THE EFFECT OF POWER PLANTS ON LOCAL HOUSING VALUES AND RENTS

Lucas W. Davis*

Abstract—This paper uses restricted census microdata to examine housing values and rents for neighborhoods in the United States where power plants were opened during the 1990s. Compared to neighborhoods with similar housing and demographic characteristics, neighborhoods within 2 miles of plants experienced 3%–7% decreases in housing values and rents, with some evidence of larger decreases within 1 mile and for large-capacity plants. In addition, there is evidence of taste-based sorting, with neighborhoods near plants associated with modest but statistically significant decreases in mean household income, educational attainment, and the proportion owner-occupied.

I. Introduction

ELECTRICITY consumption in the United States is forecast to increase 30% between 2008 and 2035, according to baseline estimates from the U.S. Department of Energy (2010a). Despite growing interest in renewable energy sources, most of this growth is expected to be met with increased production from power plants using coal, natural gas, and other fossil fuels. A substantial investment in new plants has already begun, with 450 new fossil fuel generators scheduled to be opened in the United States between 2010 and 2013 (U.S. Department of Energy, 2010b). Nationwide over $500 billion is expected to be spent on new fossil fuel power plants between 2010 and 2030 (Brattle Group, 2008).

One of the biggest challenges in siting new plants is resistance from local communities. Citizen groups argue that power plants are a source of numerous negative local externalities, including visual disamenities and noise. This paper evaluates these claims using evidence from the housing market. If households value these disamenities, then power plant openings should lead to a decrease in the price of housing in the immediate vicinity of plants. In addition, plant openings should be associated with changes in local demographics as households sort across neighborhoods based on their willingness to pay to avoid living near a plant. This paper tests these predictions using evidence from 92 large power plants that opened in the United States between 1993 and 2000.

The main empirical challenge in such a study is constructing a counterfactual for the locations where power plants were opened. Power plant siting is a highly political process, and the paper shows that plants tend to be opened in locations near neighborhoods with housing and demographic characteristics that differ from the rest of the United States. In order to better control for these differences, the analysis focuses on power plant openings rather than cross-sectional comparisons between locations with and without plants. This makes it possible to control for a rich set of demographic and housing characteristics from 1990, before the plants were opened. Some specifications also include neighborhood characteristics from 1970 and 1980 to control for differential time trends. In addition, propensity score weighting is used to equate the mean characteristics of neighborhoods in the sample with the mean characteristics of the neighborhoods near where plants were opened. This approach for mitigating omitted variables concerns is not a panacea, but it offers considerable advantages over a conventional cross-sectional analysis and yields reasonable results across a range of different specifications and validity tests.

The results indicate modest declines in housing values and rents within 2 miles of plants. In the preferred specification, housing values decrease by 4%–7%. Results are similar for rents, consistent with commensurate changes in current and expected future amenities. The analysis also sheds light on the evolution of neighborhood demographics near plants. Power plant openings are associated with statistically significant decreases in mean household income, educational attainment, and the proportion owner-occupied. These changes are consistent with taste-based sorting in which willingness to pay to avoid living near a plant varies across households. Again, however, the magnitude of the effects is small. For example, the analysis indicates that within 2 miles of plants, the proportion owner-occupied decreases by 2 to 5 percentage points compared to a mean of 68%.

The baseline estimates imply an average housing market capitalization of $13.2 million per plant. This is small compared to, for example, the cost of constructing new plants and reflects the fact that most plant openings during this period occurred in locations with low population density. It is important to emphasize that this capitalization captures only some of the external costs from power plants. Power plants are, for example, a major source of nitrogen oxides and other criteria pollutants that have negative impacts on human health (Chay & Greenstone, 2003; Currie & Neidell, 2005). However, under normal operating conditions, the vast majority of these pollutants are diluted in the atmosphere and carried far away, resulting in relatively modest disproportionate impacts in the immediate vicinity of power plants. A comprehensive analysis of the negative externalities from power plants

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* Haas School of Business, University of California, and National Bureau of Economic Research.

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would need to, in addition, measure these broader welfare consequences.

This study is germane to an extensive literature that examines the impact of locally undesirable facilities on housing markets. Previous studies have examined hazardous waste sites (Gayer, Hamilton, & Viscusi, 2000; Greenstone & Gallagher, 2008), waste incinerators (Kiel & McClain, 1995), nuclear power plants (Nelson, 1981; Gamble & Downing, 1982), coal-burning power plants (Blomquist, 1974), and facilities that report to the Toxic Release Inventory (Bui & Mayer, 2003; Oberholzer-Gee & Mitsunari, 2006; Banzhaf & Walsh, 2008). Other studies have used similar methods to examine environmental public goods more generally, including air quality (Chay & Greenstone, 2005; Bayer, Keohane, & Timmins, 2009) and water quality (Leggett & Bockstael, 2000). This paper is the first large-scale study of power plants.

A key feature of this study is the use of a restricted version of the U.S. decennial census. These data, which must be accessed at a census research data center under authorization from the Census Bureau, include all of the demographic and housing characteristics in the decennial census and identify households at the census block, the smallest geographic unit tracked by the Census Bureau. This precision is important for the analysis because the impact of many of the externalities from power plants is highly localized. In addition, the large (one in six) national sample ensures broad geographic coverage even in nonurban areas.

The format of the paper is as follows. Section II briefly reviews the hedonic price method and discusses the primary predictions of the model. Section III reviews relevant background about power plants, focusing on externalities that are likely to be important to households living in the immediate vicinity of a plant. Sections IV and V describe the data and results, and section VI offers concluding remarks.

II. Analytical Framework

A large literature uses the hedonic price method to test whether households value nonmarket amenities. Dozens of studies dating back at least to Ridker and Henning (1967) have used data from the residential housing market to estimate the association between housing prices and environmental quality. This section briefly reviews the relevant features of the hedonic model. For a more complete description, see Freeman, 2003. The model provides two main testable implications: (a) a decrease in environmental quality will cause housing prices and rents to decrease, and (b) households will respond to a decrease in environmental quality with taste-based sorting.

