The Adverse Impact of Particulate Matter on Property Values

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Recent litigation with regards to property damage associated with carbon black emissions provides an opportunity to measure the impact of particulate matter (PM), a Clean Air Act pollutant. By using property-specific PM concentrations, we estimate the impact of PM on residential property values, which accounts for relevant characteristics and multiple pollution sources. This study simultaneously incorporates all important econometric modeling features cited in the prior literature. We find that a 10-percent increase in PM concentration results in a statistically-significant 1.1-percent decrease in value. In 2007 dollars, a one-standard deviation increase in PM concentration results in a statistically-significant reduction of approximately $4,800.

Keywords:

Hedonic; Property value; Particulates; Spatial analysis

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1.   Introduction

Recent litigation has provided an opportunity to demonstrate the use of spatial econometric techniques to determine the extent of property-value diminution from particulate emissions in the face of two separate pollution sources. Property-specific exposure data from both sources obtained from air quality data has made this possible. This analysis also distinguishes itself by focusing on particulate matter (PM), which has not been the focus of many previous property diminution studies in the U.S. Finally, the analysis demonstrates that the necessary data to conduct such studies are now readily obtainable. The paper is organized into five sections following this introduction. First, a brief background on the litigation that prompted the study will be presented, which is followed by a literature review, study description, presentation of the data and results, and conclusion.

2.   Background

The Ponca Tribe of Indians, located in north central Oklahoma, is the downwind of a carbon-black plant owned and operated by the Continental Carbon Corporation (CCC). The Tribe and its members filed a suit against the CCC, claiming damages from the plant's emissions of PM[1]. The lawsuit was settled in 2009. During the procedural course of the lawsuit, time-series information on ambient air quality, property values, and neighborhood characteristics were collected to conduct a hedonic property value (HPV) analysis to measure the impact, if any, of the plant's PM emissions on residential real estate values. The accurate measurement of such an impact would have been an essential element of any calculation of damages or method to allocate a lump sum settlement.[2] PM is designated as a criteria pollutant under the U.S. Clean Air Act (42 U.S.C. §7401).[3] The HPV analysis was complicated by the presence of another source of PM emissions, a nearby

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[1] The Ponca Tribe of Indians of Oklahoma, et al. v. Continental Carbon Company, et al. v. ConocoPhillips (Civ-05-445-C). A similar lawsuit was brought against CCC by Ponca City, OK and also settled.

[2] While Judge Couthran determined that the evidence of property diminution based on the HPV model would not be admitted, she did not reject the use of a regression analysis in general or HPV modeling in particular. She concluded that, "… the diminution of value calculations are unhelpful and not relevant to the nuisance claims asserted." (Memorandum Opinion & Order, January 23, 2009, p.17.) In contrast, the judge allowed the use of the pollution exposure information to allocate nuisance damages defined as clean-up costs. Thus, the pollution exposure data (based on the air quality modeling combined and geocoding described in this paper) played an important role in the proceeding.

[3] Other criteria pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, and sulfur dioxide. The Clean Air Act instructs the U.S. Environmental Protection Agency (EPA) to establish and monitor ambient emission standards for these criteria pollutants. See http://www.epa.gov/air/criteria.html.

oil refinery, owned by Conoco-Phillips. We refer to these PM sources as the CCC and COP plants, respectively. Figure 1 displays the geography of the area.

