Spatially Delineated Public Goods and Spatially Located Public Bads: A Hedonic Approach to Measuring Urban Revitalization

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A regression discontinuity approach is used to measure the impact of public-goods creating programs in a declining inner city neighborhood of Worcester Massachusetts. Using GIS data, we develop a hedonic model of residential sales, using a parcel-level GIS tax assessment and land use database linked to property sales data for the years 1988 through 2007, to test the effect of the creation of a new high-performing public school, as well as other locational amenities and disamenities on neighborhood housing prices, by comparing properties adjacent to either side of the school catchment area boundary.

Key Words: regression discontinuity, spatial hedonic model, urban revitalization

As with many inner city colleges and universities in the United States, the deterioration of its central city neighborhood over the past several decades has posed a challenge for Clark University. Located in Worcester, Massachusetts, the University was founded in 1887 as a graduate research university and today is a liberal arts research university with nine Ph.D. programs and a population of about 2,600 undergraduate and graduate students. The University is located in the inner city Main South neighborhood about one mile southwest of Worcester's central business district (CBD) (see Figure 1). Worcester is the second largest city in New England, with a population of approximately 175,000. It is located in central Massachusetts, about 50 miles west of Boston and 150 miles northeast of New York City. The city has always attracted immigrants, including large groups of Armenians, French-Canadians, and Vietnamese. Overall, 14.5 percent of current residents are foreign-born, compared with 12.2 percent for the state as a whole. Worcester has a larger minority population, at 36 percent, than the state average of 21.5 percent. Median household income in 2009 was $47,415, about three-quarters of the median household income in Massachusetts.

The development of the Clark neighborhood over the past half-century mirrors changes in inner city neighborhoods in a host of older industrial cities of the Midwest and Northeast: de-industrialization and the decline of CBD employment. Up until about 1960, the Main South neighborhood was a middle-class to upper-middle-class neighborhood. Machine-making companies and several foundries located to the south and southeast of the University provided employment for several thousand workers, many of whom were highly skilled. As Figure 1 suggests, the presence of these factories prompted construction of two- and three-family dwellings nearby. Ready access to employment in the downtown of Worcester meant that areas to the north and west of the Uni-

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The authors would like to thank Mahesh Ramachandran and Arnab Biswab for research assistance as well as two anonymous reviewers for very helpful comments. The authors are responsible for any remaining errors. In addition, research support for this project from the Lincoln Institute for Land Policy and the Dean of Research Office at Clark University is gratefully acknowledged.

This paper was presented at the workshop "The Economics of Land Use Change: Advancing the Frontiers," organized by Lori Lynch (Center for Agricultural and Natural Resource Policy, University of Maryland) and Jacqueline Geoghegan (Clark University), in Washington, D.C., June 25–26, 2009. The workshop received financial support from the U.S. Environmental Protection Agency, the Lincoln Institute of Land Policy, and the Center for Agricultural and Natural Resource Policy at the University of Maryland. The views expressed in this paper are the authors' and do not necessarily represent the policies or views of the sponsoring agencies.

