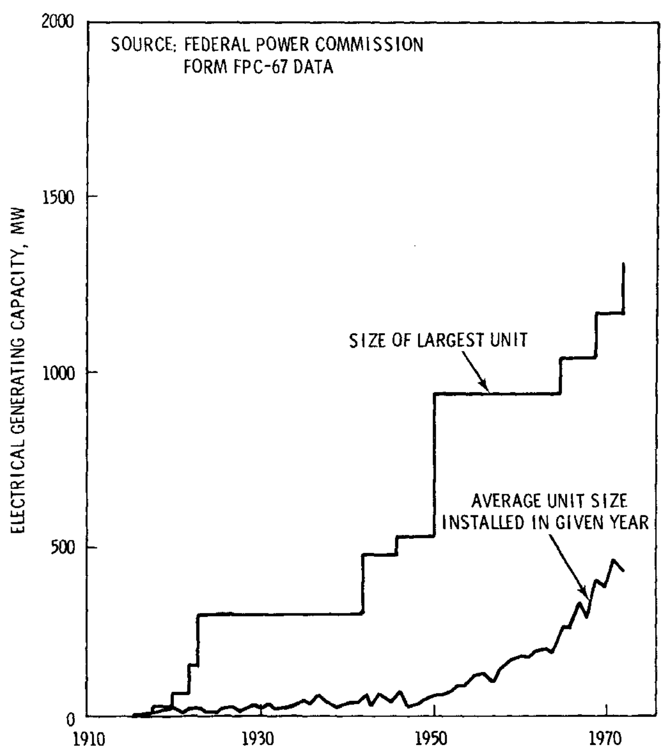
	Dependent variable: Infant Mortality Rate						
	Alternate samples		Alternate treatment radii		Log	Hydro Capacity	
	Counties < 150 miles from plant	Counties < 30 miles from plant	Coal capacity within 50 miles	Coal capacity within 100 miles	infant mortality rate	< 30 miles	< 50 miles
Panel A: Overall effects							
Coal capacity	0.188***	0.154***	0.105***	0.065***	0.005***		
	(0.027)	(0.027)	(0.017)	(0.011)	(0.001)		
Hydro capacity						-0.905*	-0.505**
						(0.494)	(0.198)
Panel B: Effects by Generating Capacity in 1940: Below vs. Above median							
Coal capacity × Below	-0.040	-0.053	0.000	0.015	-0.001		
	(0.058)	(0.059)	(0.028)	(0.015)	(0.002)		
Coal capacity × Above	0.203***	0.165***	0.119***	0.071***	0.006***		
	(0.027)	(0.028)	(0.018)	(0.011)	(0.001)		
Panel C: Effects by Household Electricity Access in 1940: Below vs. Above median							
Coal capacity × Below	0.002	0.017	-0.012	0.012	0.000		
	(0.043)	(0.047)	(0.028)	(0.015)	(0.001)		
Coal capacity × Above	0.196***	0.154***	0.125***	0.080***	0.005***		
	(0.029)	(0.028)	(0.021)	(0.012)	(0.001)		
Full controls	Y	Y	Y	Y	Y	Y	Y

Notes: This table reports robustness tests for the difference-in-differences analysis from equation (2). Each column in each panel reports the point estimates from a different regression. All models include the full set of controls from Table 3. Alternate samples are constructed based on county proximity to the nearest power plant in 1962. All regressions are weighted by live births. 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