Figure 1   Area Geography
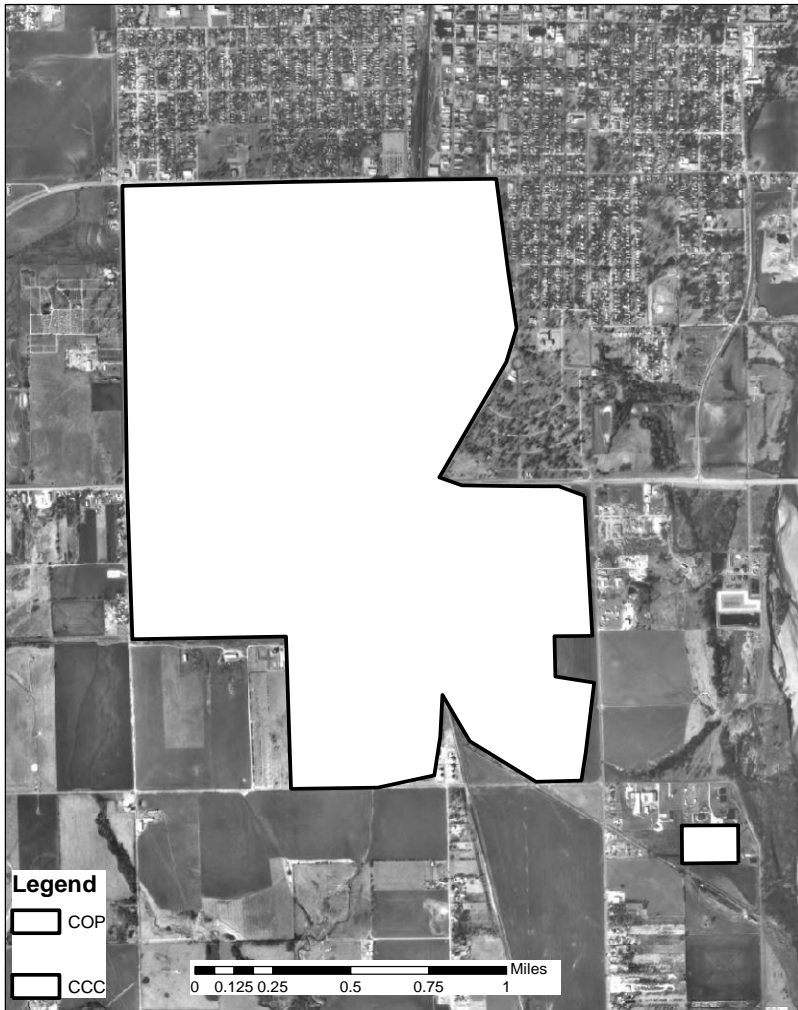
The pollutant that is the primary focus of this study is carbon black, a granular substance primarily used in automobile tires where it serves as a reinforcing agent. It is also used in the production of plastics, paint, and ink. There are several manufacturing processes for carbon black, the most common of which involves the use of high temperature furnaces to burn hydrocarbons, the

production process used at the CCC plant. The smoke that results from this process contains a black powder, which is separated from the combustion gases, and ultimately filtered. Carbon black powder is very fine, and smaller particles are an important product characteristic. The combustion and filtering processes require substantial environmental controls to prevent fine particles from escaping into the atmosphere because emissions can result in soiling, among other things. The effects of this process can be readily seen from an aerial photograph of the CCC plant presented in Figure 2. In particular, note the blackened area around the plant itself.

