Canary in a Coal Mine: Impact of Mid-20th Century Air Pollution on Infant Mortality and Property Values *

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Abstract

This paper uses the mid-20th century expansion in U.S. coal-fired electricity generation to study the local impact of air pollution on infant mortality and housing prices. The empirical analysis exploits the timing of coal-fired power plant openings and annual variation in plant-level coal consumption in the U.S. from 1938 to 1962. The estimates suggest that the rise in power plant coal consumption was responsible for an additional 3,500 infant deaths per year by the end of the sample period. We examine whether individuals perceived these health costs. Although hedonic estimates of the average marginal willingness to pay for clean air are close to zero, there is substantial heterogeneity in the housing market response. At low levels of electricity access, expansions in coal-fired electricity generation have positive effects on housing prices. At high levels of electricity access, this relationship is negative. These results suggest that households traded off the pollution costs of coal-fired power against the benefits of low-cost electricity.

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1 Introduction

Today, air quality is highly valued in the U.S. and other developed nations (e.g., Chay and Greenstone, 2005). This is likely due to the preponderance of evidence on the harmful effects of pollution (e.g., Chay and Greenstone, 2003a, 2003b; Currie and Neidell, 2005). Historically, however, it is unclear the extent to which the public perceived these health risks, a situation analogous to developing countries nowadays. The lack of an effective air quality management system prior to the passage of major legislations such as the 1963 Clean Air Act made it difficult to (i) establish a link between air pollution and health, and (ii) assess the value of environmental amenities. As a byproduct of economic growth, air pollution was associated with tangible benefits hard to disentangle from potentially hidden health costs.

The expansion of the power grid in the U.S. around mid-20th century presents a unique opportunity to examine these issues, and may provide guidance for policymaking in the current energy challenge faced by developing countries (Greenstone and Jack, 2015). First, the opening of a number of coal-fired power plants in the 1940s and 1950s allows for the credibly estimation of the impact of local air pollution on infant mortality during a period of unregulated and unmonitored emissions. Second, coal-fired power had clear tradeoffs: benefits from electricity generation and health costs due to air pollution. Third, the time frame precedes landmark epidemiological studies on the health effects of air pollution by several decades (Lave and Seskin, 1970; Pope, 1991), so citizens were unlikely to have full information of the health risks posed by coal-fired emissions.

This paper uses newly digitized annual administrative data on power plants from 1938 to 1962 to examine the effects of the rapid expansion of electricity generation on infant mortality and housing values. We first establish the link between coal-fired power generation and mortality by exploiting (i) the timing of power plant openings, and (ii) the annual variation on plant-level coal consumption and generating capacity. We then estimate hedonic models to assess the extent to which the public perceived those health risks and whether households traded off the costs and benefits of coal powered electricity.

The first research design is based on the timing of power plant openings. Guided by the literature on pollution transport, we identify a 'treatment' radius of 30 miles around a plant.[1] The analysis compares the relative outcomes in counties within this radius to outcomes in counties slightly farther away, before and after a plant opening. Because both treatment and control counties benefited similarly from the electricity produced by these plants, these models identify the cost of pollution, net of the gains associated with increased electricity production. The second empirical strategy exploits spatial and temporal variation in annual coal consumption generating capacity by electric utilities, in a county fixed effects framework. These models capture the net impact of both the costs and benefits of local coal-fired generation for health and property values. Importantly, we estimate these relationships at different levels of baseline electricity access, which allows us to disentangle these two opposing forces.

We find that coal-fired electricity generation had substantial negative effects on health. The opening of a large fossil fuel power plant (>75mw) is associated with a 2 percent increase in infant mortality. On average, the costs of air pollution overwhelm the health benefits associated with electricity access, and our estimates imply that the rise in coal-fired electricity generation between 1938 and 1962 was responsible for an additional 3,500 infant deaths per year by 1962.

Despite the large health impacts, average housing values did not respond to local power plant coal consumption. The estimates for households' willingness-to-pay to avoid pollution are small and statistically insignificant. Given imperfect information, the estimates may understate the true costs of this local externality. Alternatively, the null result could reflect a tradeoff between the health costs and the economic gains of electricity access. To shed light on this question, we evaluate the impact of power plant coal consumption at different levels of baseline electricity access. Local coal consumption has positive and statistically significant effects on housing prices at low levels of access and negative and statistically

[1] See section 2.1 for a detailed discussion.

significant effects at high levels of access. These effects mirror the relationship between electric utility coal consumption and infant mortality at different levels of electricity access. Together the findings suggest that households were able to infer the health costs associated with coal-fired emissions, despite a lack of direct evidence on this relationship. Nevertheless the housing market response is substantially smaller than would be predicted based on the standard value of a statistical life (VSL) for this period (Costa and Kahn, 2004), suggesting that information on these health risks was at best incomplete.

This paper makes three main contributions to the literature. First, it sheds light on the effects of local air pollution on health in a setting with virtually no environmental regulation and a poorly informed public. Previous work has focused on the post-Clean Air Act period, when the public was better informed of these health effects and pollution levels were significantly lower. Influential studies such as Chay and Greenstone (2003a, 2003b) and Currie and Neidell (2005) either exploit Clean Air Act regulations to uncover health effects of pollution, or focus on post-CAAA periods.[2] Perhaps the closest studies to ours are Hanlon (2015a) and Hanlon and Tian (2015) on the mortality associated with coal consumption in manufacturing in the 19th century England, and Barreca, Clay and Tarr (2014) on the mortality effects of coal burning for home heating in mid-20th century U.S.

Second, this study offers a new methodology for evaluating local air quality in settings in which direct pollution monitors are unavailable. This strategy complements other innovative approaches recently used in the developing context. For example, Jayachandran (2009) uses satellite aerosol monitoring data to measuring the missing children associated with extreme pollution exposure during infancy and in utero due to forest fires in Indonesia. Arceo-Gomez, Hanna, and Oliva (forthcoming) use the frequency of thermal inversions, which trap pollutants close to the ground, to assess the impact of pollution exposure on infant mortality in Mexico City. Almond et al. (2009) and Chen et al. (2013) use the geographic discontinuity

[2]Other studies such as Currie and Walker (2011), Currie et al. (2015), Schlenker and Walker (forthcoming), and Severnini (2015) use air pollution shocks that might not be fully perceived by the public to estimate their impact on health, but are all in settings with some type of emission control.

created by a Chinese policy to subsidize coal north of the Huai River to estimate the effect of particulate matter on life expectancy.

Third, the paper adds to recent work assessing the reliability of the hedonic method (see Currie et al, 2015). Our results show that standard WTP estimates for air quality can yield puzzling results when amenities arising directly from pollution-intensive activities are not accounted for. Conflicting estimates of the willingness to pay for air quality might be due to omission of amenities generated directly by pollution.[3]

More broadly, the paper relates to the literature on the effects of electrification, and on the historical development of the American economy. While a growing body of research has focused on the benefits of electrification to female employment (Dinkelman, 2011; Lewis, 2014a), local development (Lipscomb, Mobarak, and Bahram, 2013; Severnini, 2014), agricultural output (Fishback and Kitchens, forthcoming), health (Lewis, 2014b), and manufacturing productivity (Allcott, Collard-Wexler and O'Connell, forthcoming), our study highlights the potential pollution costs associated with increasing electricity access. Similarly, while the role of transportation infrastructure in transforming the American economy in the 19th and 20th centuries has been studied intensively (Fogel, 1964; Haines and Margo, 2008; Atack et al., 2010; Atack and Margo, 2011; Atack, Haines and Margo, 2011; Donaldson and Hornbeck, forthcoming; Baum-Snow, 2007; Michaels, 2008), the expansion of the U.S. power grid has been overlooked.

This paper proceeds as follows: Section 2 discusses the history of electrification in the United States. Section 3 describes the data. Section 4 presents our empirical framework. Section 5 reports our findings, and Section 6 concludes.

[3] In a related study, Hanlon (2015b) shows that omission of coal consumption by manufacturing in the estimation of city growth models could lead to misleading findings. Industrial activity may create jobs and pull workers from other places, but it might also emit tons of pollutants that push workers away.