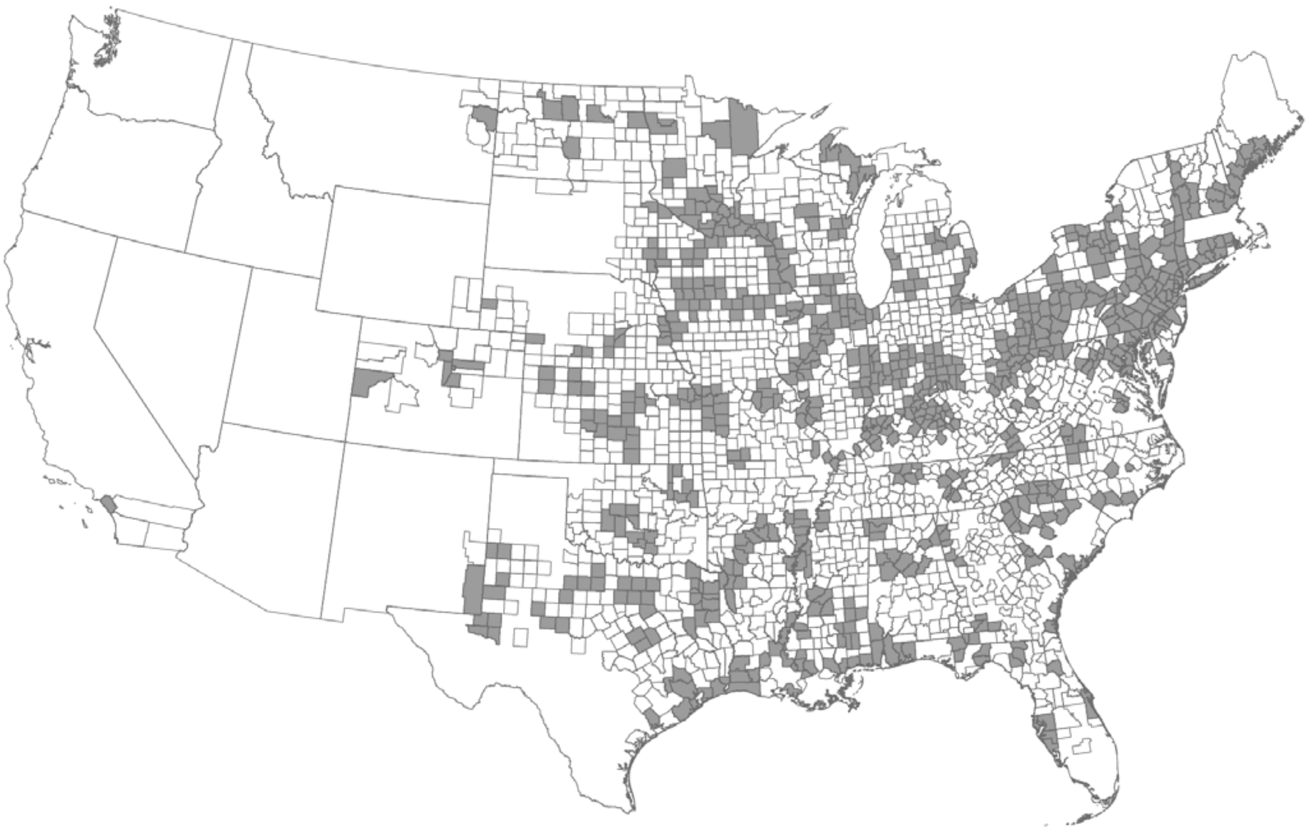
(a) Stack Height of Newly Installed Power Plants



(b) Capacity of Newly Installed Power Plants

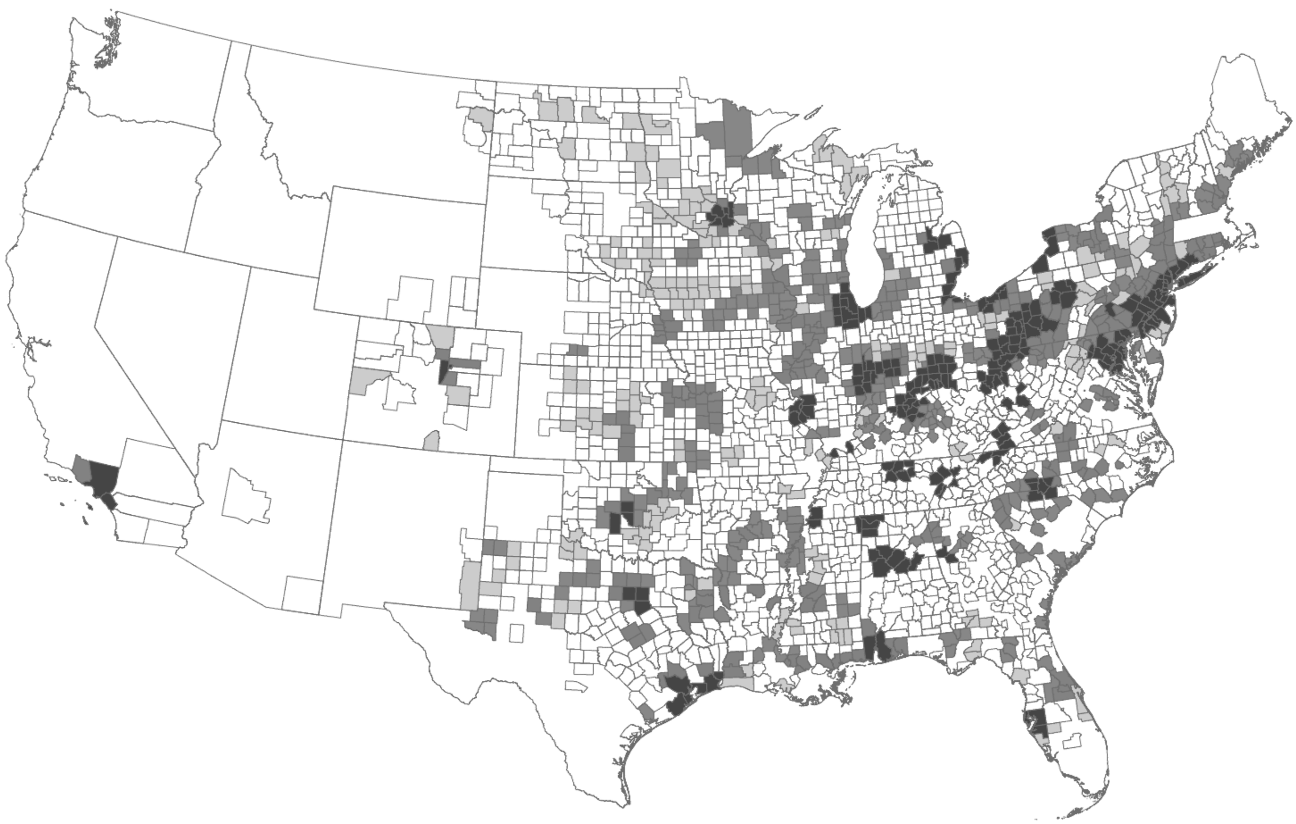
Notes: From Hales (1976).