Figure 2   CCC Plant
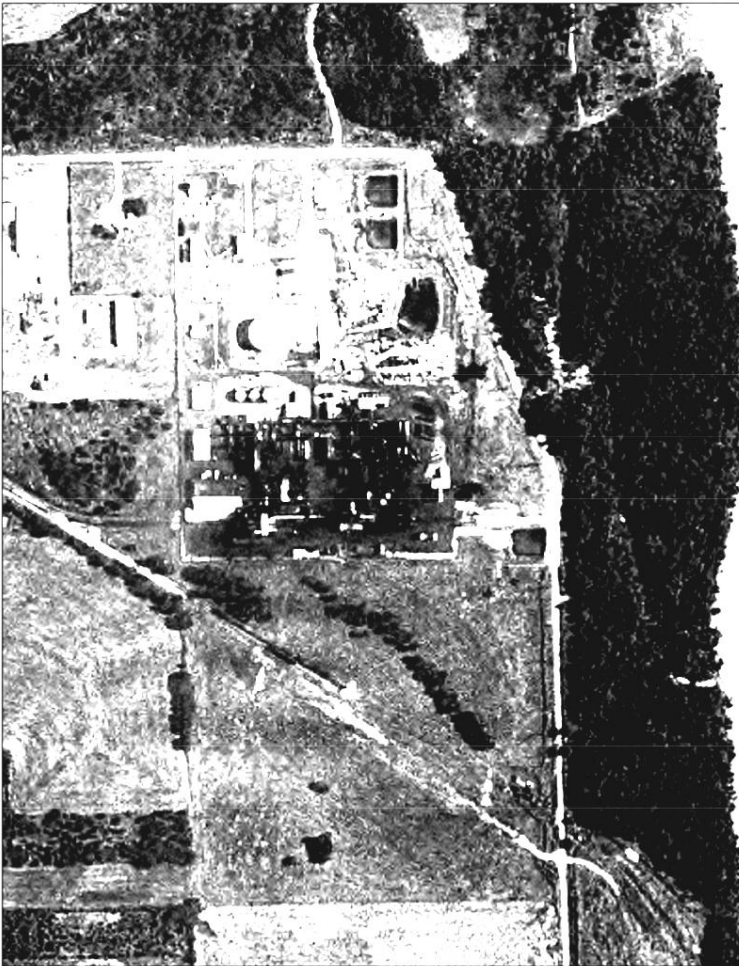
Carbon black particulate emissions also contain several sulfur compounds that the Environmental Protection Agency (EPA) has reviewed as possible hazardous air pollutants (Crump 2000). The dose-response relationship with regards to the health effects of these and other components of PM, however, remains controversial (Schlesinger 2007).[4] While there were no specific health claims in the litigations for which the HPV analysis was conducted, there were frequent complaints to the Oklahoma Department of Environmental Quality over an extended period with regards to PM, and to a lesser extent, odor. As shown in Figure 3, such complaints were steadily made between 1993 and 2003. Consequently, there is no single pollution "event," but rather a chronic pollution problem, which could have influenced purchase decisions.[5] As a result, an event-based empirical study would not be particularly informative. Additionally, 95 percent of the complaints logged against the CCC between 1993 and 2008 were for carbon black or black smoke, whereas, over the same period, only 5 percent of the complaints against the COP were for black smoke or black emissions.[6]

Figure 3   Number of Complaints Filed

Source: Oklahoma DEQ

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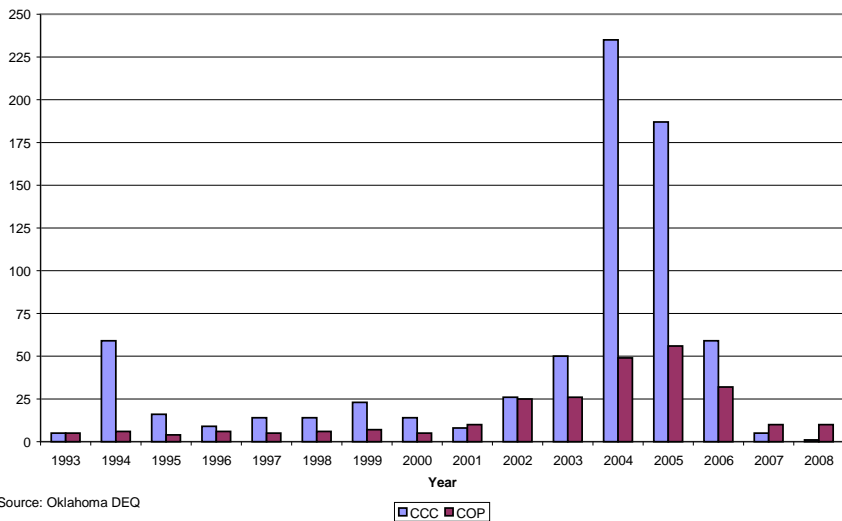
[4] A dose-response function is meant to capture the health impact from exposure to some potentially-harmful compound.

[5] As noted in the literature review below, subjective evaluations [and expectations] of air quality may prove important explanatory variables in hedonic models. Here, the past performance of the plant could easily affect purchase decisions.

[6] Kay County, Oklahoma, Department of Environmental Quality Complaints Database (1993 to 2008).

3.   Prior HPV Literature

There is a rich empirical literature that examines the effects of pollutants by using HPV models. The seminal review is Boyle and Kiel (2001), which examines this literature as far back as the 1960s.[7] As they document, studies of air pollutants have examined the effects of PM, sulfur dioxide (SOx), nitrogen dioxide (NOx), and ozone (O_3) on a variety of dependent variables, including residential property values.[8] Generally, these air pollution studies have found that property values, measured by sales transactions, fall as proximities from polluting sources, typically measured as linear distance, decrease.[9] In other words, the studies have found that property values are adversely affected by pollution. The statistical significance of these negative relationships considerably varies, due in part to the variety of different HPV models estimated. Similar to this analysis, Flower and Ragas (1994) have examined the house-price effects from the pollutants of two nearby oil refineries in St. Bernard Parish, LA. To distinguish the impact of the two plants, the authors rely on a distance differential between the plants. Consistent with the literature cited in Boyle and Kiel (2001), they find a negative and statistically-significant effect between proximity and house prices.

