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The Impact of Brownfields on Residential Property Values in Cincinnati, Ohio: A Spatial Hedonic Approach

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Abstract. This paper empirically assesses the impact brownfield sites have on market values of single-family residential properties. Using three different hedonic model specifications, Ordinary Least Squares and Spatial Autoregressive and Spatial Error Models, this study shows that properties located less than 1,000 feet from a brownfield site experience a significant depreciation in property values. As expected, spatial dependence among real estate property values is present, meaning that the two spatial hedonic model specifications are superior to the Ordinary Least Squares specification. The study contributes to the relevant real estate and urban economics literature by determining the negative impact brownfield sites have on the value of single-family residential properties in our study region in Cincinnati, Ohio, by explicitly accounting for the phenomenon of spatial dependence in the dependent variable and by addressing the declining influence of brownfield sites on property values in a nonlinear relationship.

1. Introduction

Brownfield sites (or simply brownfields) are abandoned, idled, or underused real properties that are currently or were formerly employed for industrial or commercial purposes and whose expansion, redevelopment, or reuse may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant (Braswell, 1999; Bacot and O'Dell, 2006; US EPA, 2009, among others). Contaminated properties yield little revenue for local governments. They are unsafe for ecosystems and human health and impair the neighborhoods that contain them, both socially and aesthetically. In addition, they negatively impact the housing prices of residential properties that are located in close proximity (Bromberg and Spiesman, 2006).

It comes as no surprise that a large number of studies have strived to understand the benefits of brownfield redevelopment. Attoh-Okine and Gibbons (2001), Amekudzi et al. (2003), and Barnett (2006), for instance, focused on the revitalization of inner city neighborhoods through housing, jobs, and tax revenues resulting from brownfield redevelopment. In an environmentally-oriented regional level study, Alberini et al. (2005) argued that redeveloping brownfields helps to reduce the harmful effects of the site's groundwater, water, soil, and/or air pollution on ecological systems as well as on human health[1]. Akinmoladun and Lewis (1998) and Attoh-Okine and Gibbons (2001) emphasize the importance of brownfield redevelopment for combating the negative environmental effects of urban sprawl. Amekudzi et al. (2003) studied the effects of infill development to address urban sprawl. Gist (1999), Amekudzi et al. (2003), and Bacot and O'Dell (2006) focused on the impacts that redevelopment of contaminated properties has on neighborhoods and their citizens.

In this study, we use the spatial hedonic pricing framework to empirically estimate the impacts

[1] See also Bartsch, 1997; Attoh-Okine and Gibbons, 2001; Bacot and O'Dell, 2006.

brownfield sites have on the market values of single-family residential properties. The applied hedonic pricing model, based on the work by Lancaster (1966) and Rosen (1974), is the appropriate method to estimate the marginal implicit prices of individually selected housing characteristics, such as structural, neighborhood, and locational characteristics[2]. In other words, we determine housing prices as a function of a set of utility-bearing intrinsic properties and estimate people's price sensitivity as to these intrinsic characteristics. Based on the relevant brownfield literature, we expect that close proximity to potentially contaminated sites will depreciate housing prices.

Though the idea to study the impact of brownfields on neighboring property prices is not new, recent studies by Kaufman and Cloutier (2006), Longo and Alberini (2006), and De Sousa et al. (2009) all chose an aspatial hedonic pricing framework, ignoring the possibility for spatial dependence. However, given that realtors, buyers, and sellers price a property based on the values of neighboring residential properties, spatial dependence might become an issue when applying the hedonic method. More specifically, aspatial models may yield biased and inconsistent coefficient estimates, which in return means that the magnitude of the impact of brownfields on property values may be marked with some inaccuracy. From a practical modeling perspective, the use of Ordinary Least Squares (OLS) becomes questionable in the presence of spatial dependence, as the fundamental OLS assumptions of independent and identically distributed error terms become void. Since property values depend on the values of their neighbors, we also provide the results of two spatial hedonic modeling techniques, namely Spatial Autoregressive (SAR) and Spatial Error (SEM) models. A second important conclusion of this research is the nonlinear relationship between the distance from a residential property to the closest brownfield (in feet) and property value. While this confirms previous findings by Kaufman and Cloutier (2006), we find the inverse exponential form of the distance measure to have the highest level of statistical significance.

Overall, this study contributes to the real estate and urban economics literature through the use of spatial hedonic pricing techniques that allow the estimation of unbiased and consistent parameter estimates. Furthermore, the use of a nonlinear distance measure adds to the understanding of the sometimes complex nature of the relationship between property values and the distance from the property to the closest brownfields. The outline of the paper is as follows. In Section 2, we discuss the relevant literature on the impact of brownfield sites on residential property values. Section 3 presents the study area and the data used for this research. Section 4 discusses the three chosen model specifications. The paper concludes in Section 5 with a discussion and comparison of the results from each of the three models.

2. Review of the relevant literature

There is unanimous agreement in the brownfield literature that unremediated sites constitute a nuisance to people, neighborhoods, and local governments. From their classification as an environmental disamenity, it follows that these brownfields are expected to have negative impacts on residential property values within the hedonic pricing framework. More recently, a body of literature has emerged attempting to quantify in terms of property values the negative impact of being in close proximity to unremediated brownfields and if/how this impact changes with remediation efforts.