2 Historical Background

2.1 Coal-fired Electricity, Pollution, and Health

Coal-fired electricity generation rose substantially during the mid-20th century. Between 1938 and 1962, 154,255 MW of electricity capacity were added, over 80 percent of which was coal powered.[4] Most of the growth occurred as new bigger plants were built and older, smaller plants were taken offline. In fact, despite the larger increases in capacity, the total number of electric utility plants actually fell from 3,903 in 1938 to 3,402 in 1963.[5]

With these expansions in coal-fired capacity, electric utilities became an increasingly important source of domestic coal consumption. Figures 1 and 2 show that coal consumption for electricity generation grew rapidly and was a rising share of overall consumption. Coal consumption was 38.4 million short tons in 1938 and 211.3 million short tons in 1963. Coal consumption grew rapidly, but less rapidly than kilowatts generated (5.5 times vs. 8.1 times), because newer larger plants were more efficient than older smaller plants. 97 percent of the coal used was bituminous coal.[6] As a share of overall consumption, coal consumption for electricity generation rose from 10 percent to 50 percent, as other uses such as coal for home heating and coal for railways declined.

The combustion of coal produces a number of air pollutants, such as sulfur dioxide, nitrogen oxides, and particulate matter. A large literature has shown that these pollutants have negative effects on both infant and all-age mortality.[7] For infants, particulates affect health through both prenatal exposure (Curry and Walker, 2011), and postnatal exposure (Woodruff et al, 2008; Arceo-Gomez et al, 2012).

Prior to the passage of the 1963 Clean Air Act, electric utilities did little to mitigate

[4]United States Bureau of the Census (1976), p.824.

[5]United States Bureau of the Census (1975), Series S53-54.

[6]Anthracite coal by use is only reported beginning in 1954. In 1954 it was 3 percent and it remained small through 1963. United States Bureau of Mines, Minerals Yearbook (1958), Table 38 (anthracite), p. 188. Table 53 (bituminous), p. 102.

[7]See Chay and Greenstone (2003a, 2003b), Currie and Neidell (2005) for the effects on infant mortality; Clay and Troesken (2010), Pope et al (1992), Clancy et al (2002), Hedley et al (2002), and Pope et al (2007), for the effects on all-age mortality.

the consequences of the 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 smoke stacks – a key determinant of pollutant dispersion – was relatively constant from 1938 to 1962 (see Figure 3). The primary mitigation of pollution came from siting of the plants further from population centers, as advances in transmission technology allowed electricity to be shipped over longer distances. Figure 4 displays the density of thermal capacity around the 50 largest cities in the United States.[8] In both time period, the largest mass of plants are concentrated within 75 miles of the city-centroids. Nevertheless, the distribution flattens by 1960, as a larger share of power plants was located further away from city centers.

The extent to which this rise in power plant coal consumption affected the health of the local population depends on local weather conditions, plant characteristics, and the properties of the pollutant in question. Fortunately, previous research on pollution transport provides some guidance on the dispersion of these pollutants. Particulate matter, widely considered the most hazardous pollutant associated with fossil fuel combustion, tends to be locally concentrated. Figure 5 plots the average density of PM2.5 by distance to the source, based on study of nine large power plants in Illinois in 1998 (Levy et al., 2002).[9] The relationship between distance and PM2.5 exposure is highly nonlinear. Over 40 percent of PM2.5 exposure occurs within 30 miles of the plant; less than 20 percent occurs at a distance between 30 and 90 miles. When differences in land area are taken into account, these differences are even starker: the average person within 30 miles of a plant is exposed to concentration of PM2.5 that is 11 times higher than the level of exposure of an individual located between 30 and 60 miles from a plant. As a result, health effects associated with power plant coal consumption should be concentrated locally.[10]

[8]Because area increases with the square of distance, the figure is constructed so that a uniform distribution would appear as a flat line in the figure.

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

[10]On the other hand, secondary pollutants such as sulfur dioxide and nitrogen oxides are diluted in the atmosphere and carried further away. For example, Levy and Spengler (2002) find that exposure to these pollutants decreases linearly with distance between 0 and 500 kilometers.

Coal-fired electricity offered a range of local benefits. Access to electricity is linked to decreases in infant mortality (Lewis 2015, Gohlke 2011).[11] Figure 6 provides evidence on the relationship between power plant openings and electricity access. The figure plots the regression estimates from a fixed effects model relating large power plant openings on the fraction of households with electricity, by county-centroid distance to the plant. The benefits of electricity access were locally concentrated. Electrification rates increased by 7 percentage points for residents within 60 miles of a power plant. Beyond 60 miles, the impact on electricity access decreases monotonically with distance. These findings are consistent with historical evidence on transmission technology during this period. Importantly, the spatial distribution over who benefited from increased electricity access is distinct from the spatial distribution of pollution exposure. This distinction will allow us to disentangle the health costs associated with pollution from the benefits associated with electricity production.

2.2 Estimating the Value of Coal-fired power with the Hedonic Method

There is a large literature that uses the hedonic price method to estimate the economic value of non-market amenities, such as electricity access and clean air.[12] In the standard model, a differentiated good can be described by a vector of its attributes, $Q = (q_1, .., q_n)$. For a house, these attributes could include both structural and neighborhood characteristics, as well as local amenities. The equilibrium relationship between prices and attributes, the hedonic price schedule, is determined by the interaction between home buyers and sellers. As Rosen (1974) first noted, at each point along $P(q_1, .., q_n)$, the partial derivative of $P(\cdot)$ with respect to attribute q_i is equal to the marginal willingness to pay for that attribute.

The opening of a coal-fired power plant will likely have two opposing effects on local housing prices. On the one hand, increased availability of low-cost electricity will tend to

[11] The mechanisms appear to be related to the labor-saving benefits of electric household appliances, which allowed families to reallocate time towards health promoting activities (Mokyr, 2000; Lewis, 2015).

[12] See Ridker and Henning (1967), Chay and Greenstone (2005), for example.

drive up housing values.[13] On the other hand, increases in air pollution will tend to drive down housing prices, in order to attract potential homeowners. Notice that this tradeoff is not necessarily constant. In particular, the sign of MWTP for local coal-fired electricity generation may depend on the level of baseline electricity access.

According to the hedonic model, the local housing price response identifies households willingness-to-pay for coal-fired power. In principle, this object could be of great interest to policymakers. This interpretation, however, relies heavily on the assumption of unbiased information. If residents are systematically ill informed of the health costs, the hedonic estimates will overstate the benefits of coal-fired electricity generation.

Air pollution has historically been viewed as a negative externality. By the late nineteenth and early twentieth centuries, air quality in U.S. cities was bad enough that it had become a significant source of concern, and mid-twentieth century air pollution appears to have been similar to levels found in cities in developing countries today (Table A.1). As smoke became significant, cities often passed legislation aimed at reducing it. [14] Historical evidence suggests that the wealthy tended to live in or move to locations with fewer negative externalities, often the neighborhoods were more distant from or higher than factories and power plants.

Several highly publicized events, such as the 1948 Donora smog and the 1952 London smog enhanced public awareness of the relationship between air quality and health. Nevertheless, epidemiological evidence on health effects of daily exposure to more moderate levels of air pollution would not emerge until the 1970s.

[13]Assuming a common local land market, this price effect will capture both the productivity and amenity benefits associated with electricity. The impact on local wages describes how these gains are split across producers and households.

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

3 Data

Our data are drawn four main sources: Federal Power Commission Reports on coal-fired power plant coal consumption, air quality measures from the Environmental Protection Agency (EPA), county-level infant mortality rates from the Vital Statistics of the United States, and home values and other county-level covariates available in the Censuses of Housing and Population. With the exception of the Census information, all data have been digitized from original sources.

We identify the location of coal-fired power plants based on a set of seven maps conducted by the Federal Power Commission in 1962 (Federal Power Commission, 1962). Using GIS software, we digitize the location of all coal-fired plants with at least 10mw of nameplate capacity. We link these power plants to information on the year of plant opening and fuel consumption, based on newly digitized information from Federal Power Commission Reports from 1938 to 1962 (U.S. Federal Power Commission, 1947-62). These data provide information on the total amount of coal burned for energy production for approximately 500 of the largest thermal power plants in the US, representing 90 percent of all power plant coal consumption nationwide. Additionally, they identify the first year of operation for 272 coal-fired power plants that opened between 1938 and 1962.