In drawing on the general framework of spatial econometrics, three recent HPV studies (Kim et al. (2003), Cameron (2005), and Anselin and Le Gallo (2006)) have demonstrated the importance of accounting for spatial characteristics of pollution when estimating HPV models.[10] Kim et al. (2003) examine NOx and SOx concentrations, measured in parts per billion (ppb), in Seoul, South Korea and their effects on residential sales prices. They demonstrate that, in theory, failure to account for spatial attributes would affect both the magnitudes and statistical significance of least squares estimates. To address this, they use two approaches, a "spatial error" model and a "spatial lag" model, to account for spatial attributes of pollution

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[7] A more recent paper, Yusef and Resosudarma (2009), builds on this review by adding three more studies, two of which address the impacts of total suspended particulates (TSP) on property damages. Two of these find negative and significant impacts. A third finds a positive, but insignificant relationship. None of these are conducted by using U.S. real estate data.

[8] In this paper, we use the more general notations of SOx and NOx. Most studies focus on sulfur dioxide (SO_2) and nitrogen dioxide (NO_2).

[9] A limited number of studies examine actual ambient air concentrations, in which case the relationship between concentration and value is negative.

[10] The term "spatial characteristics" implies a formal dependence based on proximity or location, which creates the so-called spatial correlation. For a discussion, see www.spatial-econometrics.com/html/wbook.pdf. Another study to note is Chay and Greenstone (2005), which examines total suspended particulate (TSP) concentrations and their effect on house values between 1969 and 1990. While extensive, their study does not directly employ spatial econometric techniques.

concentration.[11]   Their preferred model, the spatial lag, uses observed prices in neighborhoods of close proximity.[12]   They find a negative and statistically significant effect of SOx concentrations on house prices, but no effect from NOx concentrations.

Cameron (2005) approaches the spatial characteristics of pollution differently. Rather than using pollution concentrations, she, like much of the HPV literature, relies on linear distances from polluting sources as proxies. She notes, however, that studies which used such proxies generally fail to account for the directionality to polluting sources, and demonstrates that in theory, such a failure may result in estimation bias. As a result, she explicitly incorporates directionality into her measures of distance to examine the effects of the "Woburn odor" on house prices in Woburn, MA. She finds that estimates that do not account for directionality are smaller in magnitude than those that account for it. She also finds that estimates that account for directionality are statistically significant. The results from her preferred model, which accounts for directionality, indicate that house prices fall when they are closer to the sources of the Woburn odor (controlling for house- and neighborhood-specific characteristics).

Applying a similar set of spatial techniques as Kim et al. (2003), Anselin and Le Gallo (2006) evaluate the effects of ozone concentrations on house prices in Southern California.[13]   Their focus is not on statistical estimation methods, but rather, methods to interpolate ozone concentrations. For this, they obtain very similar results for the different techniques that they use. By expressing their results as marginal willingness to pay (WTP), they find a positive and statistically significant WTP for reduction in ozone concentrations. Finally, Berezansky et al. (2010) address the question of subjective evaluations of local air quality vs. objectively measured air pollution values in Haifa, Israel. The authors find that the former significantly performs better in explaining observed price differentials, which leads them to conclude that the inclusion of subjective measures in HPV models may be helpful.

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[11] Their spatial error model is essentially an error-component specification.

[12] In their case, close proximity means houses within the same subdistrict or within four kilometers. Due to potential price endogeneity, they estimate their preferred model by using maximum likelihood (by assuming normality of the disturbance term) or instrumental variables (by using lagged prices as instruments).

[13] When estimating their spatial-lag model, they applied a somewhat different technique to obtain their weighting matrix than Kim et al. (2003). As they noted, there is little theoretical guidance on determining the weights. Otherwise, the approaches are similar.