Figure A.2: Event Study Sample



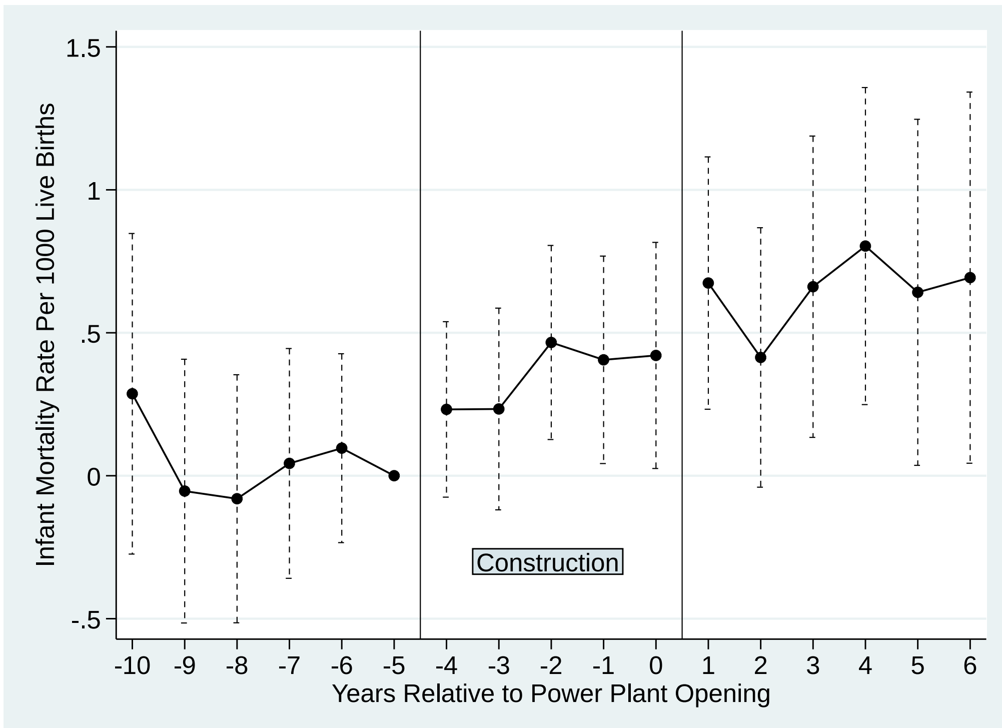
Notes: This figure depicts the sample for the event-study analysis. White outlines identify 'control' counties located 30 to 90 miles from a power plant opening. Grey shades identify 'treatment' counties located within 30 miles of a power plant opening from 1938 to 1962.