Power plants are linked to counties based on latitude and longitude.[15] Based on the pollution transport literature, we identify a treatment radius of 30 miles. We construct a dataset of pairwise combinations of power plants and county-level outcomes. For each power plant opening, we identify treatment status based on county-centroid distance to the plant. Treatment counties are located within 30 miles of a power plant, control counties are located between 30 to 60 miles or 30 to 90 miles away. In other specifications, the data are collapsed to a county-year observation, where treatment is defined based on annual variation in total power plant coal consumption (100,000s of tons) within 30 miles of the county-centroid.

To study the effects of power plant coal consumption on health, we use annual county-

[15]The sample is restricted to counties that were within 200 miles of a power plant in 1962.

level data on infant mortality drawn from the *Vital Statistics of the United States*. Price Fishback digitized the data from 1938-1951, and he kindly shared the data with us. We digitized additional data for the period 1952-1962. There are several reasons why we focus on infant mortality rather than all-age mortality. First, changes in adult mortality driven by an increase in local pollution levels may have little impact on life expectancy if they occur among an already sick population (Spix et al, 1994; Lipfert and Wyzga, 1995). Second, the focus on infants limits misspecification due to the fact that current pollution concentrations at a particular location may not reflect an individuals lifetime exposure. Third, given the high respiratory rate and underdeveloped immune system, infants are particularly susceptible to the consequences of air pollution. As a result, the infant mortality rate was likely the most salient measure of health available to the public during this period.

To study the effects of local emissions on health, we use annual county-level data on infant mortality drawn from the *Vital Statistics of the United States*. Price Fishback digitized the data from 1938-1951, and he kindly shared the data with us. We digitized additional data for the period 1952-1954. By focusing on infant mortality, we hope to reduce misspecification caused by the fact that health capital is a function of both current and previous pollution levels. For these regressions, we construct an unbalanced sample of 1,208 counties for the period 1938 to 1954. The main sample is constructed as counties reporting infant mortality rates in at least three-quarters of the sample years, along with information on housing prices and economic characteristics for the census years 1940, 1950, and 1960.

To study the effects of power plant emission on the housing market, we rely on county-level property values from the Census of Housing for 1940 to 1960 (Haines and ICPSR, 2010; DOC and ICPSR, 2012). Our main outcomes of interest are (decadal) median dwelling value and (decadal) median dwelling rent. Additional data is used as controls in the analysis. The 1940 Census of Housing also reports information on the proportion of households with electric lighting, which is used as a proxy for baseline electricity access. "Geography" variables include time-varying controls for annual precipitation, temperature, degree days below 10C, and degree days above 29C, and county latitude and longitude. "Economy" covariates include total employment, manufacturing employment, and manufacturing payroll per worker at the baseline from the Census of Manufactures (1940).

4 Empirical Strategy

4.1 Difference-in-differences based on the opening of power plants

Our primary empirical approach relies on the opening of new power plants. The analysis relies on the opening of 272 coal-fired power plants between 1938 and 1962. We adopt a difference-in-differences strategy that compares health outcomes in counties near a power plant to counties slightly farther away. Counties within 30 miles of a power plant are considered as treatment counties; counties between 30-60 miles and 30-90 miles are control'. An important feature of this research design is that the benefits associated with the opening of a power plant are held constant across treatment and control groups. In particular, Figure 6 shows that the impact of a power plant opening on local electricity access is roughly constant within 90 miles. Thus, the estimates capture the health impact of a power plant opening driven by air pollution net of any potential benefits associated with local electricity production.

We estimate the effect of power plant openings on infant mortality by estimating the following econometric model:

$$\begin{aligned} IMR_{pdt} =& \beta_0 + \beta_1 1[PPopen]_{pt} + \beta_2 1[d < 25mile]_{pd} + \beta_3 1[PPopen]_{pt} \times 1[d < 25mile]_{pd} \\ &+ \eta_{pd} + \tau_{st} + \beta_4 X_{pd} \times \xi_t + \epsilon_{pdt} \end{aligned}$$

where IMR_{pdt} denotes infant mortality rate near plant site p, within distance group d, in year t. For each plant, there are two observations per year: treatment counties (within 30 miles of the plant) and control counties (30-60 miles or 30-90 miles from the plant).

The variable $1[PPopen]_{pt}$ is an indicator for whether plant p is operating in year t, and $1[d < 25mile]_{pd}$ is equal to one for counties within 30 miles of a current or future plant site. The model includes a vector of plant-county pair fixed effects, η_{pd} to control for time-invariant determinants of infant mortality at a given distance from each plant. We also include a vector of year fixed effects, ξ_t, to control for overall trends in air pollution levels. The equation also includes state-by-year fixed effects, τ_{st}, to flexibly allow for state trends in infant mortality. The term X_{pd} denotes a vector of time invariant economic and geographic covariates (total employment, manufacturing employment, manufacturing payroll per worker in 1940, as well as latitude and longitude). These characteristics are interacted with year fixed effects to allow treatment and control counties to trend differentially according to observable baseline characteristics.

The parameter of interest, β_3, is the coefficient on the interaction term, $1[PPopen]_{pt} \times 1[d < 25mile]_{pd}$. Because equation (1) includes the vector of plant-by-distance fixed effects, η_{pd}, this parameter is identified by the opening of power plants. It captures the differential impact of a plant opening on mortality across counties near and slightly farther away. Because the sample is restricted to counties within either 60 or 90 miles of a power plant, these estimates capture the effect of the change in air quality driven by the plant opening, holding constant its effects on electricity access.

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

4.2 Annual variation in power plant coal consumption and capacity

The second empirical strategy exploits spatial and temporal variation in the capacity and coal consumption of power plants. We regress outcome Y in county c in year t on local power plant coal consumption, $CoalCons_{ct}$, year fixed effects, δ_t, county fixed effects, η_c, and a linear state trend, λ_{st}.[16] In addition, we include a vector of time-varying covariates for geography (annual precipitation, temperature, degree days below 10C, and degree days above 29C, and latitude and longitude), X_{ct}, invariant controls for county longitude and latitude, Z_c, interacted with the year fixed effects, δ_t, and baseline county economic characteristics, $Econ_c$ (total employment, manufacturing employment, and manufacturing payroll per worker in 1940), interacted with δ_t. The estimating equation is given by

$$Y_{ct} = \alpha + \beta CoalCons_{ct} + \theta X_{ct} + \delta_t Z_c + \delta_t Econ_c + \lambda_{st} + \eta_c + \delta_t + \epsilon_{ct}. \qquad (1)$$

The variables of interest, $CoalCons_{ct}$, denotes either the total annual power plant coal consumption (in 100,000s of tons) or total capacity of coal-fired plants (100s of megawatts) within 30 miles of the county-centroid. Again, this distance is chosen to identify the population most exposed to power plant emissions. The reduced form estimates of β capture the overall impact of coal-fired generation: a combination of the costs from plant emissions and the economic benefits due to increased electricity production. In order to disentangle these offsetting effects, we estimate a generalized version of equation (2) in which the impact of $CoalCons_{ct}$ is allowed to vary across different levels of baseline electricity access.[17]

The identifying assumption requires that annual changes in plant capacity and coal consumption be unrelated to contemporaneous determinants of infant health and housing prices. To address concerns that local economic conditions might simultaneously influence the demand for electricity, health, and property values, we control directly for measures baseline economic conditions interacted with year fixed effects. Importantly, equation (2) is estimated using both annual variation in coal consumption and capacity. Although plant-level coal consumption might respond to short-term fluctuations in demand for electricity, changes in capacity – from either the construction of a new plant or additions to existing capacity – required a multi-year planning process, and were typically made on the basis of 20 to 30

[16] In some specification, we replace λ_{st} with a vector of state-by-year fixed effects.