In an earlier study, Gunterman (1995) explains potential decreases in property values through existing on-site contamination of nearby landfills. The author finds that solid waste landfills negatively impact the selling price of nearby industrially-zoned land and, of course, that of the landfills themselves. Once these solid waste landfills are closed, they do not adversely affect land values as they did before. Longo and Alberini (2006) confirm these findings for industrial properties in Baltimore, Maryland. In addition, they find that commercial properties are affected differently by proximity to a site with a history of contamination. More specifically, the authors find that commercial properties suffer an external cost due to their proximity to a contaminated site, a cost that is not cleared once the site has been cleaned up or has been pronounced harmless. Simons et al. (1997, 1999) focused their studies on the impact on residential property sales prices of underground storage tanks known to have leaked. They concluded that sales prices are prone to a statistically significant reduction of approximately 15% if it is known that they have been contaminated by neighboring leaking underground storage tanks.

Jenkins-Smith et al. (2002) argue that the public release of information on the locations and/or the

[2] Please see Table 1 below for a complete list with all included housing characteristics.

type and degree of contamination in itself devalues surrounding property values. The authors show, based on a probit model, that the mere disclosure of information about contamination, cleanup, and subsequent legal action caused as many as 30% of potential buyers of contaminated sites to not pursue the purchase. In addition they find that the buyer's willingness to pay for the typical home in the area drops by approximately $11,000 and that nearly half of the sellers accepted a $12,000 loss in the purchase price from the sale of properties situated in the proximity of contaminated sites. Kaufman and Cloutier (2006) studied the combined impacts of two brownfields and one neighborhood park on residential property values in Kenosha using a semi-log model and OLS estimation technique. Distance measures from each house to the two brownfields and the park were included. Confirming prior expectations, the authors show that brownfields exert a negative impact on residential property values, while the park has the opposite effect. They further determine that residential property values tend to increase once the brownfields are remedied. Lastly, the conversion of former brownfields into greenspaces further significantly increases the value of the neighboring residential properties.

Green Leigh and Coffin (2005) estimate a hedonic model applying the OLS technique to property values in Atlanta, Georgia, and Cleveland, Ohio. They find that contamination has a negative impact not only on the value of nearby properties, but also on the value of the brownfield sites themselves. However, the magnitude of the negative impact on the neighboring properties varies with proximity to the contaminated site and whether the respective site has been remediated or not. Simons and Saginor (2006) performed a metadata OLS regression using results from 75 previous studies. Their results generally confirm that environmental contamination of sites (not particularly brownfields) does discount property values and that this discounting effect decreases with increasing distance from the source of contamination. In addition, the loss in property value differs by region, the type of contamination, undertaken remediation efforts, and other factors, such as legal liability.

Of much interest for the presented research are the studies that also account for spatial dependence in the data. Ding et al. (2000) use a hedonic price model that includes a spatially lagged dependent variable (SAR) to determine the infill development effect on nearby property values. Allowing for two separate types of residential property investments, they find that the impact of new construction is more spatially extensive than that of rehabilitation (300 feet as compared to 150 feet). Further, new construction also produces a higher average increase in housing values: $4,500 more per house as compared to $2,000 per house following rehabilitation. However, these effects vary across neighborhoods, being greater in low-income and predominantly white areas. Ihlanfeldt and Taylor (2002), compare the hedonic modeling results from the standard nonspatial OLS model with the results from the Spatial Error Model (SEM) for commercial and industrial properties located in the vicinity of hazardous waste sites in Fulton County, Georgia. Both sets of results indicate a statistically significant reduction in the value of commercial and industrial properties surrounding the contaminated sites. By including space in the analysis, the SEM results are preferred, as this allows the authors to establish the perimeter of the negative impact of contaminated sites, and, in return, to estimate total property value losses for the entire county at as high as $1 billion. Further, the density effect (i.e., the number of contaminated sites within a certain distance of each property) is less important than a property's proximity to the closest contaminated site.

Svetlik (2007) evaluates the determinants of land prices in Monongalia County, West Virginia, with a specific focus on the impacts of local brownfields on residential property values. More specifically, he examines the influence of structural characteristics (i.e., square footage and age), locational amenities (i.e., elevation and distance from the analyzed Metropolitan Statistical Area (MSA)), and recreational amenities (i.e., streams) on the price per acre of land. Brownfields are identified as sites that either participate in the West Virginia Voluntary Remediation Program (VRP) or are known open dump sites.

Svetlik accounts for spatial dependence in land prices using both standard spatial approaches, namely the SAR and the SEM frameworks, and concludes that the SAR and SEM results are more robust than the OLS estimation results, as the spatial approaches produce unbiased and consistent coefficient estimates. He determines that price per acre is positively associated with square footage, structural amenities, and locational amenities such as access to sewer and location in the Morgantown MSA, and negatively related to the age of the structure, the lot size, elevation, and increasing distances from Morgantown and from recreational amenities such as streams. Not surprisingly, the coefficient on the distance from brownfield sites is significant and positive, showing a positive relationship between distance from brownfield sites and property values.

3. Study area, data sample, and research design

Our study area is the City of Cincinnati, core of the Cincinnati-Middletown, OH-KY-IN, Metropolitan Statistical Area (MSA). Like other older cities in the Northeast and the Midwest of the US whose economies were once based on heavy industrial activity (e.g., Pittsburgh or Detroit) Cincinnati has a large number of contaminated brownfield sites (Amekudzi et al., 2003). The former dominance of manufacturing from industry's golden years and the subsequent flight of manufacturing activities to city edges, the Southwest, or the West, have left many "Rust Belt" cities with a large footprint of contaminated land (Fukuyama, 1999; Lopez, 2004), often in prime locations, as is the case in Cincinnati.