Figure A.3: Coal Capacity Sample



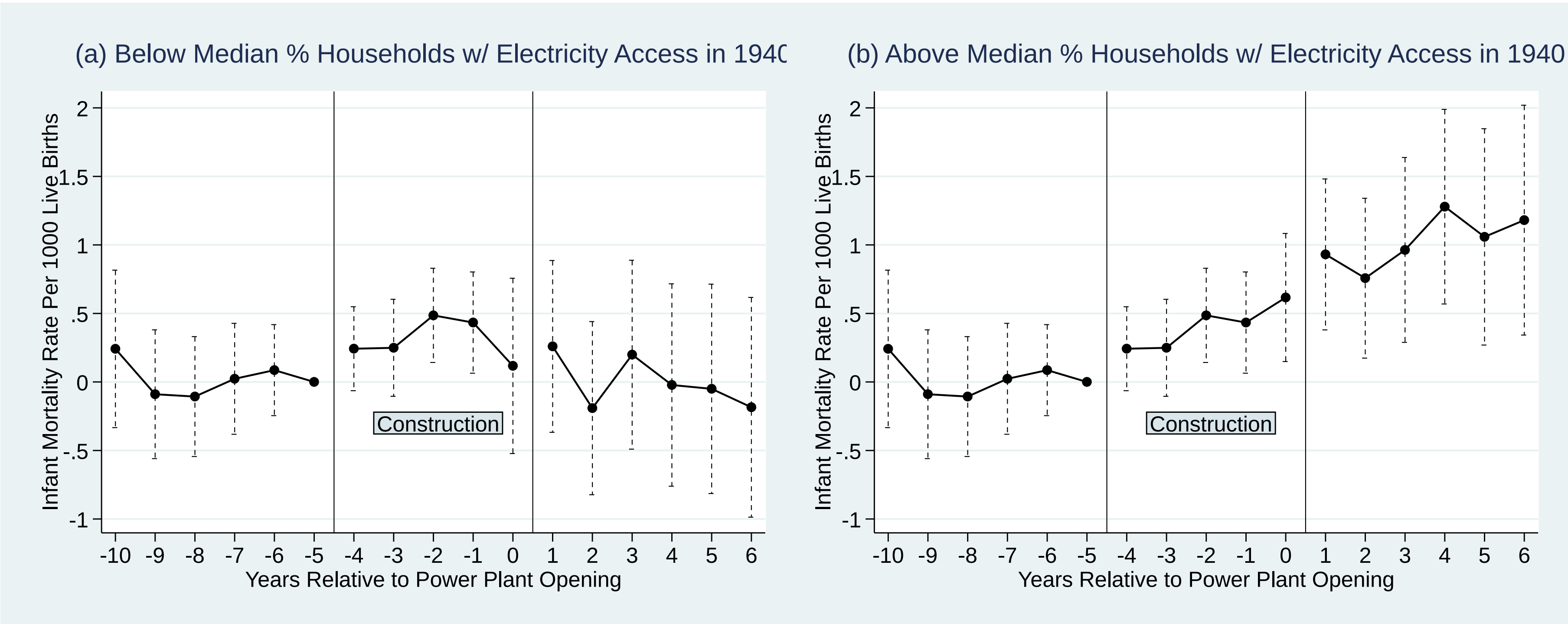
Notes: This figure depicts the sample for the difference-in-differences analysis. White outlines identify counties located 30 to 90 miles from a capacity change. Shaded counties identify counties within 30 miles of a capacity change from 1938 to 1962. Shaded counties are classified according to quartile of change (<88MW, 88-263MW, 263-617MW, >617MW), where darker shades indicate larger capacity increases.

Figure A.4: Event Study: The Effect of Coal-Fired Power Plant Openings on Infant Mortality



Notes: This figure reports the event study estimates based on equation (1). 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). The period $t \in \{-10, -5\}$ identifies pre-construction, $t \in \{-4, 0\}$ identifies likely construction, and $t \in \{1, 6\}$ identifies post-opening. Following (Kline, 2012), we estimate the regression for the period $t \in \{-11, 7\}$ and suppress the endpoint coefficients. Vertical dashed lines denote the 95% confidence intervals based on standard errors that are clustered at the county-level.

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



Notes: These figures report the event study estimates based on equation (1), separately for counties with below and above median percentage of households with electricity access in 1940. 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). The period $t \in \{-10, -5\}$ identifies pre-construction, $t \in \{-4, 0\}$ identifies likely construction, and $t \in \{1, 6\}$ identifies post-opening. Following (Kline, 2012), we estimate the regression for the period $t \in \{-11, 7\}$ and suppress the endpoint coefficients. Vertical dashed lines denote the 95% confidence intervals based on standard errors that are clustered at the county-level.

B Appendix: Additional Information

B.1 Conceptual Framework

We develop a simple partial equilibrium model to study the health impacts of expansions in coal-fired generating capacity. 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.[53] 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.

[53] Notice that this setup is a variation of Greenstone and Jack (2015)'s 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.

B.2 Power Plant Data Construction

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

Line No.			Cannon Street $1000	Cannon Street Mills Kwh	B. C. Cobb $1000	B. C. Cobb Mills Kwh	Bryce E. Morrow $1000	Bryce E. Morrow Mills Kwh	Saginaw River $1000	Saginaw River Mills Kwh
14	PRODUCTION EXPENSES:									
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	

Line No.			Cannon Street Quantity	Cannon Street Cost	B. C. Cobb Quantity	B. C. Cobb Cost	Bryce E. Morrow Quantity	Bryce E. Morrow Cost	Saginaw River Quantity	Saginaw River Cost
25	FUEL USED:									
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										

Line No.		Cannon Street	B. C. Cobb	Bryce E. Morrow	Saginaw River
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 (Added	3,600 - March,	18.0 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