In the standard hedonic model, a differentiated good is described by a vector of characteristics $(z_1, z_2, \ldots, z_n)$. For a house, these characteristics include structural attributes, neighborhood amenities, local environmental quality, and other factors. Prices are determined by equilibrium interactions between home buyers and sellers. The equilibrium relationship between prices and characteristics is the hedonic price schedule (HPS):

$$P(z_1, z_2, \ldots, z_n).$$

Figure 1.—A Hedonic Market for Environmental Quality

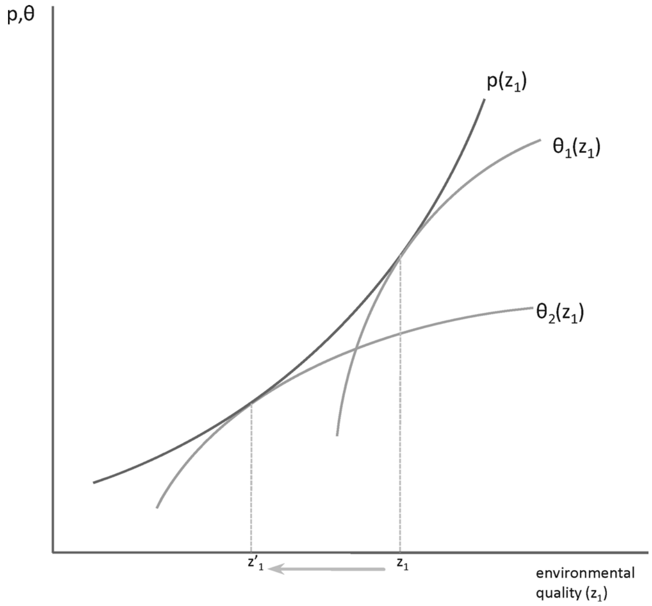

Figure 1 plots the HPS as a function of one particular characteristic, z_1, holding constant the level of all other characteristics. Suppose z_1 is a measure of local environmental quality such as distance to the nearest power plant. If buyers value this characteristic, then houses in locations with low environmental quality must have lower prices than equivalent houses in other locations in order to attract households to these locations. The preferences of buyers are represented by their bid function, denoted θ, an indifference curve in (p, z_1) space. Utility maximization occurs at the point where the bid function is tangent to the HPS. The figure depicts bid functions for two types of households. Type 1 households have a strong taste for environmental quality and choose to consume a relatively high level of z_1, whereas type 2 households have weaker tastes for environmental quality and choose a lower level. As Rosen (1974) first pointed out, at each point on the HPS, the marginal price of a characteristic is equal to the marginal willingness to pay (MWTP) of households that choose to locate at that point.

For nonmarginal changes in amenities, the observed price differential is equal to a weighted average of MWTP for households that choose to locate between the two points. To see this, consider a decrease in environmental quality from z_1 to z_1', as indicated in figure 1. The observed price differential between z_1 and z_1' understates the MWTP of household 1 and overstates the MWTP of household 2. The observed differential is equal to the weighted average of MWTP for households that sort themselves into the range between z_1 and z_1'. It is important to note that this is not the population average MWTP. However, from a policy perspective, the population average MWTP is often not particularly relevant. Policymakers are typically evaluating interventions that have an impact on a set of locations with a particular level of amenities often very different from the distribution of amenities in the population.[1]

In the thought experiment described above, it is assumed that the HPS does not shift in response to the decrease in environmental quality. Large-scale national changes in environmental quality will cause the entire HPS to shift as equilibrium prices adjust to a new portfolio of housing alternatives. In such cases, observed price differentials are best interpreted as the difference between two equilibrium prices rather than a single equilibrium differential. See Sieg et al., 2004, who use a general equilibrium approach to study the effect of air quality on housing values. For power plant openings, however, the assumption of a constant HPS is likely to be a good approximation because only a tiny fraction of the U.S. housing market is affected. The power plant openings between 1993 and 2000 occurred in just 92 of 65,433 total U.S. Census tracts.

A measure of the implied change in total welfare from a local decrease in environmental quality can be calculated by multiplying the observed equilibrium price differential by the number of local residential housing units. This measure of welfare change assumes no change in the HPS, that there is a parallel shift in the demand curve, and that housing supply is perfectly inelastic. This last assumption is reasonable in the short run because housing is durable. In the long run, a decrease in local housing demand will also decrease the quantity of housing as older homes are razed. See Greenstone & Gallagher, 2008, for a detailed discussion of measuring welfare changes using the hedonic price method.

In response to a decrease in environmental quality, there will also be a change in the composition of local neighborhoods. Again consider a decrease in environmental quality from z_1 to z_1' as indicated in figure 1. After the decrease, type 1 households find themselves in a neighborhood with a suboptimally low level of environmental quality, and these households can increase utility by moving to a neighborhood with the level of quality that they selected originally. After the decrease and subsequent sorting, households in the neighborhood will be those with relatively weaker tastes for environmental quality. Thus, for example, if environmental quality is a normal good, then household income will tend to go down after a decrease in environmental quality. Documenting this taste-based sorting is of significant independent interest (see Banzhaf & Walsh, 2008).

III. Background: The Local Impact of Power Plants

Several local externalities are likely to be important for households living in the immediate vicinity of power plants. Power plants are large industrial facilities that can be seen from a distance because of their tall stacks. These visual disamenities are especially acute for the large plants (more than 100 megawatts) that are the subject of this analysis. Another local externality from power plants is noise pollution. Fossil fuel plants produce electricity using giant engines that generate high levels of noise and vibration. Natural gas plants use turbine engines, which can be particularly noisy. Air intake systems and cooling fans also generate noise. Although available technologies help mitigate these problems, it is not uncommon for noise from power plants to be heard far away, particularly when plants are being tested or cleaned. Another potential source of negative externalities from power plants is traffic from fuel deliveries. Whereas natural gas is delivered by pipeline, coal typically arrives by train, truck, or barge. Coal plants in the United States use over 1 billion tons of coal annually (over 690,000 tons per generator).[2] These deliveries require thousands of trips at all hours of the day, generating noise and traffic as well as fly ash from coal processing.