A recent effort by the Ohio Kentucky Indiana (OKI) regional council of governments to compile a complete inventory of brownfield sites in the Cincinnati metropolitan region stalled in an early phase because of massive resistance from property owners to having their properties on an official list of contaminated sites (Jackson, 2004). With no official brownfield list existing for Cincinnati, for the presented study we compiled an inventory list of brownfield sites based on voluntary information received from various sources. Among others, these sources include the Ohio Brownfield Inventory, the Ohio Environmental Protection Agency, the Port of Greater Cincinnati Development Authority, the Clean Ohio Revitalization Fund, and the US Environmental Protection Agency's (EPA) Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS)[3]. Regardless of where the brownfield sites information originated from, all brownfield sites included in our final database have in common that: i) the sites are abandoned, idled, or underused, ii) they formerly served industrial or commercial purposes, and iii) their redevelopment or reuse may be complicated by the (potential) presence of a certain degree of contamination. Using the Cincinnati Area Geographic Information System (CAGIS), a publicly available ArcGIS database, we geocoded all identified sites. The result of the final database of brownfields in Cincinnati is shown in Figure 1.

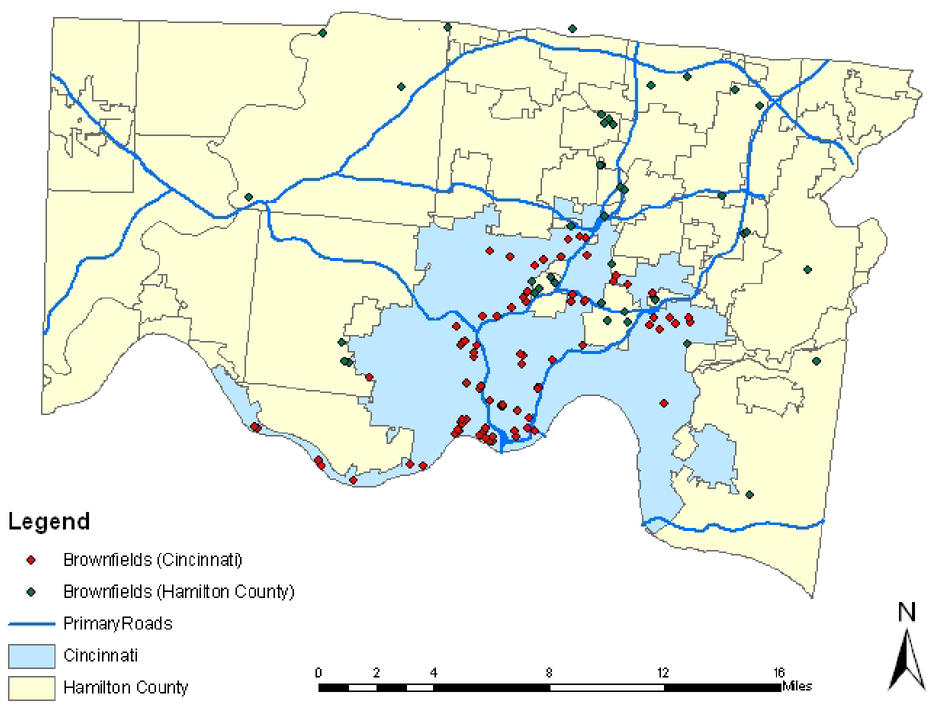

Figure 1. Cincinnati brownfield sites.

[3] Only a total of 18 sites located in the City of Cincinnati were included in the US EPA CERCLIS database for Cincinnati while an additional 69 brownfield sites were identified by the Ohio Brownfield Inventory, the Ohio Environmental Protection Agency, and the Port of Greater Cincinnati Development Authority, all of which were included in the current analysis.

The data about property values in Cincinnati have been collected from the Hamilton County Auditor's Office. CAGIS resources were then used to geographically locate this information and to calculate necessary distance measures. Based on preliminary examination of the data, and supported by the relevant literature which reports the strongest impact to occur within 150 to 1,500 feet, all residential properties located within 1,000 feet of a brownfield were selected for this research (Ihlanfeldt and Taylor, 2002; Green Leigh and Coffin, 2005; De Sousa et al., 2009). Altogether, we identified 1,607 properties. In order to include essential variables (e.g., median household income and education) that were defined only at the ZIP code level for the analyzed period, we used ZIP code as the unit of reference.

The choice of explanatory variables has been guided by the relevant hedonic literature. We follow Freeman (2003) and include neighborhood and locational characteristics in addition to the commonly used structural housing characteristics in our study. Structural characteristics, often denoted "property characteristics", include the lot size, the square footage of the house, the number of bedrooms and bathrooms, and the age of the house. They also include various property improvements, such as the existence of air conditioning systems, fireplaces, attached or detached garages, and the number of stories (Hess and Almeida, 2007; Cebula, 2009; Landry and Hindsley, 2011). In addition, Bin et Al. (2008) argue for the inclusion of a variable denoting the condition of the house. Median household income (Lindsey, 2004; Conway et al. 2010), quality of the school district (Dougherty et al., 2009; Clapp et al., 2008), and educational attainment (Lynch and Rasmussen, 2001; Geoghegan et al., 2003) are three commonly used neighborhood characteristics. Locational characteristics usually measure the proximity of the property to certain amenities and/or disamenities. Depending on the study area, these may include proximity to the CBD (Ryan, 1999), highway exit ramps (Atkinson-Palombo, 2010), parks (Crompton, 2005), and public transport systems (Debrezion, 2007). Following data availability and/or compatibility and potential multicollinearity problems, and guided by the principle of parsimony, we selected a subset of explanatory variables from the list of potential explanatory variables identified by the hedonic literature. Our final list of variables is shown in Table 1 along with some descriptive statistics in Table 2.

Table 1. Variable definitions.