[17] Baseline electricity access is calculated as the fraction of households with electricity in 1940 based on the 1940 Census of Housing.

year forecasts of demand (EIA, 2010). Thus, local capacity should be far less responsive to contemporaneous economic activity. As a test of the research design, we conduct a placebo test for the impact of local hydroelectric capacity.

5 Results

5.1 The Impact of Coal-Fired Power Plant Openings on Infant mortality

To motivate the regression analysis, and evaluate the validity of the common trends assumption of the difference-in-differences strategy, we first present event study graphs based on the timing of power plant openings. These graphs are based on a generalized version of equation (1), that allows the coefficient β_3 to vary with event time $t \in \{-6, 6\}$.

Although the transparency of these graphs is appealing, several caveats should be mentioned. First, the opening of a coal-fired power plant is not an 'event study' in the sense that a negligible amount of pollution is produced prior to opening. Coal-fired power plants are major construction projects, which contributes to local levels of pollution several years prior to opening.[18] Second, the Federal Power Commission volumes do not report the first month of plant operation. As a result, the estimates of $\beta_3^{t=0}$ will understate the impact of power plant operations on mortality, since most plants would have polluted for only a fraction of their first year of operation. Third, power plants generally scale up production in the years after initial opening. Thus, treatment counties would have been exposed to a differential rise in pollution following a plant opening, rather than one time shift in the level of pollution.

Figure 7 reports the event study coefficients for the years before and after a plant opening. Although not individually significant, the reported coefficients provide suggestive evidence that exposure to pollution form coal-fired power plants was harmful to infant health. Post-opening, infant mortality is relatively higher in treatment counties, and this gap widens with

[18]The construction times cited by the Federal Power Commission ranged from one to four years.

time. The results also show a slight upward shift in mortality during the typical construction period. Importantly, there is no evidence that mortality was trending differentially across treatment and controls counties prior to treatment.

The health impact of power plant opening should depend on its size. Figure 8 plots average annual coal consumption for large and small power plants (capacity above or below 75mw). In the first year of operation, large plants burned six times more coal than smaller plants, and this gap widened as the larger plants expanded production over time.[19]

Figures 9 reports the event study coefficients for large power plants. Infant mortality rises sharply the first full year of power plant operation, and the effect widens with event time. These results coincide with the annual changes in power plant coal consumption reported in Figure 10. Taken literally, the estimated effects imply that a 100,000 ton increase in local power plant coal consumption is associated with a 0.08 increase in the infant mortality rate. On the other hand, there is no systematic relationship between the opening of small power plants and infant mortality, consistent with the relatively small change in coal consumption that occurs following an opening.

In Table 1, we report the estimates from the difference-in-differences estimation strategy based on new plant openings. Panel A reports the estimates for all power plants. Across all three specifications and both control groups the results are positive and statistically significant, ranging from 0.63 to 2.2. Panel B reports the estimates effects separately for large and small power plants. The overall effect is driven entirely by the large plants, consistent with the substantial spike in coal consumption shown in Figure 8. The preferred estimates imply that the opening of a large power plant is associated with a 2 percent increase in the local infant mortality rate. In fact, these estimates can be combined with information on change in coal consumption that occurred following a large plant opening to derive the impact of power plant coal consumption on infant mortality. The preferred

[19]The sample includes 75 small power plants that upgraded capacity and crossed the 75mw threshold within 6 years of initial operation. To avoid concerns that coal consumption is endogenous to the timing of initial opening, these observations fall under the 'small' category in event years in which capacity is below 75mw and the 'large' category in event years in which capacity is above 75mw.

estimates imply that a 1 million ton increase in annual coal consumption is associated with an increase of $(1.03/8.4)\times 10 = 1.23$ in the infant mortality rate. Given that plants were historically concentrated in densely populated areas, these findings imply substantial health costs associated with power generation.

5.2 The Impact of Power Plant Coal Consumption and Capacity on Infant mortality

Table 2 reports the impact of annual variation in power plant coal consumption and capacity on infant mortality based on equation (2). Columns (1) to (4) report the estimates of $CoalCons_{ct}$ for different specifications. In column (1) we include only year and county fixed effects, in column (2) we add baseline economic and geographic covariates interacted with year, in column (3) a state-year fixed effect is included to allow for differential trends in mortality across states, and column (4) includes the full set of controls.

Panel A of Table 2 reports the results based on all annual variation in coal consumption. The point estimates range from 0.085 to 0.142 and are all statistically significant. Notably, the inclusion of economic covariates reduces the magnitude of the point estimates. The change in the estimate could reflect the fact that changes in coal consumption and industrial activity were related. Failing to account for the direct impact of industrial pollution on health would lead to upward-biased estimates.

Panel B reports the results based on coal and hydroelectric capacity. This comparison provides a useful placebo test, since both sources of electricity should have similar effects on local economic activity. Across all four specifications, coal-fired capacity is associated with large statistically significant increases in infant mortality. Meanwhile, the point estimates for hydro capacity are insignificant and substantially smaller in magnitude. Together these findings support the research design.

To interpret the magnitude of the effects, Figure 11 reports the additional infant deaths in the sample that are attributable to coal consumption by electric utilities. We report these estimates separately based on the number of live births in 1938, and based on annual births. Calculations based on the latter are substantially larger, given that the baby boom led to an increase in the number of infants potentially exposed to air pollution. In 1938, fewer than 500 infant deaths can be attributed to coal-fired electricity. As coal-fired generation expanded in the 1950s, the health costs grew dramatically. By the end of the sample period, the rise in coal consumption by electric utilities was responsible for an additional 3,500 infant deaths per year.

5.3 Effects in the Housing Market

Together, the results from Tables 1 and 2 show that local power plant emissions were harmful for health. These findings are consistent with recent evidence on the effects of local coal consumption on mortality (Currie et al., 2013; Hanlon, 2014). Nevertheless, it is unclear how individuals traded-off these health costs against the benefits of local thermal electricity. To investigate this question, we adopt a hedonic approach, using changes in the housing market and wages to infer the implicit price associated with this nonmarket amenity. We estimate the relationship between coal consumption by electric utilities and housing rental values for decennial years 1940, 1950, and 1960.[20]

Table 3 presents the estimates of the capitalization of power plant coal-use into property values. We report the estimates separately for coal consumption and coal-fired capacity within 30 miles. For reference, columns (1) and (2) report the estimates for infant mortality based on the same sample used in the housing market regressions. Panel A shows the estimates for electric utilities coal consumption. Although there were significant negative effects on health, we find no relationship between coal consumption and property values. We find similarly small results based on coal-fired capacity. In fact, the substantial increase in electric utility coal-use between 1940 and 1960 can account for less than 1% percent of variation in housing prices over this period.

[20] We focus on rental prices since they are more highly correlated with local amenities than housing prices (Banzhaf and Farooque, 2013).

There are several possible explanations for the limited response in the housing or labor market. First, the findings might simply reflect the fact that individuals were unaware of the health costs associated with pollution, and thus generally unresponsive to changes in local coal consumption. Media coverage during this time period did identify the potential risks associated with pollution, however, epidemiological evidence on the link between pollution and mortality did not emerge until the 1970s. Alternatively, if there was heterogeneity in tastes for clean air, individuals may have sorted across locations on the basis of the unobservable preferences. In this case, our estimates of the marginal willingness to pay (MWTP) could reflect the preferences of a specific subpopulation that, for example, may have placed a relatively low value on clean air. Third, the findings may simple capture the fact that individuals valuations of the benefits associated with local electricity generation roughly offset the pollution costs. To differentiate amongst these competing explanations, we exploit heterogeneity in the housing market response.

5.4 Heterogeneous Responses in the Housing Market

To assess heterogeneity in the effects of coal-fired emissions, we split US counties into two bins according to baseline electricity access.[21] We split the sample evenly between these bins, and re-estimate the effects for infant mortality and housing across the two groups. There were wide differences in electrification access across the two groups: the mean baseline electrification rates were 50 and 93 percent for the low and high bins, respectively. This stark distinction allows us to disentangle the pollution costs from the benefits associated with electricity access.