Each year power plants in the United States emit 8 million metric tons of sulfur dioxide and 3 million metric tons of nitrogen oxides, as well as other criteria pollutants (U.S. Department of Energy, 2010b). Under normal conditions, however, the vast majority of these emissions are diluted in the atmosphere and carried far away. Studies using regional atmospheric models (Levy & Spengler, 2002; Levy et al., 2002; Mauzerall et al., 2005) find little evidence of disproportionate impact on neighborhoods in the immediate vicinity of the plant. For example, Levy and Spengler (2002) find that exposure to health risks from sulfur dioxide and nitrogen oxides decreases approximately linearly between 0 and 500 kilometers from the source of emissions, with more than half of the social costs from emissions borne 100 kilometers or more from the source.[3]

Power plants also emit low levels of uranium, thorium, and other radioactive elements, as well as mercury and other heavy metals. These toxic pollutants have been associated with serious health problems including cognitive impairment, mental retardation, autism, and blindness (U.S. Departmental of Health and Human Services, 2007). Although emitted in far smaller quantities than the criteria pollutants described above, these emissions have a potentially larger impact on local communities because large airborne particles typically settle out from the air relatively close to their emission

[1] Rosen (1974) explains that in a second stage, the HPS could be used together with quantities and additional information about buyers and sellers to identify the underlying MWTP function. Although for evaluating many policy interventions, it would be important to know the entire MWTP function, the overwhelming majority of hedonic studies have focused on the HPS. Identification of this MWTP function continues to be an active area of research. See Ekeland, Heckman, and Nesheim (2004) and Bajari and Benkard (2005).

[2] U.S. Department of Energy (2010b) ES1. As a point of reference, a train car can hold approximately 100 tons of coal. Therefore, a typical four-generator power plant uses about 75 train cars of coal per day.

[3] In a related paper, Kahn (2009) examines the proximity between power plants and population centers. Kahn finds that Census tracts within 2.5 miles of the 100 dirtiest power plants in the United States have slower population growth than other tracts, consistent with a national migration pattern toward the South and West where electricity tends to be produced using newer, cleaner plants.

source.[4] Moreover, a small but nonnegligible amount of toxic emissions is released at ground level. Power plants in 2006 reported 1.1 million pounds of so-called fugitive emissions.[5]

Power plants also generate immense quantities of ash and other residues. When fossil fuels are burned, the noncombustible portion of the fuel is left behind, along with residues from dust-collecting systems, sulfur dioxide scrubbers, and other emissions abatement equipment. These residues consist mostly of silicon, aluminum, and iron, but they also contain lead, cadmium, arsenic, selenium, and mercury. Many plants landfill these residues on site. If they are managed improperly, particles can be picked up by wind and transported locally or enter drinking water supplies.

In short, power plants are the source of numerous local externalities. The baseline empirical specification examines neighborhoods within 2 miles of power plants. This will tend to include the entire area affected by visual disamenities, noise, traffic, fugitive emissions, and fuel residue. For some of these local externalities, the impact is typically even more localized. For assessing the total welfare change, however, it is important to choose an area that is large enough so that it includes the entire relevant area. Estimates will also be presented of the gradient of the HPS with respect to distance. This more flexible approach provides an opportunity to empirically assess the impact of plants at different distances.

IV. Data

A. *Power Plant Characteristics*

Power plant characteristics come from the U.S. Environmental Protection Agency's Emissions and Generation Resource Integrated Database (eGrid) for 2007. This database is a comprehensive inventory of the generation and environmental attributes of all power plants in the United States. Much of the information in eGrid, including plant opening years, comes from the U.S. Department of Energy's *Annual Electric Generator Report* compiled from responses to the EIA-860, a form completed annually by all electric-generating plants. In addition, eGrid includes plant identification information, geographic coordinates, number of generators, primary fuel, plant nameplate capacity, plant annual net generation, and whether the plant is a cogeneration facility. The geographic coordinates in the eGrid data were verified using aerial photos from Google Maps and are highly accurate.

The sample of plants used for the main results includes all fossil fuel plants that began operation between 1993 and 2000. This choice of years is motivated by the use of the 1990 and 2000 decennial census data described in section IVB. Plant construction typically takes at least two years, making plant openings from 1991 and 1992 less valuable because information about these plants was presumably widely available and capitalized into housing prices by 1990. In order to evaluate the sensitivity of the results to this choice, results are also presented for plants opened between 1993 and 1999 and between 1994 and 2000.

The analysis includes all non-cogeneration fossil fuel plants of 100 megawatts or more that were opened during this period. Plants smaller than 100 megawatts are excluded because they tend to be built simultaneously with existing or expanding facilities such as industrial plants. Because the objective of the study is to disentangle the disamenities from power plants, it makes sense to concentrate on these large plants that tend overwhelmingly to be independent facilities. Similarly, cogeneration plants (those that produce both electricity and heat, typically in the form of steam) are excluded because they tend to be constructed simultaneously with industrial plants, large commercial buildings, and other facilities. The sample is restricted to plants in new locations. Existing facilities that increase the number of generators on site and plants that change their primary energy source (for example, switch from coal to natural gas) are excluded. Changes in capacity and emissions levels may indeed affect the local desirability of power plants, but including these changes in the analysis would make the results difficult to interpret. Moreover, these changes often occur simultaneously with other changes at the plant, complicating the interpretation of results.

The resulting sample contains 92 plants. Figure 2 illustrates the geographic distribution. For validity tests, alternative samples were also constructed that describe all plants opened during the 1970s and 1980s and from 2003 to 2006.

B. *Demographic and Housing Characteristics*

Demographic and housing characteristics come from restricted census microdata for the decennial census from 1990 and 2000. The primary advantage of these data is their geographic detail. These data identify households at the Census block, the smallest geographic unit that the Census Bureau uses. An alternative to restricted census microdata would have been to use publicly available aggregate data for 1990 and 2000. Although basic neighborhood characteristics about population, age, and race from the short-form survey are available at the Census block level, most of the more detailed information from the long-form survey, for 2000 is available only at the Census block group level. Because of the focus on highly localized amenities, it is critical to use the most disaggregated data available.

The Census Bureau's Census 2000 Block Relationship Files were used to create geographic identifiers linking 1990

[4] U.S. Environmental Protection Agency (2004). Also, U.S. Environmental Protection Agency (1997) reviews the evidence on mercury transport, reporting evidence from environmental monitoring studies that suggest that measured mercury levels are higher around stationary industrial and combustion sources known to emit mercury.

[5] U.S. Environmental Protection Agency, Toxic Release Inventory, Explorer (Version 4.7), Releases: Chemical Report (Electric Utilities, NAICS 2211). As a point of comparison, 670 million pounds of toxic chemicals were released in 2006 through "point source" air emissions, that is, through gas stacks.