Variable	Description
MKTVALU	Market value of land and improvements in 2009 (Hamilton County Auditor)
AREALOT	Land area in square feet
FRONT	Number of feet of street footage
HOUSESQFT	Total finished square footage of the house
ATTIC	Attic square footage
TOTALROOMS	Total number of rooms
BEDROOMS	Number of bedrooms
FULLBATHS	Number of full baths
HALFBATHS	Number of half baths
AGE	Age of building in years
GARAGE	Car capacity of the basement garage
STYHEIGHT	Story height in feet
FIREPLACES	Number of fireplace stacks
CVPOOR	Dummy variable denoting a very poor condition of the house
AIRCOND	Dummy variable denoting a central air conditioning system
HEATING	Dummy variable denoting a heating system
MEDHHINC	Median household income by ZIP code
EDUCATION	Percent of population 25 with higher education by ZIP code
DISTBR	Euclidean distance to the closest brownfield site
DISTHW	Euclidean distance to the closest highway exit
DISTCBD	Euclidean distance to the Central Business District (CBD)

The structural housing characteristics reveal that the average house in our sample is 92 years old, is valued at 94,595 dollars, and is built on a lot of 5,911 square feet. Though the average house in our sample has as many as 6.0 rooms, its finished square footage is rather low, with 1,431 square feet. Further, the average home has 2.6 bedrooms, 1.3 full baths, and only 0.2 half baths. Data from the US Census Bureau (2010) indicate that the median household income in our study region is 30,858 dollars and that 24.6% of the population 25 years and older has a bachelor's degree or higher, compared to 33,855 dollars and 12.1% city-wide.

Table 2. Data – summary statistics.

Variable	Mean value	Standard deviation	Minimum value	Maximum value
MKTVALU	94,595.07	94,180.05	1,800	2,420,500
AREALOT	5,911.49	12,016.97	116.53	225,922.28
FRONT	5,208.66	5,350.72	0	46,700
HOUSESQFT	1,431.32	592.29	448	8,012
ATTIC	109.17	185.62	0	1,402
TOTALROOMS	5.98	1.50	3	17
BEDROOMS	2.63	0.87	1	8
FULLBATHS	1.28	0.53	0	6
HALFBATHS	0.20	0.42	0	3
AGE	92.11	25.49	4	180
GARAGE	0.28	0.52	0	3
STYHEIGHT	1.56	0.50	1	3
FIREPLACES	0.18	0.41	0	3
CVPOOR	0.01	0.11	0	1
AIRCOND	0.56	0.50	0	1
HEATING	0.99	0.09	0	1
MEDHHINC	31,012.63	7,587.80	12,219	60,470
EDUCATION	24.68	14.37	8.50	55.40
DISTBR	712.03	213.56	9.83	999.99
DISTHW	5,481.57	5,211.13	476.65	34,675.28
DISTCBD	26,849.86	9,153.22	2,043.60	50,047.61

All three distance measures used in our study were calculated in ArcGIS using direct "as the crow flies" (i.e., Euclidean) distances. More specifically, these distances include the distance of each sample property – defined by its centroid – to the closest highway exit and to the Central Business District (CBD), as well as the distance from each property to the closest brownfield site. As stated by Eiser et al. (2007), Euclidean distance measures are preferred over network distances, as the perception of being in close proximity to a brownfield site is a more decisive factor for devaluating housing prices than the accessibility to this brownfield site. In other words, while people are aware of the close proximity of a brownfield site to their property and their perception is that possible pollution may have a negative influence based on direct distances to surrounding properties, their access to these brownfield sites via roadways is not of importance, as presumably home owners and potential buyers would neither walk nor bike there regularly for specific purposes. Guided by the relevant literature, we used the same principle of perception when calculating the distances to the closest highway exit and to the CBD.

In the presented study, we gave preference to the use of assessed values, rather than sale prices, of single-family residential properties as our dependent variable. In Ohio, assessed property values represent 35% of their market values (Ohio Revised Code, 2010a). Gaddy and Hart (1993) and Ventolo and Williams (1994) define the market value as "the highest price estimated in terms of money which the property would bring if exposed for sale in an open market, with reasonable time allowed in which to find a purchaser, buying with knowledge of all of the uses and purposes to which it is adapted and for which it was capable of being used." As such, the market value is an appropriate measure to use in hedonic pricing models, as it does represent the most probable price for a property sale occurring under normal market conditions - in other words, under an arm's length transaction. Market values in Ohio are estimated based on the most recent sales price (if occurring within a reasonable length of time), recent sales of comparable properties, and available pertinent market data, e.g., rates of depreciation (Gillman, 2010; Hamilton County Auditor's Office, 2010; Ohio Revised Code, 2010b). Kaufman and Cloutier (2006) also argue for market values as the appropriate measure when studying the impacts of small brownfields and greenspaces on residential property values.

Although recent sales data might provide the most accurate measure of market value, infrequent property sales, especially in depressed neighborhoods, create serious data limitations. Green Leigh and Coffin (2005) point out that brownfield sites are often located in more depressed neighborhoods and, as a result, available sales data for residential properties might not be sufficient for thorough research. Ihlanfeldt and Taylor (2002) also support the use of appraised market values but at the same time argue that the researchers need to be aware of the fact that in fast-appreciating neighborhoods appraised market values may lag behind the changes in actual market values. As Green Leigh and Coffin show in their 2005 study, sales data may not be available during periods of economic crisis, due to the lack of sales. Our study area includes several of the most depressed neighborhoods in Cincinnati, and, therefore, appraised market values provide the best available data and are used as the dependent variable for our study.