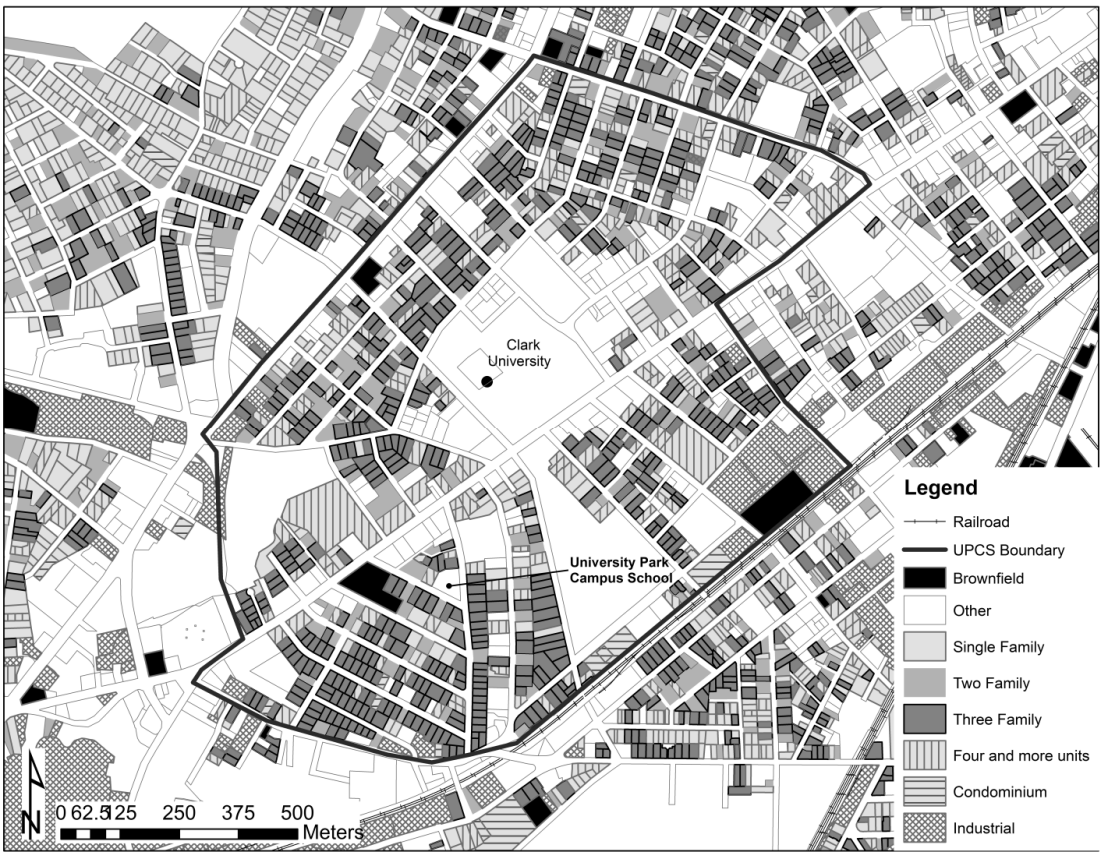

Figure 1. The Main South Neighborhood of Worcester, Massachusetts: Land Use and the Catchment for the University Park Campus School

Source: City of Worcester parcel map and Clark University

versity had more single-family homes mixed in, but the principal housing stock of the neighborhood is multi-family dwellings.

The changes after 1960 are familiar. Factories closed during the 1960s and 1970s, and the downtown experienced a steep decline. These events in the city's economy had strong impacts on the Main South neighborhood surrounding Clark. By 1980, most of the neighborhood industrial sites had been abandoned or converted to use by small shops. A familiar process of housing deterioration, tax delinquency, and outright abandonment set in. Illegal drug activity and prostitution were extensive in some parts of the neighborhood.

Census data for 1970 and 2000 confirm the extent of the transition. During the period, the average family income in the Main South neighborhood around Clark University fell from 83 percent of the city average to 44 percent.[1] Relative and absolute poverty increased so that, by 2000, one-third of residents were below the poverty line. Home ownership rates dropped from one-half to one-third of the city average. By 2000, the majority of the population belonged to ethnic minorities and about 55 percent of residents spoke a language other than English.