FIGURE 2.—MAIN SAMPLE: POWER PLANTS OPENED 1993–2000 (92 PLANTS)

Census blocks with 2000 Census blocks. For expositional simplicity, these linked units will be referred to as Census blocks, and in cases where there is a one-to-one matching, these units are indeed Census blocks. In cases where Census block definitions changed and the relationship is one-to-many, many-to-one, or many-to-many, geographic identifiers correspond to the smallest consistent geographic unit across the two surveys.[6]

The restricted data are complemented with tract-level data from the Geolytic's Neighborhood Change Database for 1970 and 1980. The Geolytics data were constructed to form a panel of Census tracts based on year 2000 Census tract boundaries. Census tracts are the smallest geographic unit that can be matched across the 1970 to 2000 Censuses, though in 1970 and 1980, nonurban areas were not tracted, so demographic and housing characteristics are not available for all tracts. The Geolytics data are valuable because the 1970 and 1980 characteristics can be used to control for time trends. These data are too coarse, however, to extend the analysis to examine plants opened during the 1970s or 1980s. Census tracts are designed to have between 2,500 and 8,000 residents. As a result, the land area in tracts varies widely, and in nonurban areas, where power plants tend to be sited, tracts can be quite large. The average land area of Census tracts with a power plant from the sample is 193.5 square miles (median 55.7 square miles). This is the land area equivalent to a circle with a radius of almost 8 miles.

Both the Geolytics data for 1970 and 1980 and the restricted data for 1990 and 2000 provide a rich set of housing and demographic characteristics. The housing characteristics used in the analysis are total owner-occupied housing units; total renter-occupied housing units; percentage of total housing units that are owner occupied; percentage of total housing units that are occupied; percentage of housing units with zero, one, two, three, four, and five or more bedrooms; percentage of total housing units that are single-unit detached; percentage of total housing units that are single-unit attached; percentage of total housing units that consist of two, three or four, and five or more units; percentage of total housing units that are mobile homes; percentage of total housing units built within the past year, two to five years ago, six to ten years ago, ten to twenty years ago, twenty to thirty years ago, thirty to forty years ago, and more than forty years ago; and percentage of total housing units with all plumbing facilities. Demographic characteristics include mean household income, percentage of total persons with income below the poverty line, percentage of households with public assistance income last year, population density, percentage of population black, percentage of population Hispanic, percentage of population under age 18, percentage of population age 65 or older, percentage of population over age 25 without a high school diploma, and percentage of population over age 25 with a college degree.

Housing values and rents in the Census data are self-reported. With any self-reported information, one may be concerned about whether households answer accurately. Housing values are self-reported in response to a question that prompts respondents to report how much they think their home would sell for if it were for sale. Particularly for owners who purchased their homes many years ago, this may be

[6] It would have been valuable to expand the analysis to include block-level data from the 1980 Census. The Census Bureau, however, completely redesigned census geography with the 1990 Census, and nothing comparable to the Census 2000 Block Relationship Files is available for matching 1980 and 1990 Census blocks or Census block groups. Moreover, there are serious concerns about the reliability of the Census block coding in the 1980 Census. By the Census Bureau's own admission, the geographic coding in 1980 was replete with "errors, omissions, and inconsistencies," particularly with regard to Census blocks and block groups. See U.S. Bureau of the Census (1994, p. 11–18).

TABLE 1.—EXAMINING NEIGHBORHOODS BEFORE POWER PLANTS WERE OPENED, MEAN CHARACTERISTICS, 1990

	(1) Within 2 Miles of a Power Plant Site	(2) Rest of the United States	(3) Rest of the United States, Reweighted	(4) p-Value: Column 1 versus Column 2	(5) p-Value: Column 1 versus Column 3
Demographic characteristics					
Household annual income (1,000s)	30.4	33.5	30.4	.00	.87
Household size (persons)	2.49	2.44	2.49	.00	.99
Number of individuals under 18 per household	.67	.64	.67	.00	.99
Number of individuals over 65 per household	.31	.33	.31	.00	.99
Proportion household head completed high school	.70	.77	.70	.00	.99
Proportion household head completed college	.25	.29	.25	.00	.99
Proportion household head black	.10	.07	.10	.00	.99
Proportion household head hispanic	.20	.16	.20	.00	.98
Housing characteristics					
House value (1,000s)	86.0	92.4	91.3	.00	.00
Monthly rent	459.8	470.6	460.3	.00	.89
Proportion occupied	.92	.90	.92	.00	.98
Proportion owner occupied	.58	.68	.58	.00	.98
Proportion 0–2 bedrooms	.45	.36	.45	.00	.98
Proportion 3–4 bedrooms	.50	.59	.50	.00	.97
Proportion built last 5 years	.04	.07	.04	.00	.98
Proportion built last 10 years	.08	.14	.08	.00	.98
Proportion complete plumbing	.99	.99	.99	.00	.99
Proportion 1 or more acres	.08	.16	.08	.00	.99
Proportion 10 or more acres	.03	.11	.03	.00	.99
Proportion multi-unit	.31	.13	.31	.00	.97

Columns 1–3 report the means of the variables listed in the row headings for the group listed at the top of the column. Column 1 describes demographic and housing characteristics for neighborhoods within 2 miles of sites where 100+ megawatt power plants opened in the United States between 1993 and 2000. Columns 2 and 3 describe characteristics for neighborhoods farther than 2 miles away. In column 3, observations are weighted using propensity weights. Columns 4 and 5 report p-values from tests that the means in the subsamples are equal.

difficult to answer. In contrast, rent is presumably not subject to the same degree of misreporting as housing values because of the saliency of rent payments. Another potential problem with housing values is that they are reported for twenty categories. In the empirical analysis, housing value is treated as a continuous variable using the midpoint of the range. Again, rental rates are less problematic. In 1990 rent was categorical, but the number of categories was larger (26 categories), and in 2000, rent was a write-in response.

V. Results

A. Examining Covariate Balance

Table 1 compares neighborhoods where power plants were opened with neighborhoods in the rest of the United States. Column 1 reports mean demographic and housing characteristics in 1990 for Census blocks for which the block centroid is within 2 miles of where a 100+ megawatt power plant opened between 1993 and 2000. Column 2 describes characteristics for all other Census blocks. Examining neighborhoods prior to when plants were opened is valuable because it sheds light on the siting process for plants and provides evidence on the validity of the rest of the United States as a comparison group.

Mean demographic and housing characteristics within 2 miles of a power plant site are significantly different from mean characteristics for the rest of the United States. Mean household income is lower, household size is higher, and household heads are less likely to have completed high school or college. In addition, the proportion of households for which the household head is black or Hispanic in the neighborhoods within 2 miles is higher.[7] Column 4 reports p-values from tests that the mean characteristics are equal in columns 1 and 2. The null hypothesis of equal means is rejected in all twenty cases.