4. Model specifications and comparison

The main objective of the paper is to estimate the impact brownfield sites in Cincinnati, Ohio, have on the variation in nearby housing prices. We use the following empirical hedonic model specification:

$$\ln(MKTVALU) = \alpha + \beta_1 S + \beta_2 N + \beta_3 L + \varepsilon \qquad (1)$$

where $MKTVALU$ is the market value of each property in its log-form; S, N, and L are matrices including structural, neighborhood, and locational housing characteristics as defined in Table 1 above; and ε refers to normally and identically distributed error terms with a zero mean and a common variance σ^2.

We chose a semi-logarithm (log-linear) functional form, partly due to its dominance in the relevant literature and partly to better control for the large variations in the housing price dependent variable (Svetlik, 2007).

Another important convention is the choice of the appropriate form for the distance measure from each property to the closest brownfield site. While simple linear straight-line distances were used in studies by Green-Leigh and Coffin (2005) and Svetlik (2007), use of these linear distance measures often failed to reveal significant relationships between housing prices and their distances to brownfield sites. In an aspatial study, Kaufman and Cloutier (2006) use both a reciprocal and a log-transformed form of the distance measures, concluding that nonlinear forms of distance measures are more sensitive in detecting the underlying relationships between housing prices and their distances to brownfield sites. More specifically, they report the highest level of significance for the log-transformed distance measures. Our study contributes to the discussion and exploration of different forms of distance measures, with the finding that an exponential transformation of the distances returns the most significant estimated regression parameter. Using the exponential function, we transformed the distances as:

$$f(distbr) = exp^{(-\frac{distbr}{500})} \qquad (2)$$

where $distbr$ is the distance from a residential property to its closest brownfield site and exp refers to the use of the exponential function exp^x. Using the exponential function implies that a constant change in the distance to a brownfield site results in the same proportional decrease (negative sign) in the housing price.

Altogether, we used three different estimation techniques: Ordinary Least Squares (OLS), Spatial Autoregressive regression (SAR), and Spatial Error Model (SEM). The use of spatial regression specifications is motivated by the presence of spatial externalities, in our case, the spatial dependence among residential property prices (Ihlanfeldt and Taylor, 2002; Svetlik, 2007). Spatial dependence refers to the fact that the values of residential properties are determined not only by their structural (S), neighborhood (N), and locational (L) characteristics, but also by the values of the neighboring real estate properties. For observations $i = 1$ and $j = 2$ representing two neighboring properties, spatial dependence can be expressed as:

$$p_i = \rho_i p_j + \beta_{ik} P_{ik} + \varepsilon_i \text{ and } \varepsilon_i \sim NID(0, \sigma^2)$$
$$p_j = \rho_j p_i + \beta_{jk} P_{jk} + \varepsilon_j \text{ and } \varepsilon_j \sim NID(0, \sigma^2) \quad (3)$$

where $i = 1, \ldots, n$ and $j = 1, \ldots, n$ with n representing the number of properties in the sample; $k = 1, \ldots, l$ with l representing the number of explanatory variables in the model; p_i and p_j referring to the house prices of properties i and j; P_i and P_j are vectors of explanatory variables; ρ_i, ρ_j, β_i, and β_j are regression coefficients; and ε_i and ε_j are normally distributed error terms with a zero mean and a common variance σ^2. Following the definition of spatial dependence in equation 3 above, the house price p_i is now directly dependent on p_j, the price of the neighboring property j and vice versa.

Considering all properties in a particular sample of size n gives us the general expression of the SAR model, which in matrix form is:

$$Y = \rho WY + X\beta + \varepsilon \quad (4)$$

where Y is a $n \times 1$ vector with the housing prices, W is the $n \times n$ spatial weight matrix, β is the $l \times 1$ vector of parameters to be estimated and X is the $n \times l$ matrix of explanatory variables, including an intercept term. The scalar ρ defines the strength of the spatial dependence and is bound by $-1 < \rho < 1$, implying the use of a row-normalized W matrix. Entering the expression WY in the regression model treats spatial dependence as a consequence of omitted variables, that is, as a structural process (LeSage and Pace, 2009).

A second approach presented in this paper to account for spatial dependence assumes that spatial dependence is a problem of spatially autocorrelated error terms. The Spatial Error Model (SEM) in matrix notation is defined as:

$$Y = \beta X + \varepsilon,$$
$$\varepsilon = \lambda W \varepsilon + u \quad (5)$$

where λ measures the strength of the spatial dependence in the spatial lag of the error terms and the unobserved random part of the SEM specification has the desired properties $u \sim NID(0, \sigma^2 I_n)$.

Both spatial versions of the hedonic price model are estimated using Maximum Likelihood (ML) estimation techniques, while the non-spatial version is estimated using OLS techniques. To have a common goodness-of-fit criterion between the spatial models and the standard OLS model, we report the log-likelihood value, the Akaike (AIC) criterion, and the Schwarz (SC) criterion. Generally, a larger log-likelihood value indicates a better fit of the model to the sample data and is therefore preferred over smaller log-likelihood values. The AIC and SC criteria are simply derivations of the likelihood function penalized for the number of parameters/ observations. They are defined as:

$$AIC = -2L + 2K,$$
$$SC = -2L + K ln(N) \quad (6)$$

where L is the likelihood function; K is the number of parameters; and N is the number of observations. Since the sign of AIC and SC are positive (opposite to the sign of the log-likelihood), smaller AIC and SC criteria indicate a better model fit.