The strategy that Clark adopted in response to the challenges posed by neighborhood transition recognized the key linkages between neighborhood quality and institutional success. The University first established a partnership with local residents, businesses, and churches to stimulate and revitalize the area in the early 1980s. Along

[1] The two Census tracts are 7312.01 and 7313. Clark University occupies a third tract, 7312.02.

with neighborhood groups, the U.S. Department of Housing and Urban Development (HUD), and local foundations, Clark spearheaded the successful application for a $74,900 SEEDCO grant from the Ford Foundation. This effort helped buttress the recently formed Main South Community Development Corporation (MSCDC), on which Clark has a seat on the board of directors. Typical for similar collaborations, the MSCDC and Clark focused first on neighborhood organizing and halting the spread of property abandonment. Over the next decade, the MSCDC acquired over 20 vacant or abandoned properties and renovated them with an investment of about $9.5 million. More than half of these properties were subsequently sold.

In 1995, the University and the MSCDC created a broad-based strategy for sustainable development of the neighborhood which became known as the University Park Partnership (UPP). The UPP extended the scope of efforts from a primary focus on the physical condition of the neighborhood to initiatives that emphasize developing neighborhood amenities and expanding the economic opportunities for neighborhood residents. The MSCDC also offers programs for first-time homebuyers, provides incentives for ensuring that multi-family dwellings remain affordable, and offers loans for home improvements and down-payments. Clark also subsidizes down-payments for faculty and staff who choose to purchase homes in the neighborhood. About twenty employees have taken advantage of this program. Clark University has contributed almost $10 million directly to this effort, and it has helped leverage another $75 million in federal, state, local, and private loans and investment (Boston Federal Reserve Bank 2005). As a result of this partnership, over 220 housing units have been renovated and an additional 80 units have been created. All told, the total of $85 million in investment in the neighborhood amounts to about $7,500 per each neighborhood resident. The partnership also expanded its scope to provide specific neighborhood amenities: improved public safety and social and recreational programs for families. The UPP has addressed concerns about safety with the establishment of a neighborhood alert center and it promotes efforts to ensure closer cooperation among the Worcester and Clark police and neighbors. The partnership was awarded the inaugural Carter Partnership Award in 2004, which is the nation's most prestigious recognition for collaborations between universities and their communities.

Perhaps the most far-reaching element of the partnership was the establishment in 1997 of a new public school for students in grades 7 through 12, the University Park Campus School (UPCS). The UPCS has an enrollment of about 225 students, all of whom must live within the area as indicated in Figure 1. The UPCS district includes a good share of the residential areas of the Main South neighborhood. The backgrounds of the students reflect the socioeconomic conditions of the neighborhood. Seventy-four percent are classified as low-income students; about 60 percent do not use English as their primary language at home; and one-half of the students entering the seventh grade are reading at a third-grade level. Given these challenging socioeconomic conditions that the students in the school face, the approach of the school with an individually student focused curriculum and innovative programming was quite experimental. The first class graduated in 2003 and revealed for the first time to the Worcester community the full potential for success. Every student graduated and all but one went on to college. The school first received statewide attention in 2003 when it was recognized as the only urban high school to be "high performing" by the public policy think-tank MassInc. More recognition has followed, including the school's selection as one of five schools nationally to receive the Education Trust's Dispelling the Myth Award for excellence in the education of low income and minority youth (Reis 2003).

The high performance continues. Students score in the 90th percentile for all schools—both urban and suburban—participating in the Commonwealth's MCAS standardized tests. Almost all students attending the UPCS receive their high school diploma and most go on to college. The drop-out rate for students at comparable Worcester public high schools is one-third. Clark allows UPCS students use of the University library and athletic facilities, and Clark faculty and students volunteer time at the UPCS (Afshar 2005).

Any student who lives in the UPCS neighborhood (as delineated in Figure 1) is eligible to participate in a lottery for admission to the UPCS. Eligible students and parents are identified through school district records and are notified by mail. The UPCS principal or other representative also meets with students at the two largest neighbor-

hood elementary schools to inform them of the opportunity. Of the eligible students, about 85 percent decide to enter the lottery. Although precise data are not available, about 50 to 60 percent of this group actually receive admission to the school. Siblings of enrolled or graduated students are automatically eligible to enroll without the lottery (Del Prete 2010). Students and their parents may choose to not enter the lottery for a variety of reasons. The nearest public high school, Worcester South High School, is well-known for its strong athletic program. Worcester Technical High School may be preferred by students with strong vocational goals.