These differences underscore the importance of controlling for observable characteristics in the analysis that follows. The main results control for these characteristics and all the other housing and demographic characteristics listed in the previous section, as well as county fixed effects. Some specifications also include 1970 and 1980 neighborhood characteristics to control for differential time trends. In addition, Census blocks farther away than 2 miles are weighted using propensity scores. The idea of propensity score weighting is to reweight the observations in the rest of the United States to balance the mean characteristics of neighborhoods within 2 miles. Propensity scores were estimated using a logit regression where the dependent variable is 1(within 2 miles), an indicator variable equal to 1 for Census blocks within 2 miles. Regressors include all variables in table 1 except for housing values and rents, which are often not both available for a single Census block. Cubics were used for all variables that are not proportions (household income, household size, number of children, and number of individuals over

[7] This last finding is consistent with evidence from a substantial environmental justice literature (see, Been, 1994; Oakes, Anderton, & Anderson 1996, Been & Gupta, 1997; Helfand, 1999; and Saha & Mohai 2005).

TABLE 2.—THE EFFECT OF POWER PLANTS ON HOUSING VALUES AND RENTS WITHIN 2 MILES

	Housing Values			Rents		
	(1)	(2)	(3)	(4)	(5)	(6)
	−.054	−.071	−.041	−.035	−.044	−.030
	(.023)	(.013)	(.017)	(.013)	(.016)	(.015)
1990 dependent variable	Yes	Yes	Yes	Yes	Yes	Yes
County fixed effects	No	Yes	Yes	No	Yes	Yes
Housing characteristics from 1990	No	Yes	Yes	No	Yes	Yes
Demographic characteristics from 1990	No	Yes	Yes	No	Yes	Yes
Housing characteristics from 1970 and 1980	No	No	Yes	No	No	Yes
Demographic characteristics from 1970 and 1980	No	No	Yes	No	No	Yes
Number of census blocks (millions)	2.4	2.4	1.1	0.8	0.8	0.4
R^2	.55	.64	.72	.42	.52	.52

This table reports estimated coefficients and standard errors corresponding to six regressions. The dependent variable in columns 1–3 is the mean housing value (in logs), and the dependent variable in columns 4–6 is the mean rental price (in logs). The sample includes all Census blocks in the United States. The variable of interest is an indicator for Census blocks within 2 miles of 1 of 92 large (100+ megawatt) power plants opened between 1993 and 2000. Housing and demographic characteristics are listed in section IVB. Observations are weighted using propensity scores, and standard errors are block bootstrap by Census tract with 100 replications.

age 65). Then, following Rosenbaum (1987), the propensity scores from this regression were used to reweight the observations in the rest of the United States by the relative odds, $\frac{p(X_{b1990})}{1-p(X_{b1990})}$, where $p(X_{b1990})$ is the conditional probability of being within 2 miles given X_{b1990}, the complete set of housing and demographic characteristics in 1990.

Column 3 reports means characteristics from the reweighted sample. After reweighting, means for all covariates are virtually identical to the means in column 1, and the null hypothesis of equal means cannot be rejected for any of the conditioning variables. Propensity weighting reduces the potential scope for functional form misspecification in the estimating equation. Moreover, the process of estimating a propensity score reveals the degree to which there are observations in the rest of the United States that are similar to observations within 2 miles. The histograms of the estimated propensity scores reveal a high degree of overlap between the two groups. Although the mean propensity score is higher in the within-2-mile group, there are hundreds of thousands of Census blocks in the rest of the United States with propensity scores higher than the median propensity score in the within-2-mile group and tens of thousands of Census blocks with scores higher than the 95th percentile propensity score in the within-2-mile group.

B. *Baseline Estimates*

This section presents baseline estimates of the effect of power plants on housing values and rents. The approach is described by the following system of equations:

$$y_{b2000} = 1(\textit{within two miles})_{b2000}\alpha + X'_{b1990}\beta + \epsilon_{b2000}, \quad (1)$$

$$1(\textit{within two miles})_{b2000} = X'_{b1990}\gamma + \eta_{b2000}, \quad (2)$$

where y_{b2000} is the mean housing value for 2000 in Census block b (in logs). Results are also reported for the mean rental price. The indicator variable $1(\textit{within two miles})_{b2000}$ equals 1 for Census blocks in which the block centroid is within 2 miles of where a 100+ megawatt power plant opened between 1993 and 2000. The coefficient of interest, α, is the price differential associated with homes within 2 miles of a plant, controlling for block-level control variables, X_{b1990}. This vector is restricted to variables measured in 1990 or before because variables measured in 2000 may be endogenous and reflect the impact of plant openings. In section VF, several neighborhood characteristics are examined as alternative dependent variables.

As illustrated in equation (2), power plant siting decisions or equivalently, $1(\textit{within two miles})_{b2000}$, are postulated to be a function of location characteristics potentially including all of the characteristics in X_{b1990}. Least squares estimation of equation (1) is consistent if $1(\textit{within two miles})_{b2000}$ is exogenous conditional on X_{b1990}—that is, if $E[\epsilon_{b2000}\eta_{b2000}] = 0$, or that unobserved determinants of housing prices and rents are not correlated with power plant siting decisions after controlling for X_{b1990}. Estimation is consistent if, for example, power plant siting during the 1990s is a function of housing prices, household income, educational attainment, housing characteristics, or any other characteristic included in X_{b1990}. This identifying assumption is likely to be a reasonable approximation given the rich set of household and demographic characteristics available in the Census data, particularly after controlling for county fixed effects. Nonetheless, it will be important in the following sections to evaluate the robustness of these results to alternative specifications and validity tests.

Table 2 reports least squares estimates of α for housing values and rents from three specifications. Columns 1 and 4 report estimated coefficients and standard errors from a specification that controls only for the 1990 dependent variable. Thus, the specification in column 1 controls for the mean housing value for 1990 (in logs), and the specification in column 4 controls for the mean rental price for 1990 (in logs). In this specification, the impact on housing values is −.054, or −5.4 percent. The estimate for rents is also negative, with a point estimate of −.035. Columns 2 and 5 add the complete set of housing and demographic characteristics from 1990 as well as county fixed effects. After controlling for these additional covariates, the coefficients for housing values and rents change to −.071 and −.044, respectively. Columns 3 and 6 add tract-level housing and demographic characteristics from 1970 and 1980 to control for within-county differential time trends. Including these lagged control variables reduces the number of observations because data are not available for nonurban Census tracts in 1970 and 1980 and decreases the point estimates somewhat. Overall, the point estimates indicate a decrease of 4%–7% for housing values and 3%–4% for rents.