4.   The Current Study

As amended in 1990, the U.S. Clean Air Act established a set of national ambient air quality standards (NAAQS) that govern the concentrations of six "criteria" pollutants: carbon monoxide (CO); lead; NOx; SOx; ozone; sulfur dioxide (SO_2); and small and large PM (PM2.5 and PM10, respectively).[14] Given the marked decline in ambient concentrations of CO, lead, NOx, and SOx since 1990, the standards for those criteria pollutants are rarely, if ever, exceeded.[15] In contrast, the EPA estimated that in 2007, nearly 73 million Americans lived in counties where the PM 2.5 standard was violated, and nearly 13 million Americans lived in counties where the PM 10 standard was violated.[16] As such, with the exception of ozone, the potential effects of PM are more policy-relevant than those of other criteria pollutants.

Ours is the first study of which we are aware that directly accounts for the spatial characteristics of its ambient distribution. In this study, we do not rely on linear measures of distance to assess the effect of carbon black, the pollutant of interest.   Instead, we develop a house-specific variable that measures the average annual PM concentrations separately generated from the CCC and COP plants.[17] We create this variable by using isopleth maps, available as a matter of record in the litigation, that contain the average annual concentrations at various concentration intervals from the two plants between 2003 and 2006.[18] As recommended by the EPA (2004), the dispersion modeling used to generate the isopleths relies on AERMOD, which incorporates the effects of the surrounding structures and topology on both air flow and particular dispersion.[19] Figure 4 displays an isopeth map for CCC emissions.

We then calculate PM concentrations between these isopleths by using a "topo-to-raster" method, a standard technique provided by Geographical Information Systems (GIS).   This approach treats the isopleths as contour lines, and estimates the likely "flow" or direction of pollution between the contour lines (Hutchinson and Dowling 1991). As a result, homes that are equidistant from either the CCC or COP plants may have different PM concentration values. Figure 5 displays a concentration map for the emissions from the CCC plant.   Our approach directly addresses the spatial

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[14] US EPA (2008).

[15] Ibid, Figure 4. For a detailed discussion of the rarity of violations of SOx standards, see Savage and Smith (2008).

[16] Ibid, p.1. It should be noted that these totals merely reflect the number of people who live in counties that have experienced at least one NAAQS violation, not the total number of people exposed to concentrations in violation of those standards.

[17] While the data analyzed include PM of all sizes, the PM modeled is largely PM10.

[18] Concentration is measured in micrograms per cubic meter. Maps were generated by Environ on behalf of the defendants in the litigation.

[19] http://www.epa.gov/scram001/dispersion_prefrec.htm#aermod.

characteristics discussed in Cameron (2005). By using this GIS technique, we have interpolated the concentrations between isopleths, and assigned to each home with a recorded sale during this time, a specific PM concentration value.[20] In addition, it allows us to differentiate the relative effects that each pollution source contributes to the potential diminution of property value.