4.1. Analysis and discussion of empirical results

Comparing the goodness of fit criteria across all three model specifications reveals that the spatial model specifications, i.e., the SAR model and the SEM, are superior to the standard OLS model. The log-likelihood value increased from -1,311.4 (OLS) to -1,305.9 (SAR) and -1,229.2 (SEM). It appears that the SEM performs significantly better than either of the other two model specifications. Evaluation of the Akaike info criterion (AIC) and the Schwartz criterion (SC) lead to the same conclusion. The AIC and the SC are smallest for the SEM with 2,490.4 and 2,576.5 respectively. In addition, the SAR model specification is superior to the OLS specification, as shown in Table 3.

Table 3. Model diagnostics for the OLS, SAR, and SEM estimations.

Diagnostics	OLS	SAR	SEM
Log-likelihood	-1,311.4	-1,305.9	-1,229.2
Akaike (AIC)	2,654.9	2,645.7	2,490.4
Schwartz (SC)	2,741.0	2,737.2	2,576.5

For reasons of multicollinearity, as identified by the Variance Inflation Factor (VIF), the Condition Number (CN), and the correlation coefficients, only fifteen of a total of twenty available explanatory variables remained in the final model specifications. Among others, the total finished square footage of the house (*HOUSESQFT*) and the total number of rooms (*TOTALROOMS*) were highly correlated with the other structural variables and were therefore removed from the model. Though multicollinearity may not reduce the usefulness of the model as a whole, it does have severe consequences for the interpretation of the marginal effects of individual regression coefficients (Chatterjee and Hadi, 2006), for example, the effect of the distance of residential properties on nearby brownfield sites (*DISTBR*). The problem of ambiguous regression results has been avoided by removing some of the severely correlated explanatory variables, while keeping almost all of the important and relevant variables in the model.

In addition, for reasons of parsimony the median household income by ZIP code (*MEDHHINC*) and the distance to the CBD (*DISTCBD*) variables were removed due to statistically insignificant parameters. Of the remaining fifteen variables, all calculated coefficients have the expected sign, an indication that no severe multicollinearity problems are present (see Table 4). Based on the Breusch-Pagan test, we reject the null hypothesis of homoskedastic error at the 99% level of confidence for both spatial models. This is a commonly observed and documented phenomenon of spatial regression models.

Table 4. Estimation results for OLS, SAR, and SEM model specifications.

	OLS		SAR		SEM	
Variable	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Constant	10.51091**	(0.000)	10.42543**	(0.000)	10.55953**	(0.000)
AREALOT	3.7870E-06**	(0.003)	3.3899E-06**	(0.007)	4.82604E-06**	(0.001)
FRONT	8.7561E-06**	(0.001)	1.0600E-05**	(0.000)	7.42170E-06**	(0.003)
ATTIC	0.00014	(0.067)	0.00013	(0.098)	0.00014	(0.065)
BEDROOMS	0.08504**	(0.000)	0.08581**	(0.000)	0.07047**	(0.000)
FULLBATHS	0.15120**	(0.000)	0.16015**	(0.000)	0.14032**	(0.000)
HALFBATHS	0.10480**	(0.002)	0.11255**	(0.000)	0.10348**	(0.001)
AGE	-0.00698**	(0.000)	-0.00672**	(0.000)	-0.00643**	(0.000)
GARAGE	0.12720**	(0.000)	0.12730**	(0.000)	0.12189**	(0.000)
FIREPLACES	0.23866**	(0.000)	0.23163**	(0.000)	0.20293**	(0.000)
CVPOOR	-0.83248**	(0.000)	-0.80300**	(0.000)	-0.86721**	(0.000)
AIRCOND	0.36702**	(0.000)	0.35357**	(0.000)	0.28278**	(0.000)
HEATING	0.31162	(0.062)	0.26759	(0.107)	0.31981*	(0.035)
EDUCATION	0.01346**	(0.000)	0.01360**	(0.000)	0.01346**	(0.000)
EXP-DISTBR	-0.22867*	(0.026)	-0.22844*	(0.025)	-0.25361*	(0.030)
DISTHW	-6.6047E-06*	(0.017)	-5.6457E-06*	(0.041)	-6.7431E-06*	(0.029)
ρ			0.01007**	(0.001)		
λ					0.32641**	(0.000)

** significant at the 99% confidence level; * significant at the 95% confidence level.

The univariate global Moran's I test statistic of 0.4919 is statistically significant at the 99% level (p-value = 0.001), which indicates the presence of spatial dependence in housing prices. This is expected, as the price of a residential property is not solely determined through an array of housing and neighborhood characteristics, but also depends on the prices of neighboring properties. As for the OLS estimators, they are biased and inconsistent in the presence of spatial correlation. Accordingly, the discussion of our regression results will focus on the spatial model specifications. The presence of spatial dependence is further supported as the additional spatial parameters $\rho = 0.01007$ and $\lambda = 0.32641$ in the SAR and SEM specifications are both statistically significant at the 99% level (Table 4). The relatively low ρ value further implies that, though highly significant, the spatial spill-over effect of neighboring residential properties is relatively small. This finding can be explained by the fact that residential properties around brownfield sites do not show large variations in their values. Our sample data indicate that 80% of the property values fall between \$30,464 and \$163,800, compared to \$67,500 to \$319,970 citywide. As a matter of fact, most properties included in our study lie in the Mill Creek

Corridor, an old and depressed industrial area known for its low property values.

The fact that the SAR specification contains a spatial lag of the dependent variable requires an additional step to allow interpretation of the coefficients from the model. We follow LeSage and Pace (2009), who suggest estimating the summary measures of the total impacts of each explanatory variable on property values as:

$$\beta^T = (1-\rho)^{-1}\beta \quad (7)$$

The estimated total impacts are shown in Table 5 below.