Table 4 presents the results for infant mortality and the logarithm of median dwelling rent. The health effects differ widely according to baseline electricity access. At low levels of access, increases in coal consumption and coal-fired capacity have negative effects on infant mortality. These findings are consistent with previous research on the positive health

[21] Electricity access is proxied by the proportion of homes with electric lighting in the 1940 Census of Housing

effects associated with household electrification (Lewis, 2015, Gohlke 2011). At high levels of electricity access, the sign of the effect flips, suggesting that the pollution overwhelm any last marginal gains associated with electricity access.

The last two columns report the estimates for housing values. The insignificant effects reported in Table 3 mask substantial heterogeneity in the housing market response. At low levels of electricity access, a 100,000 ton increase in coal consumption would lead to a 2.8 percent rise in local housing values, whereas at high levels of access it would lead to a decrease of 6.1 percent.

The heterogeneous housing response captures how the tradeoffs of power plant coal consumption evolve as a greater share of the population electrify. At low levels of electricity access, increases in energy production offer large potential benefits to the local population. As a greater fraction of the population gain access, the scope for these gains is diminished. On the other hand, the pollution costs of power generation are generally independent of electricity access. Individuals will assign more value the amenity benefits associated with increases in electricity production at low levels of electricity access, and place greater importance on the pollution costs of coal consumption at high levels of access. As a result, the MWTP to avoid power plant emissions should increase with the level of electricity access, consistent with the heterogeneity we observe in the hedonic regressions.

The fact that the MWTP to avoid power plant emissions depends on the level of electricity access has important implications for energy policy. Fossil-fuel generators have long lifespans, ranging from 30 to 50 years (IEA, 2010). Consider the case of the Gorgas power plant. This large thermal power plant was built in the late 1920s near the town of Parrish in Walker County, Alabama. Initially, 70mw of capacity were installed, and the plant consumed roughly 150,000 tons of coal per year. At the time of installation only 13% of residents had electrical services. Given these low levels of electricity access, our estimates imply that at the time of construction of this plant would have caused a 0.3% increase in local home values, generating a net gain of $379,000 (1990 USD) in the local housing market. By 1950, 90% of homes in Walker County had electrical services. As a result, the pollution costs would have overwhelmed the local benefits of greater electricity access, and led to a 0.9% fall in local home prices a total decline of $1,653,000 in the value of the county's housing stock. Given these large changes in the response of the housing market, policymakers must take careful account for the evolving preferences for thermal power when investing in energy infrastructure.

6 Conclusion

This paper uses the sharp expansion in U.S. fossil fuel powered electricity during the mid-20th century to study the tradeoffs associated with coal-fired power generation. The analysis draws on newly digitized information on the timing of power plant openings, coal consumption, and health. Increases in power plant emissions are associated with higher levels of local pollution and a greater incidence of infant mortality. Although these negative environmental effects were not considered a disamentity on average, we find substantial heterogeneity in how individuals valued local thermal capacity. In particular, our estimates imply a positive MWTP for thermal power at low levels of electricity access, and a negative MWTP at high levels of access, suggesting that the benefits of electricity may diminish with economic development.

Our estimates suggest that there was a remarkable reversal in preferences for local thermal electricity during the mid-20th century. In 1925, the construction of a thermal power plant would have been considered a gain to local residents in the majority of U.S. counties, and a local disamenity in just 2% of counties. By 1955, fossil fuel power plants were viewed as a local disamenity in 98% of counties. Perhaps in response to these evolving preferences, the subsequent fifty years have witnessed increasingly stringent regulations of power plant emissions under the 1963 Clean Air Act and subsequent amendments. There were substantial costs associated with meeting these requirements, including costs associated with decommissioning existing plants and upgrading capacity to meet emission standards. Given these potentially large adjustment costs, policymakers must take into account both current and future preferences for electricity and air quality when making electricity infrastructure investment decisions.

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7 Figures and Tables

Table 1: The Effect of Power Plant Openings on Infant Mortality

Dep Variable: Infant Mortality						
	Sample selection:					
	<60 miles from a plant			<90 miles from a plant		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: All Power Plants						
I(PP open)× Near	2.2051**	1.5159***	0.6477*	1.9541*	1.4091***	0.6255**
	(1.1212)	(0.5006)	(0.3440)	(1.0053)	(0.4827)	(0.2704)
Panel B: Large vs. Small Power Plants						
I(PP open)× Near×						
Large PP	2.4333**	1.8707***	1.0393***	2.1541**	1.7604***	1.0300***
	(1.1893)	(0.5044)	(0.3630)	(1.0613)	(0.4898)	(0.2969)
Small PP	1.0972	-0.0590	-0.3929	0.8940	-0.2380	-0.4453
	(0.8190)	(0.5658)	(0.4354)	(0.7351)	(0.5054)	(0.3613)
Observations	69,650	69,650	69,650	141,300	141,300	141,300
# Plants	267	267	267	281	281	281
Controls						
Year+County-plant FE	Y	Y	Y	Y	Y	Y
State-year FE		Y	Y		Y	Y
Geog & econ × year			Y			Y

Table 2: The effect of power plant coal consumption and capacity on infant mortality

Dep Variable: Infant Mortality				
	(1)	(2)	(3)	(4)
Panel A: Coal Consumption Within 30 Miles				
Coal Consumption Within 30 Miles	0.1418***	0.0897***	0.1082***	0.0850***
	(0.0357)	(0.0257)	(0.0194)	(0.0167)
Panel B: Coal Capacity vs. Hydro Capacity				
Coal Capacity Within 30 Miles	0.0022***	0.0018***	0.0019***	0.0016***
	(0.0005)	(0.0004)	(0.0003)	(0.0003)
Hydro Capacity Within 30 Miles	-0.0013	0.0005	0.0004	-0.0003
	(0.0026)	(0.0013)	(0.0012)	(0.0014)
Counties	1,983	1,983	1,983	1,983
Observations	49,575	49,575	49,575	49,575
Controls				
County & Year FE	Y	Y	Y	Y
State-Year FE			Y	Y
Geog & economic covariates		Y		Y

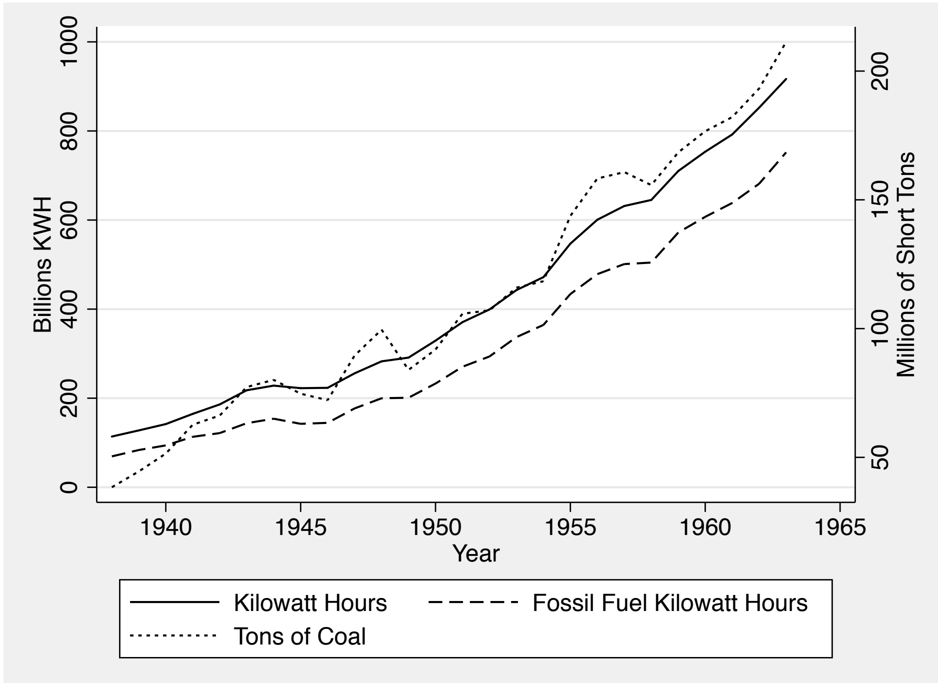
Table 3: The effect of power plant coal consumption and capacity on property values