Standard errors in table 2 and throughout the rest of this paper are estimated using block bootstrap by Census tract with 100 replications. In contrast to the point estimates, which are estimated using the complete sample of Census blocks, the bootstrap standard errors are estimated using all Census blocks within 2 miles of a plant and a 5% random sample of all other Census blocks. For each bootstrap sample, the propensity score logit regression is reestimated in order to account for the variance component due to estimation of the propensity scores. The confidence intervals are fairly wide. For example, the 95% confidence interval for the estimate in column 1 ranges from −.008 to −.099. Nonetheless, the estimates in all six specifications are statistically different from 0 at the 5% significance level. It is also possible to rule out empirically relevant hypotheses on the high end. For example, the null hypothesis of a 10% decrease can be rejected at the 5% significance level in all six specifications.

C. *Total Change in Local Welfare*

The estimates in table 2 can be used to calculate a measure of the total change in local welfare from power plant openings. In 1990 approximately 205,000 housing units were within 2 miles of locations where power plants would be opened between 1993 and 2000. The mean housing value from table 1 implies that the average total value of the housing stock within 2 miles of a plant site is $322 million in year 2008 dollars. Multiplying this by the estimate from column 3 in table 2 yields an average housing market capitalization within 2 miles of a plant of $13.2 million. Although not negligible, this measure of the total change in local welfare is small compared to the capital costs of a new plant. For example, to build a new coal-burning power plant costs approximately $2,000 per kilowatt of capacity, so even a relatively small (100 megawatt) plant costs $200 million. Natural gas plants are somewhat less expensive, costing approximately $1,000 per kilowatt of capacity, or $100 million for a 100 megawatt plant (U.S. Department of Energy, 2009). Another point of comparison is the cost of building electricity transmission. The typical cost of a large-capacity (435 kilovolt) transmission line is $800,000 per mile (Hirst & Kirby, 2002).

When interpreting this measure, it is important to keep in mind that local housing market capitalization is a valid measure of the change in local welfare only under the assumptions outlined in section II. These include that there is a parallel shift in the demand curve and that housing supply is perfectly inelastic, for example. Also, it is important to highlight that this measure of the change in local welfare reflects the impact on residential property but not the impact on industrial, commercial, or undeveloped property and thus may understate the total local welfare change. While some industrial uses may not be substantially affected by power plant proximity, commercial property and, perhaps more important, undeveloped property will be affected. In addition, it is important to point out that while the results imply moderate welfare impacts on average, there are large differences across plants in the implied market capitalization. Some of the plants opened during this period are located in almost completely uninhabited areas, whereas others are located in relatively highly populated areas. Finally, when interpreting this measure, it is important to remember that the local housing market capitalization reflects only some of the externalities from fossil fuel power plants. Power plants emit sulfur dioxide and nitrogen oxides, as well as large quantities of carbon dioxide, the principal greenhouse gas associated with climate change. Most of the impacts of these pollutants are experienced far away from plants and are not captured in this estimate.

D. *Semiparametric Estimates*

Figures 3 and 4 plot semiparametric estimates of the gradient of housing values and rents with respect to distance to the nearest power plant. First, equation (1) was estimated without the 1*(within two miles)* indicator. The complete set of 1990 housing and demographic characteristics was used along with county fixed effects as in columns 2 and 5 in table 2. Second, the gradient with respect to distance was estimated using local linear regression with an Epanechnikov kernel and a 1 mile bandwidth.

For housing values, the point estimates start between −.10 and −.05 at the plant and then converge to 0 between 1 and 4 miles. Beyond 4 miles, the estimates are consistently very close to 0. For rents, the estimates start near −.10 at the plant and reach 0 near 2 miles. Farther away from the plant, the rent gradient is consistently close to 0 except for a slight increase between 8 and 10 miles. The figures also plot 95th

FIGURE 3.—SEMIPARAMETRIC ESTIMATES OF THE EFFECT OF POWER PLANTS ON HOUSING VALUES

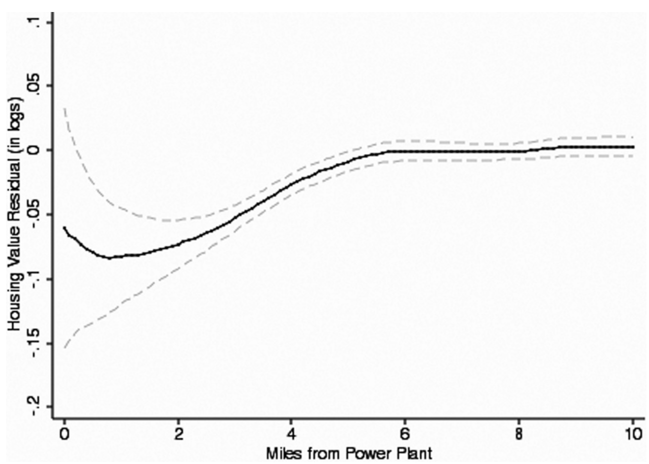

FIGURE 4.—SEMIPARAMETRIC ESTIMATES OF THE EFFECT OF POWER PLANTS ON RENTS

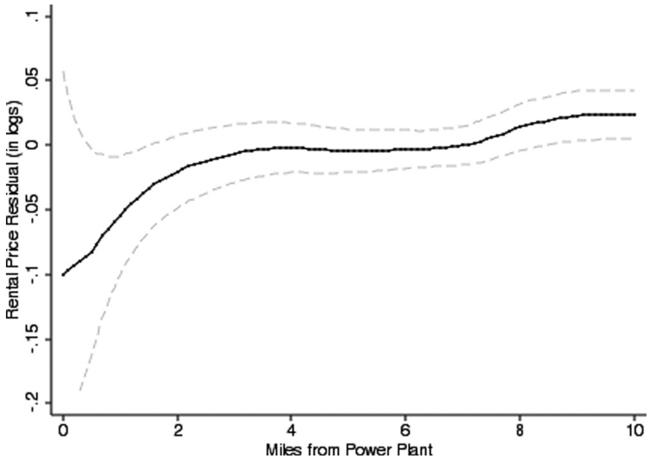

TABLE 3.—THE EFFECT OF POWER PLANTS ON HOUSING VALUES AND RENTS WITHIN 2 MILES: ALTERNATIVE SPECIFICATIONS AND VALIDITY TESTS