Table 5. Calculated total SAR impacts.

Variable	Estimated SAR coefficients	Total SAR impacts
Constant	10.42543	10.53148
AREALOT	3.3899E-06	3.4244E-06
FRONT	1.0600E-05	1.0708E-05
ATTIC	0.00013	0.00014
BEDROOMS	0.08581	0.08668
FULLBATHS	0.16015	0.16178
HALFBATHS	0.11255	0.11369
AGE	-0.00672	-0.00679
GARAGE	0.12730	0.12860
FIREPLACES	0.23163	0.23399
CVPOOR	-0.80300	-0.81117
AIRCOND	0.35357	0.35717
HEATING	0.26759	0.27031
EDUCATION	0.01360	0.01374
EXP-DISTBR	-0.22844	-0.23076
DISTHW	-5.6457E-06	-5.7031E-06

Most of the variables in each of the three model specifications are statistically significant at the 99% level of confidence. The exception is the attic square footage (*ATTIC*) variable, which is only significant at the 10% level in each of the three models. Further, the presence of a heating system (*HEATING*) appears to be significant at the 95% level in only the SEM model specification. In addition, both distance measures, i.e., distance to brownfield sites and highways, are significant at the 95% level as well.

The interpretation of the spatial dependence in the SAR specification is a structural process, based on the assumption of omitted variables (LeSage and Pace, 2009). As such, the SAR approach does account to some extent for these unobservable latent influences, such as noise and crime issues and other excluded variables. The total SAR impacts in Table 5 show that one additional bedroom adds 8.67% to the market value of a house, while a full bath and a half bath add 16.18% and 11.37%, respectively. Having a central air conditioning system increases the property value by 35.72%, while a heating system adds 27.03% and a garage adds 12.86%. As expected, the age of the property and educational attainment level of the residents impact residential property prices to a lesser extent. An increase in the age of the house by one year causes a decrease in the property value by only 0.68%, and a 1% increase of the population aged 25 or older holding a bachelor's degree or higher by ZIP code increases the property values by 1.37%. Also of note is that properties in very poor and unlivable condition are devalued by 81.12%.

The total estimated impact with respect to the distance from a property to its closest brownfield is -0.2308. Relying on a non-linear distance function, as shown in Figure 2, means that the estimated decrease in property value with respect to the distance to the closest brownfield site needs to be calculated using the exponential form $f(distbr) = exp^{(-\frac{distbr}{500})}\%$, where $distbr$ denotes the distance to the closest brownfield in feet.

Referring to Figure 2 we see that decreasing the maximum distance allowed to a brownfield site, i.e., from 1,000 to 0 feet in our study, is equivalent to a reduction of the exponential function of $exp^{(-1000/500)}$ to $exp^{(-0/500)}$, which is equivalent to a reduction from 0.1353 to 1.00 on the vertical axis. This translates into a maximum possible reduction in property value of $(1-0.1353)*23.08\%$ or 19.96%. In other words, given that the maximum change in the explanatory variable is $(1-0.1353) = 0.8647$, the largest change possible in a residential property value is 19.96%. The relationship between selected changes in actual distances in feet to the closest brownfield site, the equivalent changes in the exponential function, and the reductions in property values are shown in Table 6 below.

As indicated in Table 6, reducing the distance from 500 to 0 feet results in a decrease of residential property values of 14.59%. Analogously, reducing the distances from 1,000 to 500 feet, from 500 to 100 feet, and from 100 to 0 feet result in property value reductions of 5.37%, 10.40%, and 4.18%, respectively. As indicated in Figure 2, the largest change in property values occurs in close proximity to the brownfield sites, while reductions in property values level off when moving beyond the 1,000 feet cut-off distance used in our study. For instance, reducing the distance from 100 to 0 feet results in a property reduction of 4.18%, while reducing the distance from 1,000 to 900 feet results in a property reduction of a mere 0.69%.