Figure 4   Isopeth Map for CCC Emissions

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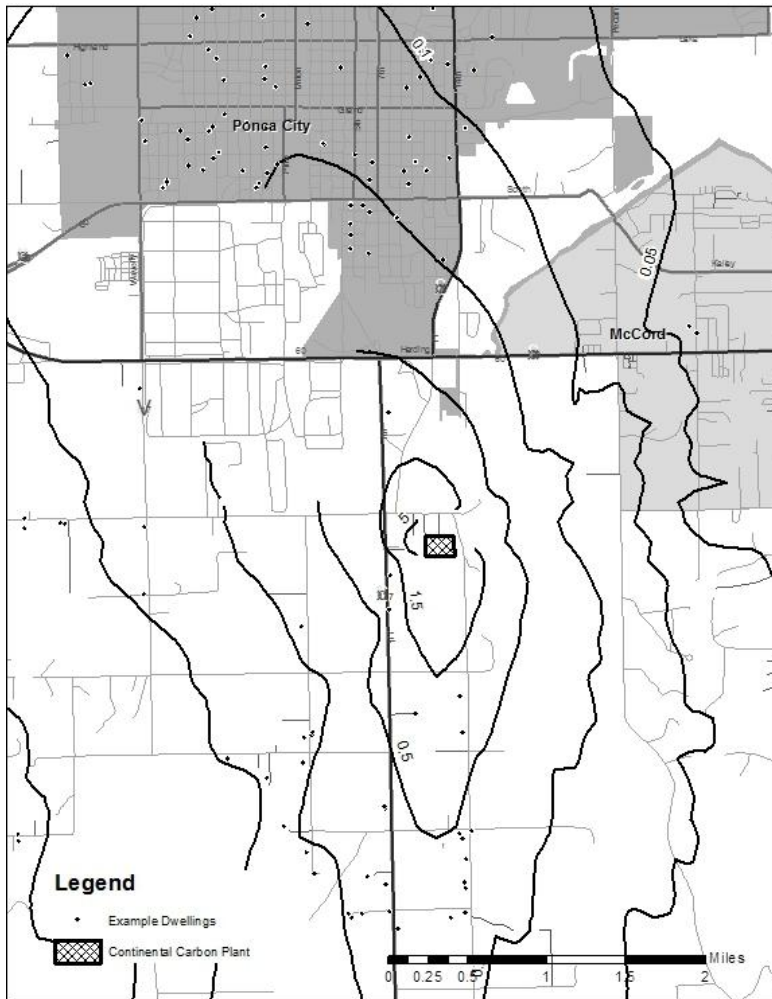
[20] Due to the on-going nature of the PM emissions from the two plants, an event-type analysis that uses, for example, a difference-in-difference estimator, is inappropriate for this study. As with most HPV studies, identification of the effect of interest is obtained through cross-sectional variation.

Figure 5   CCC Concentration Map
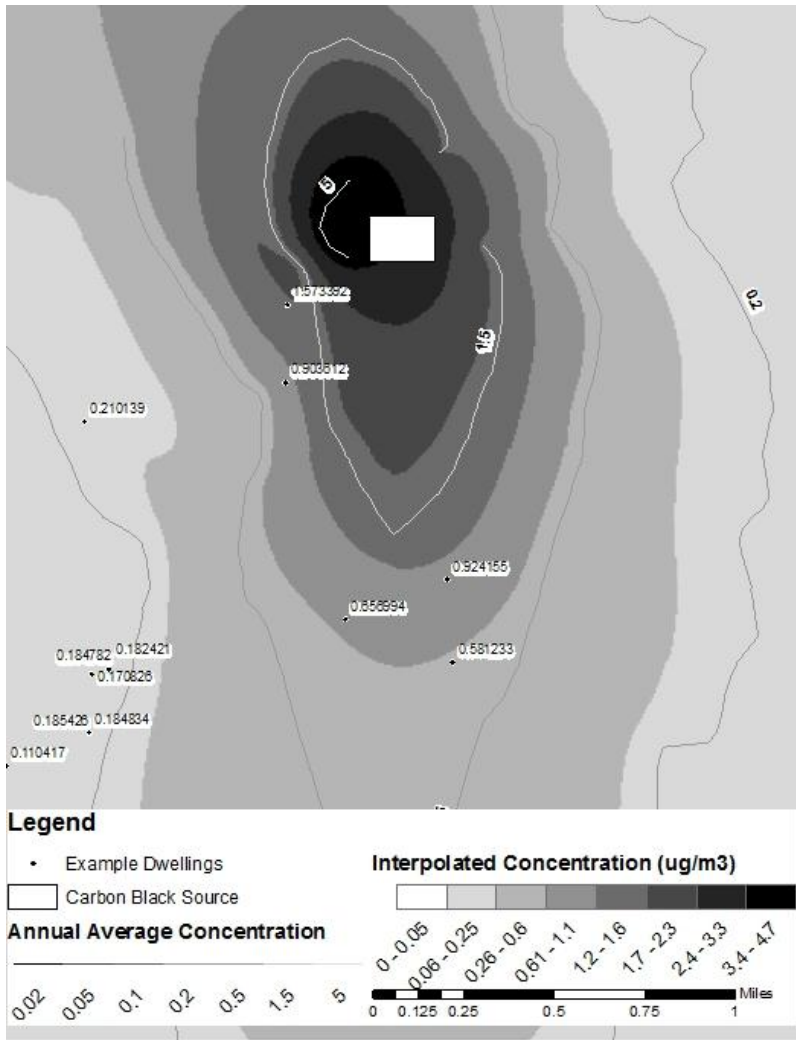
5.   Data and Results

By following the general thrust of the HPV literature, we assemble an analytic dataset from multiple sources. The publicly-available data include EPA regulated sites,[21] schools in the Ponca City area,[22] and ESRI street map

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[21] http://www.epa.gov/air/data/geosel.html#bylist.