	Infant Mortality		**Ln(Median Rent)**	
	(1)	(2)	(3)	(4)
Panel A: Coal Consumption Within 30 Miles				
CC30Miles	0.1288*	0.1010**	-0.0021	0.0011
	(0.0658)	(0.0465)	(0.0015)	(0.0009)
Panel B: Coal Capacity Within 30 Miles				
Cap30Miles	0.2391***	0.2650***	-0.0083***	0.0000
	(0.0652)	(0.0691)	(0.0025)	(0.0019)
Counties	1,983	1,983	1,983	1,983
Observations	49,575	49,575	49,575	49,575
Controls				
County & Year FE	Y	Y	Y	Y
All covariates		Y		Y

Table 4: Heterogeneity in the effects on property values, by baseline electricity access

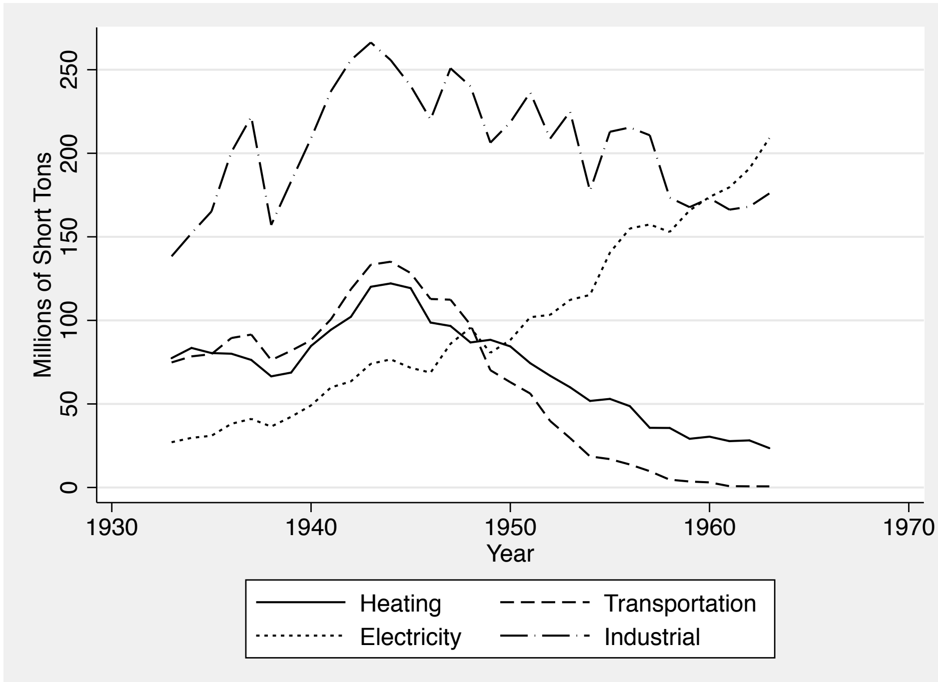
	Infant Mortality		**Ln(Median Rent)**	
	(1)	(2)	(3)	(4)
Panel A: Coal Consumption Within 30 Miles				
CC30Miles x L-Electricity	-0.2169***	-0.1760***	0.0032***	0.0028***
	-0.0678	-0.061	-0.0009	-0.0008
CC30Miles x H-Electricity	0.2411***	0.2487***	-0.0204***	-0.0061**
	-0.0709	-0.0546	-0.0042	-0.0024
Panel B: Coal Capacity Within 30 Miles				
Cap30Miles x L-Electricity	-0.5817***	-0.4108**	0.0085***	0.0064***
	(0.1893)	(0.1634)	(0.0024)	(0.0022)
Cap30Miles x H-Electricity	0.2976***	0.3701***	-0.0247***	-0.0086***
	(0.0652)	(0.0768)	(0.0043)	(0.0028)
Controls				
County & Year FE	Y	Y	Y	Y
All covariates		Y		Y

Figure 1: Trends in Electricity Generation



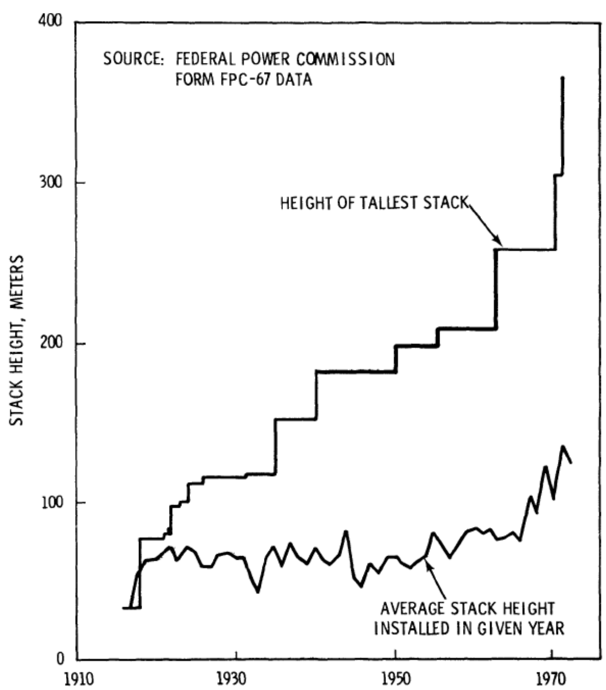
Notes: Data are from Gartner et al, *Historical Statistics of the United States* (2006). Table Db218-227. Electric utilities-power generation and fossil fuel consumption, by energy source: 1920-2000.

Figure 2: Coal Consumption, by Source



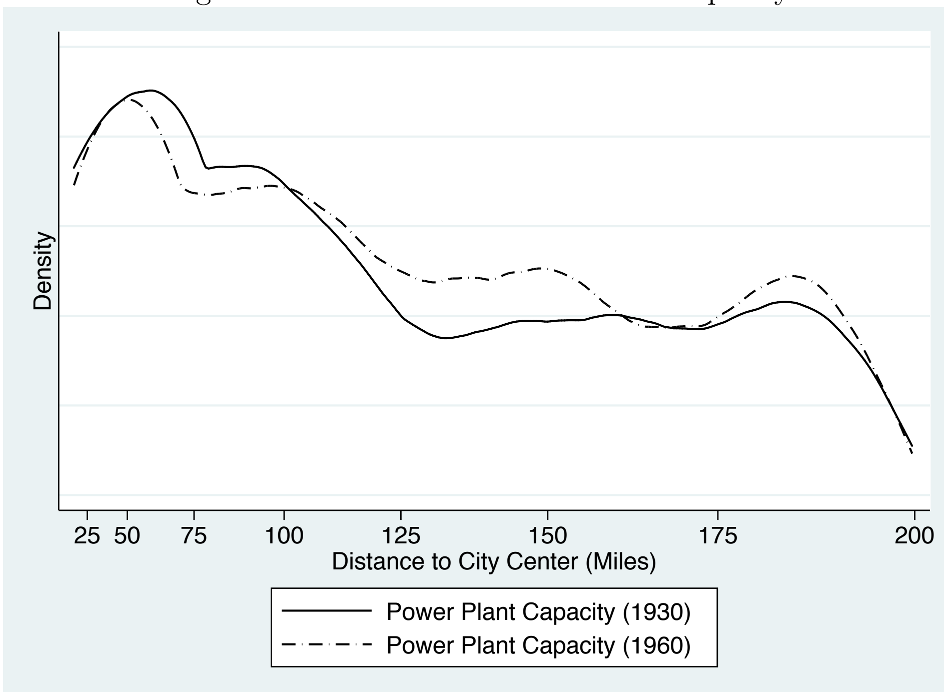
Notes: Data are from United States Bureau of Mines, Minerals Yearbook (various years).