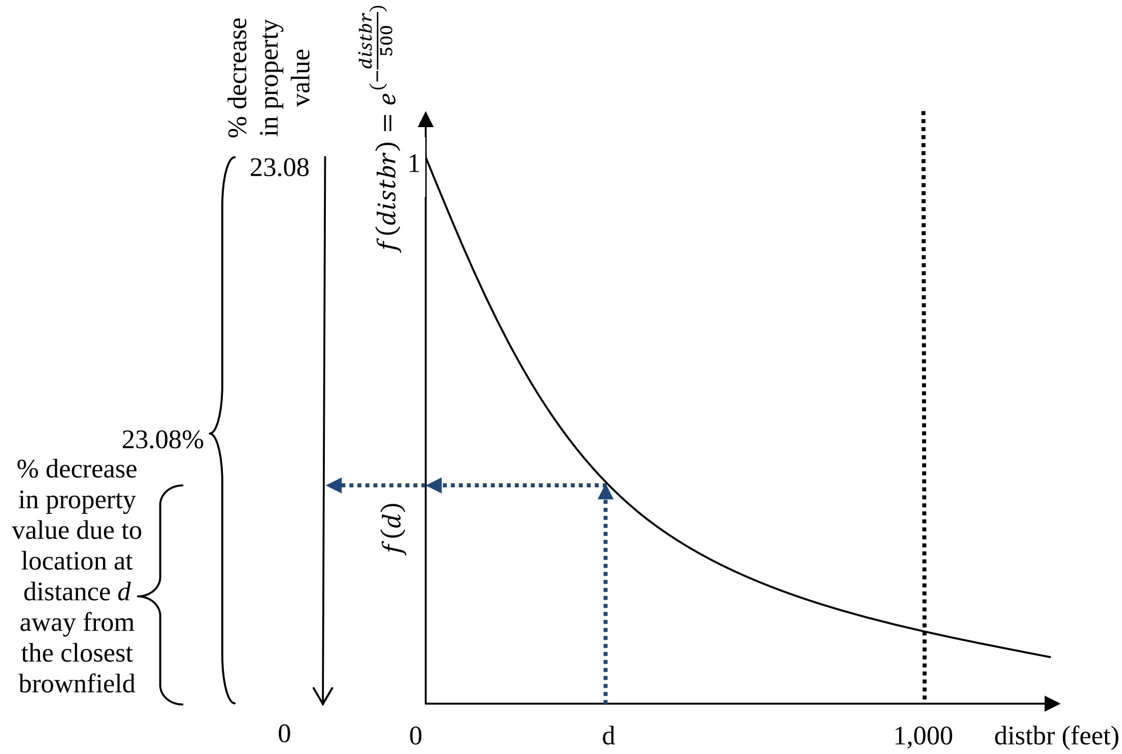

Figure 2. Exponential distance function.

Table 6. Estimated reduction in property values (SAR model).

Change in distance to brownfield	Change in $\exp^{(-distbr/500)}$	Decrease in property value
1,000 to 0	0.1353 to 1.00	19.96%
500 to 0	0.3679 to 1.00	14.59%
1,000 to 500	0.1353 to 0.3679	5.37%
500 to 100	0.3679 to 0.8187	10.40%
100 to 0	0.8187 to 1.00	4.18%

Assuming spatial autocorrelation only in the unobserved random part of the specification, the Spatial Error Model (SEM) addresses spatial dependence through spatially structured random effects in the disturbance process (LeSage and Pace, 2009). Referring back to Table 4, the SEM results indicate that one additional bedroom, a full bath, and a half bath add 7.05%, 14.03%, and 10.35%, respectively, to property values. An increase in property value of an estimated 28.28%, 31.98%, and 12.19% is associated with adding an air conditioner, a heating system, and a garage, respectively, while age and very poor condition reduce property values by 0.64% and 86.72%, respectively. Again, a 1% increase in the population with at least a college degree increases the property values by 1.35%.

With an estimated coefficient of -0.2536, brownfields have in the SEM specification a somewhat higher influence on residential property prices. Here, a maximum possible reduction in property value is calculated as $(1 - 0.1353) * 25.36\%$ or 21.93%, related to reducing the distance to the closest brownfield site from 1,000 to 0 feet. Table 7 below shows for comparison distance reductions to brownfield sites and their influences on property values.

As seen in Table 7, reducing the distance from 500 to 0 feet under the SEM model results in a decrease of residential property values of 16.03%, while reducing the distances from 1,000 to 500 feet and from 500 to 100 feet results in property reductions of 5.90% and 11.43%, respectively. The nonlinear relationship implies that brownfield sites have a larger impact on the prices of properties that are closer than of those that are further away. More specifically, reducing the distance from 100 to 0 feet in the SEM specification results devaluates a property by 4.60%, while reducing the distance from 1,000 to 900 feet devalues a property by 0.76%.

Table 7. Estimated reduction in property values (SEM model).

Change in distance to brownfield	Change in $\exp^{(-distbr/500)}$	Decrease in property value
1,000 to 0	0.1353 to 1.00	21.93%
500 to 0	0.3679 to 1.00	16.03%
1,000 to 500	0.1353 to 0.3679	5.90%
500 to 100	0.3679 to 0.8187	11.43%
100 to 0	0.8187 to 1.00	4.60%

5. Conclusion

It is well understood that location is an important factor for home buyers as well as home owners and, as such, location becomes an essential component in determining property values. In this paper we showed that brownfield sites have a significant influence on the price of houses when they are located within close proximity to them. More specifically, using the results from the Spatial Autoregressive (SAR) or the Spatial Error Model (SEM) specification, we estimated that brownfield sites in the City of Cincinnati, Ohio, devalue housing prices by as much as 19.96% to 21.93%, respectively, for those properties that are adjacent to brownfield sites. For the average priced house of $94,595 in our sample that means a devaluation of $18,881 to $20,745.

Our research adds to the hedonic pricing literature on brownfield sites in that we account for the existing spatial dependence between residential property prices by comparing the classical Ordinary Least Squares (OLS) results with the results of two spatial model specifications, i.e., the SAR and SEM. The phenomenon of spatial dependence can be easily explained by the fact that realtors as well as home buyers/owners price properties based on recent sales of similar properties in close proximity. Though the question of spatial dependence is sometimes ignored in the hedonic pricing literature, it must be emphasized that it leads to biased and inconsistent OLS parameter estimates. In our research, only the two spatial model specifications achieved unbiased and consistent parameter estimates. Further, using goodness-of-fit diagnostic criteria, i.e., the log-likelihood value, the Akaike info criterion, and the Schwartz criterion, we conclude that the SEM specification provides the best fit to our data set and as such is the preferred model specification.

Lastly, we found that the use of an exponential form of distance measure from each property to the closest brownfield site significantly improves the model results when compared to the more widely used linear distance measures. We see room for additional research related to questions of i) how far the negative influence of brownfield sites on property values expands, ii) how to measure distances (i.e., functional form of distance measures) from brownfield sites to residential properties, and iii) whether the observed spatial dependence is a local or global phenomenon.

In addition, the results provide a base for further calculations of the total combined decrease in all property values within 1,000 feet of brownfield sites inside our study area. Though not included in our study, the combined devaluation of all property values in our study region could be a first indication for policy makers of the potential monetary gains of cleanup and/or redevelopment of existing brownfield sites.

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