USA[23].   Each of these locations was assigned a longitude and latitude, and then projected to an NAD83 UTM Zone 14 Datum ("geocoded"). Information on sales and dwelling characteristics were obtained from County Records, Inc. for Kay County, OK for all years on record from 1890 to 2007.[24] We adjust all sales prices to 2007 dollars by using a standard house price index.[25] We use home sales that begin in 1993, continuing through to 2007, and restrict our analysis to owner-occupied, single-family properties that were sold through arms-length transactions. Such properties were also geocoded.   Distances, where used, were calculated as a linear distance between two points in a straight line, which is typical in HPV studies. As a result, we develop an analytic database to estimate the effects of PM on property values, which accounts for spatial characteristics, other polluting sources, and house and neighbor-specific characteristics. Table 1 describes the variables used in this analysis, and their summary statistics. We follow the standard general specification for HPV models: $P_{it} = h(S_{it}, N_{it}, E_{it})$ where P_{it} represents the sales price, S_{it} represents house characteristics, N_{it} represents neighborhood characteristics, and E_{it} represents environmental characteristics.

We estimate our specification by using least squares and calculate the standard errors and t-statistics by using standard bootstrap methods based on 1,000 replications. The results from our specification are displayed in Table 2. They are consistent with our prior conjectures, and with those found in much of the HPV literature. First, house values (in 2007 dollars) increase as size, measured by square footage, rises. For houses in the Ponca City area, an additional square foot is valued at about $62, and garage space, where available, is worth about $17 per square foot. In addition, older houses are valued less than newer ones, but the relationship is nonlinear in that the devaluation effect of age diminishes with age. Holding the square footage constant, the availability of bedrooms and bathrooms has, as a matter of conjecture, an ambiguous effect on house value because smaller bedrooms, although more numerous, may not be as valuable as larger, less numerous bedrooms. This may also be true for an additional bedroom, holding the number of bathrooms constant. By evaluating the variables at their mean, we find that house values fall slightly by about $2,300 for each additional bedroom, but rise by about $8,600 for each additional bathroom (in each case, holding house size constant). We do find, however, that an additional bathroom for each bedroom increases house value, which we consider consistent with our conjectures.

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[22]http://www.greatschools.net/search/search.page?c=school&lc=e&q=ponca+city&search_type=0&state=OK.

[23] http://www.esri.com/software/arcgis/extensions/streetmap/index.html.

[24] http://wagoner.oklahomacounties.us/contact.asp.

[25] State-level house price index from the Office of Federal Housing Enterprise Oversight, available at: http://www.ofheo.gov/hpi_state.aspx

Table 1   Variables Used in Analysis

Variable	Definitions	Effect on dwelling value	Mean	Standard Deviation
Sale Price	Price of home sale in HPI adjusted 2007 dollars		91,121.01	69,284.81
Bedrooms	Number of bedrooms in the dwelling	?	2.80	0.70
Bathrooms	Number of bathrooms in the dwelling	?	1.57	0.61
Bedrooms*Bathrooms	Number of bedrooms interacted with the number of bathrooms	+	4.66	2.89
Square Footage	Square footage of dwelling	+	1,512.54	621.00
Garage Square Footage	Square footage of garage	+	373.71	201.63
Dwelling Age	Age of dwelling	-	45.92	19.44
Dwelling Age Squared	Age of dwelling squared	+	2,486.48	1,849.76
Annual Number of Dwelling Sales	Number of dwelling sales each year	-	233.79	130.65
Closest Elementary School	Linear distance to closest school	+	0.46	0.34
Number of EPA sites within 1 mile	Linear distance to EPA regulated air pollutant sources (other than CCC and COP) clustered within one mile	-	2.26	1.96
Number of EPA Sites within 2 miles	Linear distance to EPA regulated air pollutant sources (other than CCC and COP) clustered within two miles	-	6.93	2.70
Distance to Ponca City Center	Linear distance to the center of the Ponca City area	?	1.25	0.62
Annual Average Concentration from CCC	Average annual concentrations at interpolated contours based on AERMOD for the Continental Carbon Black plant for the period 2003-2006	-	0.10	0.05
Annual Average Concentration from COP	Average annual concentrations at interpolated contours based on AERMOD for the Conoco Phillips plant for the period 2003-2006	-	1.28	1.17