Figure 3: Coal-Fired Power Plant Smoke-Stack Height



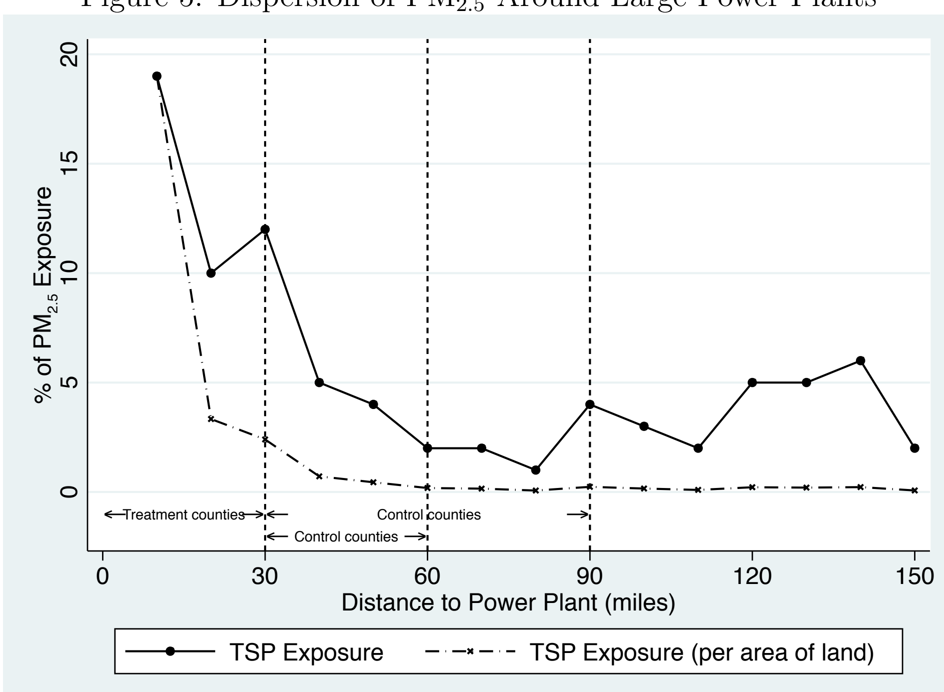
Source: Hales (1976) Figure 3, p.10.

Figure 4: Distribution of Fossil-Fuel Capacity



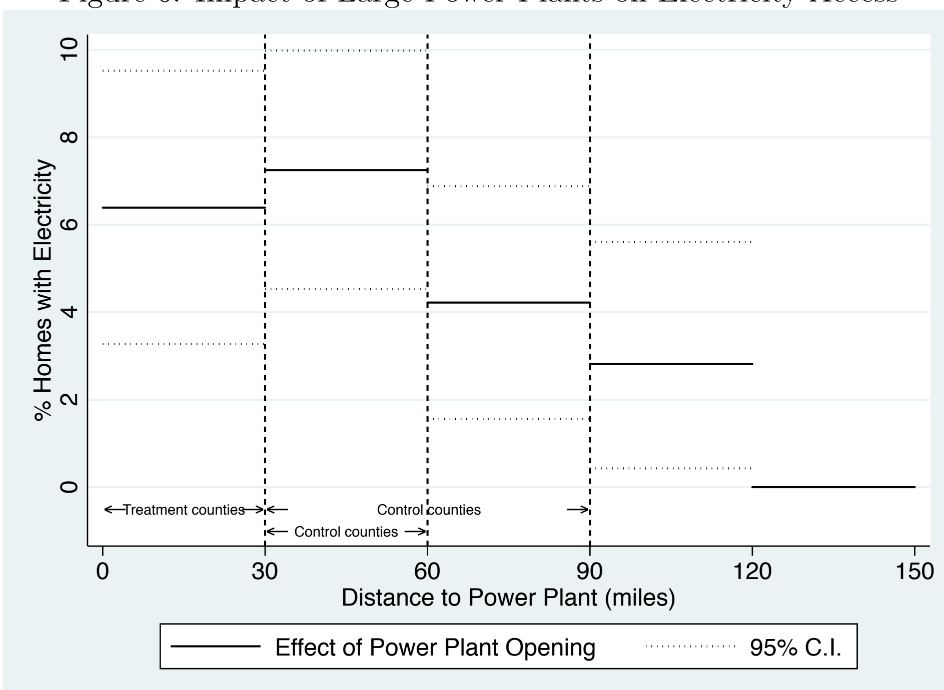
Notes: This figure report the density of fossil-fuel capacity within 200 miles of the
city-centroid for the 50 largest cities in the US.

Figure 5: Dispersion of $PM_{2.5}$ Around Large Power Plants



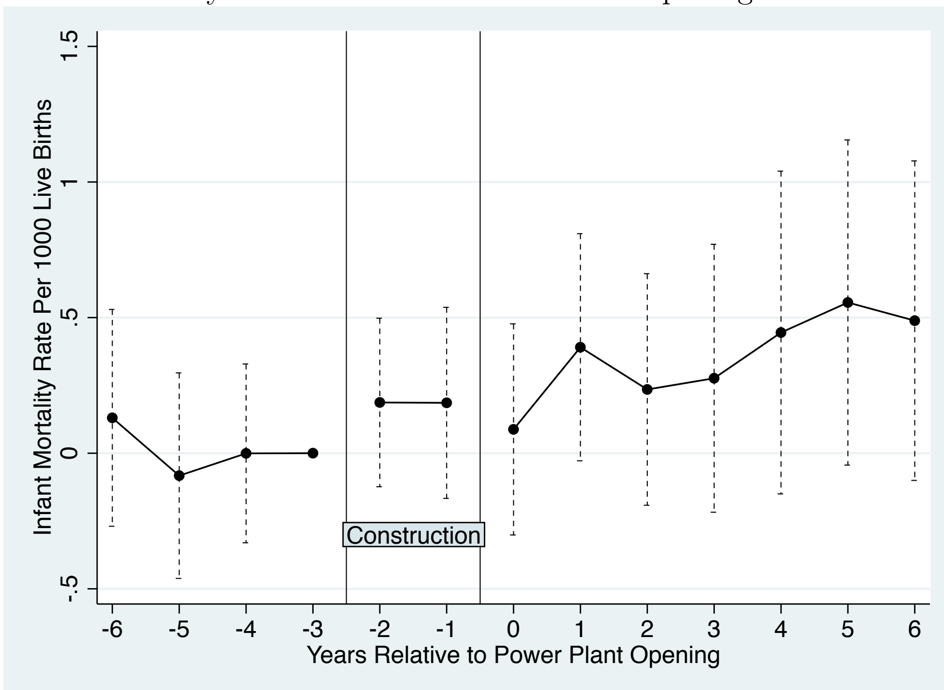
Source: Levy et al (2002)

Figure 6: Impact of Large Power Plants on Electricity Access



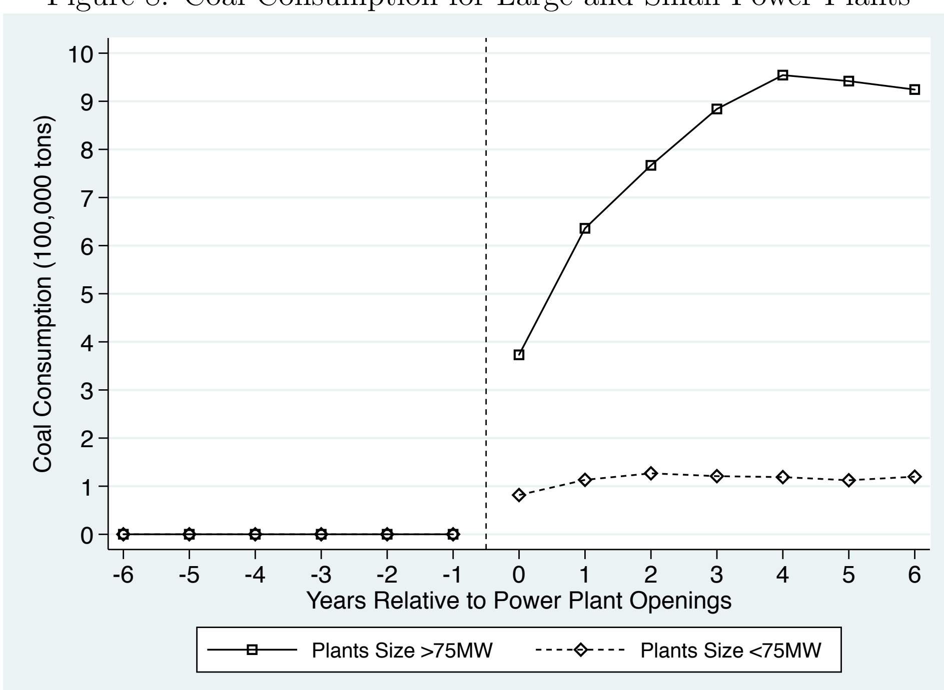
Notes: This figure plots the regression estimates from FE models relating fraction
of households with electricity to opening of large power plants (>30mw)