	(1) Housing Values	(2) Rents
A: Alternative Specifications		
Plants opened 1993–1999 (50 plants)	−.058	−.049
	(.017)	(.013)
Plants opened 1994–2000 (89 plants)	−.073	−.044
	(.020)	(.018)
Natural gas plants only (85 plants)	−.072	−.044
	(.017)	(.014)
Large-capacity plants only (46 plants)	−.093	−.056
	(.030)	(.022)
Small-capacity plants only (46 plants)	−.060	−.032
	(.019)	(.017)
B: Validity Tests		
Power plants opened during the 1970s (139 plants)	.013	−.020
	(.018)	(.010)
Power plants opened during the 1980s (60 plants)	−.004	.039
	(.030)	(.042)
Power plants opened 2003–2006 (96 plants)	−.031	.011
	(.015)	(.010)
C: By Type of Household		
Downwind households only	−.048	−.023
	(.033)	(.021)
Upwind households only	−.080	−.051
	(.018)	(.015)
Low-income (bottom tercile) households only	−.101	−.073
	(.042)	(.026)
Medium-income (middle tercile) households only	−.067	−.020
	(.023)	(.018)
High-income (top tercile) households only	−.027	.006
	(.017)	(.022)

This table reports estimated coefficients and standard errors corresponding to 26 separate regressions. The dependent variable in column 1 is the mean housing value (in logs), and the dependent variable in column 2 is the mean rental price (in logs). All specifications include the 1990 dependent variable, county fixed effects, and the complete set of 1990 housing and demographic characteristics as in table 2, columns 2 and 5. The sample includes all Census blocks in the United States. Observations are weighted using propensity scores, and standard errors are block bootstrap by Census tract with 100 replications. Large plants are those for which the nameplate capacity exceeds the median in the sample (380 megawatts).

percentile confidence intervals estimated using block bootstrap by Census tract with 100 replications. The estimates are sufficiently imprecise, particularly for rents, to make it impossible to make definitive statements about the exact shape of the gradient. Nonetheless, for both housing values and rents, it is possible to rule out the null hypothesis of a 0 effect for at least part of the 0–2 mile range.

The lack of evidence of a housing market impact beyond a few miles is interesting because one might have expected there to be indirect effects such as household mobility. Suppose power plants cause households to move out of neighborhoods in the immediate vicinity of the plant but labor market and other considerations make it undesirable for these households to move far away. These estimates provide no evidence of such spillover effects. Still, the gradients are not precisely estimated enough to rule out relatively small effects. The gradients are also valuable because one might have been concerned that the impact of local externalities was obscured by employment or tax revenue effects. According to the U.S. Bureau of Labor Statistics (2008), there were 35,000 power plant operators in the United States in 2006. Employment from power plants increases demand for local housing, causing a positive (and potentially offsetting) effect on housing values and rents. Similarly, power plants are typically a substantial source of local tax revenue. The estimated gradients provide an opportunity to evaluate these factors because whereas many of the externalities from plants are highly localized, increased employment and property tax revenues affect all households within a given labor or housing market. The lack of a distinguishable positive impact beyond a few miles provides no evidence of employment or tax revenue effects, though again, the estimates are not precise enough to rule out small effects.

Overall, the semiparametric estimates are consistent with the results in table 2 and provide some support for the baseline empirical specification that focuses on Census blocks within 2 miles of a plant. The rent gradient suggests larger effects within 1 mile, consistent with larger negative externalities. However, the lack of statistical precision makes it difficult to make definitive statements about the exact shape of the gradient within 2 miles. Moreover, for both housing values and rents, most of the total impact appears to occur within 2 miles. This is particularly the case for rents in which point estimates converge to 0 almost exactly at 2 miles. For neither housing values nor rents is the gradient particularly steep at 2 miles, suggesting that minor changes in the specification used in table 2 would be unlikely to substantially change the results.

E. *Alternative Specifications and Validity Tests*

Table 3 reports results for alternative specifications and validity tests. For each regression, the table reports the estimated coefficient and standard error corresponding to 1*(within two miles)*. All specifications are weighted using propensity scores and include county fixed effects and the complete set of housing and demographic characteristics from 1990 as in table 2, columns 2 and 5.

Panel A reports estimates from alternative sets of plants. First, results are reported separately for plants that opened between 1993 and 1999 and plants that opened between 1994 and 2000. An unusually large number of plants were opened in 2000, and it is reassuring that the results are not unduly sensitive to exclusion of the plants opened in that year. Second, results are reported from restricting the sample of plants to include only natural gas plants. Between 1993 and 2000, 85 of the 92 plant openings were natural gas plants, and restricting the sample to these plants does not meaningfully change the estimates. It would have been interesting to report results separately for coal plants, but there were too few coal plant openings between 1993 and 2000 for the estimates to meet Census disclosure requirements, which prevent reporting coefficients based on a small number of observations. Finally, estimates are reported separately for large and small plants. Large plants are defined as those for which nameplate capacity exceeds the median nameplate capacity in the sample (380 megawatts). The point estimates indicate moderately larger effects for big plants for both housing values and rents, though the differences are not statistically significant. It would have been valuable to more fully characterize this relationship between plant size and local impact or, alternatively, report estimates separately by plant. Further disaggregation would not, however, meet Census disclosure requirements.

Panel B reports estimates from three validity tests. Instead of plants opened between 1993 and 2000, these specifications examine plants opened during the 1970s and 1980s and from 2003 to 2006. Because these plants were either already open in 1990 or not yet opened in 2000, there should be no housing market effect in 2000 after controlling for 1990 characteristics.[8] As expected, the estimates are close to 0, with no consistent pattern. This lack of evidence of a relationship between these openings and housing prices or rents is reassuring because it suggests that the results for plants opened between 1993 and 2000 are not driven by unobservable factors associated with the type of locations where plants tend to be sited.

Panel C reports alternative specifications aimed at describing how estimates vary for different types of households. First, the effect of 1*(within two miles)* was estimated separately for Census blocks upwind and downwind from plants.[9] The results provide no evidence of a disproportionate impact on homes downwind of plants. If anything, there would appear to be somewhat larger effects on upwind households, but the differences are not statistically significant. Second, the effect of 1*(within two miles)* was estimated separately by income tercile. The estimates are decreasing in income, with the largest effects for Census blocks that in 1990 were in the bottom income tercile. Again, however, these results should be interpreted with some caution because of the lack of statistical precision.