Table 2   HPV Regression Results

Variable	Estimate	t-statistic	95 Percent Confidence Interval	
Bedrooms	-20,138.7	-2.44	-36,303.5	-3,973.9
Bathrooms	-23,156.9	-1.34	-57,032.8	10,719.0
Bedrooms*Bathrooms	11,333.5	2.02	331.9	22,335.1
Square Footage	62.2	15.42	54.3	70.1
Garage Square Footage	16.5	2.44	3.3	29.7
Dwelling Age	-1,577.0	-4.36	-2,286.0	-867.9
Dwelling Age Squared	8.0	2.6	2.0	14.1
Annual Number of Dwelling Sales	-7.8	-1.35	-19.2	3.6
Closest Elementary School	9,249.5	2.8	2,782.4	15,716.7
Number of EPA sites within 1 mile	-1,339.9	-3.11	-2,184.4	-495.3
Number of EPA Sites within 2 miles	-1,759.1	-2.66	-3,056.4	-461.8
Distance to Ponca City Center	-6,764.4	-2.47	-12,122.3	-1,406.5
Annual Average Concentration from CCC	-103,214.0	-3.51	-160,897.9	-45,530.1
Annual Average Concentration from COP	-823.0	-0.62	-3,408.3	1,762.4
Constant	115,635.1	3.5	50,914.2	180,355.9
Observations		2,590		
R-Squared		0.80		

In examining the effects of local attributes, our results are also consistent with our prior conjectures. Closer proximity to the nearest public or private school means higher house value. More numerous proximate non-CCC and non-COP polluting sources mean lower house values. In contrast, values fall, other things constant, the further that a property is from the center of Ponca City. In addition, property values are adversely affected by the number of EPA-regulated sites within one and two miles of a house.[26] These results are consistent with the urban location theory.

We now turn to the particulate concentration measures for the CCC and COP plants. Note that both of these concentrations are measured in micrograms per cubic meter ($\mu g/m^3$). This plant specific information enables us to precisely determine the specific impacts of emissions from each plant. Based on our results, we find that concentrations from the COP plant, while higher on average although more variable, have no statistically significant effect on house values. In contrast, we find that concentrations from the CCC plant have a negative and statistically significant effect. This is consistent with the observed difference in PM between the plants. CCC emissions in the form of carbon black appear to have much greater soiling impact, creating a sticky substance on surfaces, which is costly to clean. Moreover, this adverse effect is quite precisely measured. Based on these regression results, we can calculate two useful measures, elasticity and the effect of a one standard deviation increase in PM concentration. For elasticity, we find that a 10-percent increase in PM concentration results in a 1.097-percent decrease in property value. The bootstrapped standard error on this elasticity is 0.314. An increase in PM concentration of one standard deviation results in a $4,798 reduction in property value in 2007 dollars, with a bootstrapped standard error of $1,367.

6.   Conclusion

Significant property value diminution is observed as a result of PM emissions from competing sources, as shown through the HPV model discussed in this analysis. By using GIS techniques and spatial econometric methods, it is possible to distinguish the effect of PM emissions taken from multiple sources in the same geographic area. This approach provides a robust measure of property diminution by further refining the concentrations of PM to a specific location. We find a 10-percent increase in PM concentration results in a statistically-significant 1.1-percent decrease in value. In 2007 dollars, a one-standard deviation increase in PM concentration results in a statistically-significant reduction of approximately $4,800.

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[26] Other EPA sources are restricted to sites that are monitored for air emission through the AirData database. See http://www.epa.gov/air/data/index.html. It draws from the Air Quality System database and the National Emission Inventory database to provide locations and classifications for facilities that emit hazardous air pollutants.

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