Figure 7: Event Study for the Effect of Power Plant Openings on Infant Mortality



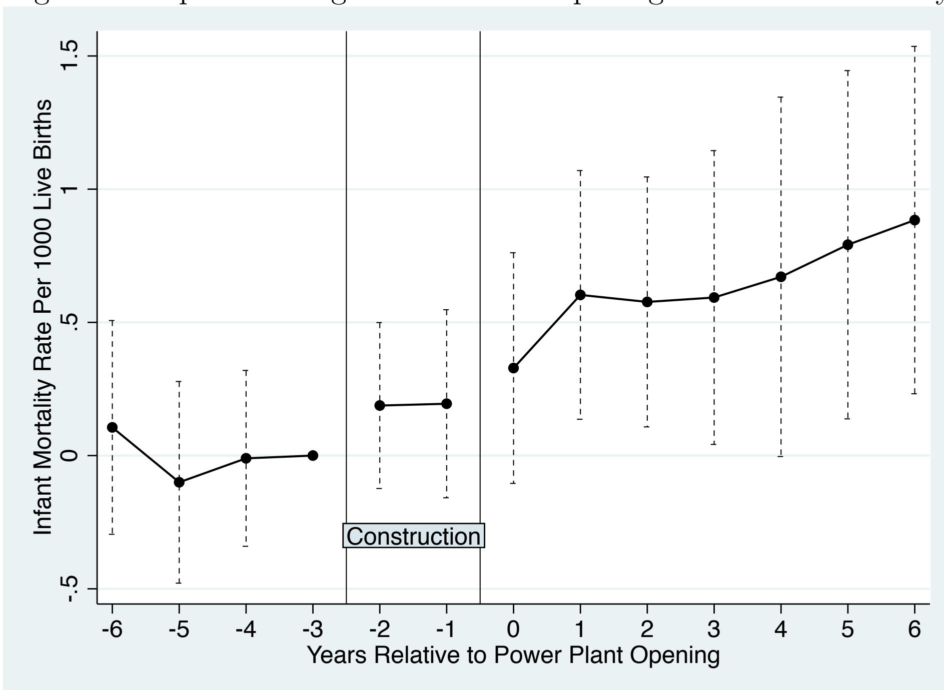
Notes: This figure plots the coefficient estimates for $t \in \{-6, 6\}$ based on equation (1).

Figure 8: Coal Consumption for Large and Small Power Plants



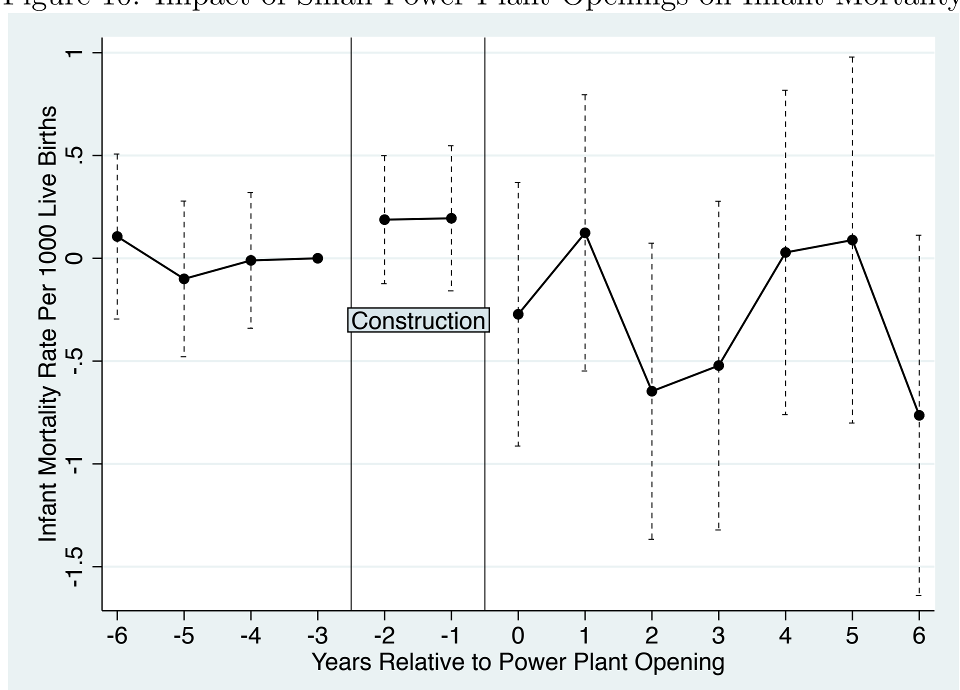
Notes: This figure plots average annual coal consumption (100,000s tons) for large (>75mw) and small (<75mw) following opening.

Figure 9: Impact of Large Power Plant Openings on Infant Mortality



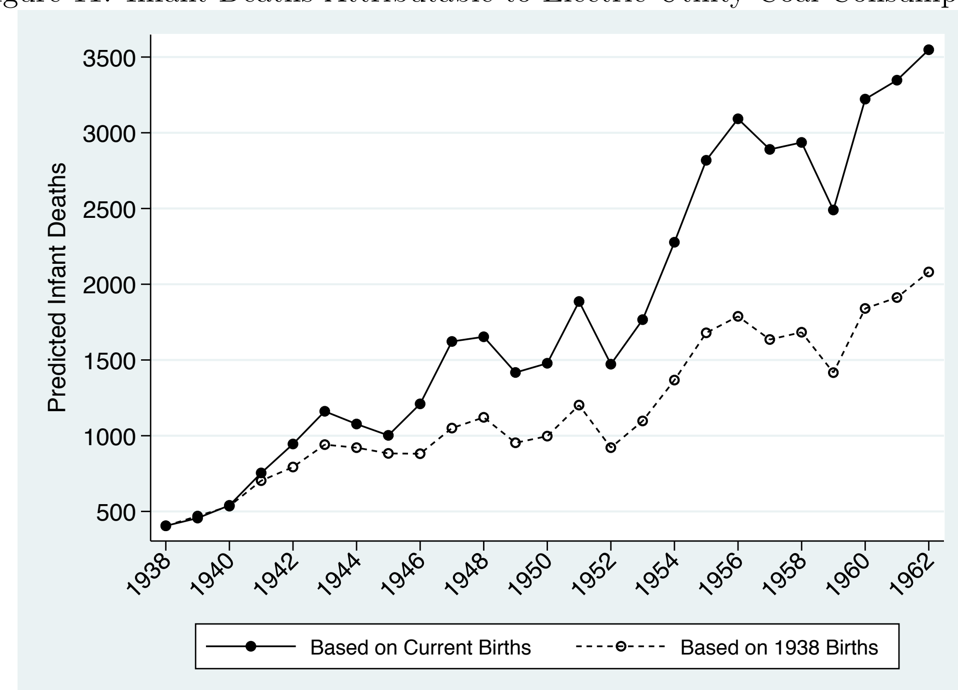
Notes: This figure plots the coefficient estimates for $t \in \{-6, 6\}$ based on equation (1) for large power plants (>75mw).

Figure 10: Impact of Small Power Plant Openings on Infant Mortality



Notes: This figure plots the coefficient estimates for $t \in \{-6, 6\}$ based on equation (1) for small power plants (<75mw).

Figure 11: Infant Deaths Attributable to Electric Utility Coal Consumption



Notes: This figure plots number of annual infant deaths in the sample attributable to electric utility coal consumption based on the estimates in column (4) in Table 2.

A Appendix

A.1 Additional Figures and Tables

Table A.1: TSP Concentration in Various Years

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

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

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

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

Source: Stern 1982, Table III, p. 45.