F. Neighborhood Characteristics and Housing Supply

Table 4 describes the effect of power plants on neighborhood characteristics within 2 miles. As described in section II, households will respond to a decrease in local environmental quality with taste-based sorting. Households that place a high value on local environmental quality will move away, while households that value local environmental quality less will move in. The table reports estimates for twelve dependent variables, including household income, educational attainment, demographics, housing unit characteristics, housing supply, and total population using three different specifications, all identical to the specifications used in table 2.

Panel A reports coefficients for household income and educational attainment. Power plant openings are associated with between a $2,000 and $4,200 decrease in household annual income within 2 miles of the plant. This effect is statistically significant at the 2% level in all specifications though modest in size relative to the 1990 mean. Results for educational attainment are similar. In columns 1 and 2, plant openings are associated with declines in the proportion completed high school and proportion completed college. However, the point estimates change considerably when housing and demographic characteristics from 1970 and 1980 are included. This could indicate that the results in columns 1 and 2 are influenced by within-county differential time trends, or it could simply reflect the fact that the estimates in column 3 come from the smaller, more urban sample for which data are available for 1970 and 1980.

Panel B reports coefficients for demographic characteristics. The estimates indicate an increase in the number of individuals under age 18 and a decrease in the number of individuals over age 65, as well as increases in the proportion of household heads who are black or Hispanic. Estimates for proportion Hispanic are positive and statistically significant at the 1% level in all three specifications. As with educational attainment, the results in this panel are sensitive to whether the specification includes characteristics from 1970 and 1980.

Panel C reports coefficients for housing unit characteristics. The estimates for the proportion of housing units that are occupied are close to 0 and not statistically significant, providing no evidence of an increase in vacancies. For the proportion of housing units that is owner occupied, the estimates are negative and statistically significant at the 1% level across specifications, indicating a modest progression toward rental properties.

Finally, panel D reports coefficients for housing supply and total population. All estimates are small relative to the mean and not statistically significant. The coefficients are estimated with enough precision to rule out reasonably small changes in the number of housing units and total population. The lack of evidence of a change in housing supply is perhaps not

[8] This type of validity test has been used effectively in other contexts. For example, Busso and Kline (2008) use empowerment zones awarded in 1999 and 2001 as a point of comparison for empowerment zones awarded in 1994.

[9] Prevailing wind direction comes from the National Oceanic and Atmospheric Administration (1998) for 321 locations in the United States summarizing over sixty years of data from weather stations. The prevailing wind direction for each plant site is determined using the closest available weather station.

TABLE 4.—THE EFFECT OF POWER PLANTS ON LOCAL NEIGHBORHOOD CHARACTERISTICS WITHIN 2 MILES

	(1)	(2)	(3)
A: Household Income and Educational Attainment			
Household annual income (1,000s)	−1.98	−4.19	−2.01
(1990 mean: 33.5)	(0.78)	(0.93)	(0.83)
Proportion household head completed high school	−.052	−.032	−.013
(1990 mean: .77)	(.009)	(.009)	(.009)
Proportion household head completed college	−.017	−.009	.006
(1990 mean: .29)	(.009)	(.010)	(.008)
B: Demographics			
Household size (persons)	.070	.035	−.025
(1990 mean: 2.44)	(.030)	(.034)	(.035)
Number of individuals under 18 per household	.027	.015	.006
(1990 mean: .64)	(.005)	(.005)	(.005)
Number of individuals over 65 per household	−.034	−.016	−.008
(1990 mean: .33)	(.005)	(.007)	(.008)
Proportion household head black	.012	.005	.002
(1990 mean: .07)	(.005)	(.006)	(.005)
Proportion household head Hispanic	.052	.053	.028
(1990 mean: .16)	(.011)	(.013)	(.010)
C: Housing Unit Characteristics			
Proportion occupied	.008	−.005	−.004
(1990 mean: .90)	(.003)	(.005)	(.005)
Proportion owner occupied	−.049	−.038	−.020
(1990 mean: .68)	(.006)	(.007)	(.007)
D: Housing Supply and Total Population			
Total housing units per Census block	−.732	−.573	−.515
(1990 mean: 31.0)	(.402)	(.819)	(.838)
Total population per Census block	−.409	−.092	−1.33
(1990 mean: 73.5)	(1.16)	(2.20)	(2.36)
1990 dependent variable	Yes	Yes	Yes
County fixed effects	No	Yes	Yes
Housing and demographic characteristics from 1990	No	Yes	Yes
Housing and demographic characteristics from 1970 and 1980	No	No	Yes

This table reports estimated coefficients and standard errors corresponding to 36 separate regressions. The row headings list the dependent variable used in each regression. The sample includes all Census blocks in the United States. The variable of interest is an indicator for Census blocks within 2 miles of 1 of 92 large (100+ megawatt) power plants opened between 1993 and 2000. Housing and demographic characteristics are listed in section IVB. Observations in all specifications are weighted using propensity scores and standard errors are block bootstrap by Census tract with 100 replications.

surprising because housing is durable, so a decrease in local amenities typically does not lead to an immediate decrease in housing supply. Moreover, the direct effect of power plants on the local supply of available land is likely to be relatively small. Even the largest power plants use at most only a few hundred acres, including all generators, the network switchyard, cooling towers, and parking, typically representing less than 2% of the total land area within a 2-mile-radius circle around the plant.

VI. Conclusion

Electricity consumption in the United States is forecast to continue to increase over the next several decades. Although wind, solar, and other alternative sources of electricity production receive a great deal of attention from policymakers, the low cost of fossil fuel electricity generation all but guarantees that it will play a central role in meeting this growing demand. At the same time, siting of power plants has become more difficult than ever before, in large part because the need for new facilities is most severe in places with large and growing populations. Policymakers face difficult, often politically contentious, decisions about where to site plants and must balance many factors. Although local amenities are typically one of the important factors considered in this process, the lack of reliable empirical evidence about the magnitude of these costs has limited the use of cost-benefit analysis.

This paper is the first large-scale effort to assess the impact of power plants on local housing markets. Across specifications, the results indicate 3%–7% decreases in housing values and rents within 2 miles of plants, with the semiparametric estimates suggesting somewhat larger decreases within 1 mile. In addition, there is evidence of taste-based sorting, with neighborhoods near plants experiencing statistically significant decreases in mean household income, educational attainment, and the proportion owner-occupied. Overall, however, the analysis suggests that the total local impact from power plant openings during the 1990s was relatively small because plants tended to be opened in locations where the population density is low.

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