For most of the residents of the UPCS district,[2] those who graduate from high school may be eligible for an additional benefit. Clark is only one of a few universities in the nation to offer an unlimited number of free tuition scholarships for neighborhood residents. Any of the approximately 10,000 residents (3,500 households) who have lived at least five years in the neighborhood and who can also meet admissions standards are eligible for a full tuition scholarship. From its inception in 1995 to now, about 45 students from the neighborhood have received these scholarships.

Research Questions and Empirical Strategy

Since 1995, the UPP and the City of Worcester, through the UPCS, have invested several million dollars in initiatives that should benefit the residents of the target area. The thrust of the program is to offer concentrated educational and other benefits that are designed to enhance residential stability and to create strong incentives for educational performance. In the terms of urban economics, these efforts are designed to augment a range of *neighborhood* amenities and may be characterized as a neighborhood good: a good generally available to all residents of a few or several city blocks of a city.

The economic theory of the determination of land rents (and value) suggests that housing markets should place a value on these benefits. Provided that some mechanism such as travel costs or limits on eligibility restricts access to the enjoyment of neighborhood goods, competitive land (and housing) markets in urban areas should lead to their capitalization in the value of (residential) property.[3] Capitalization occurs because renters (or purchasers) of housing who are similar in wealth and preferences should also receive equal well-being, wherever they locate in the urban area.

In a reasonably efficient housing market, bidding among potential residents of any urban area for scarce housing creates site-specific premia for features of property that are not elastically supplied. The premia will ensure equalization of well-being for similar residents.[4] These premia provide lower-bound estimates of how much residents of the city value a site-specific amenity. The market discount for a disamenity provides an upper-bound estimate.[5] In the case of the University Park Partnership and the success of the University Park Campus School, we would expect that the amenities provided by the partnership's programs only to residents of the area should generate a market premium for housing sold in the area.

The unique spatial feature of the UPCS school district boundary lends itself to an application of a variant of the hedonic pricing approach.[6] Since access to the benefits of the UPP and admission to the UPCS are spatially restricted, the clear demarcation of a boundary running through otherwise similar sub-districts of the Main South neighborhood will help to test the hypothesis that the neighborhood amenities provided by the

[2] The boundary of the UPP-delineated neighborhood is not co-determined with the UPCS boundary. The UPP area eligible for scholarships to Clark does not include the southwest "triangle" neighborhood that the UPCS is located in (see Figure 1).

[3] Fujita (1989, ch. 6) provides both a precise definition and an overview of the capitalization phenomenon.

[4] This will not necessarily be true if wages also capture some of the localized amenity, but that seems improbable for workers in such a small sub-area of the Worcester labor market.

[5] If the bid of a household with a given level of utility u and consumption of all other goods X for an amenity of level A is $\varphi(u, X, A)$, then the rent $R(A)$ actually paid for the amenity will be equal to or less than φ, which in turn must have been greater than all other bids $\varphi' < \varphi$. Households receiving greater utility from A (given the same level of other consumption, X) will in turn offer a higher bid. In any event, their valuation could be significantly higher than the price actually paid. Note as well that among households of similar income and resources, those with stronger preferences for the education, safety, and recreational benefits of the UPP and UPCS would be likely to outbid the others. This is an implication of the capitalization hypothesis that will be explored in subsequent research.

[6] See Cheshire and Sheppard (1995) for an illustration of this approach, which successfully identifies separate influences on land rents using information on housing prices.

UPCS have been capitalized into housing values. The use of boundaries such as these has been successfully exploited in the burgeoning regression discontinuity literature, where the assignment of a treatment (here, access to the benefits of the UPCS) is determined by a fixed threshold. In this case, the threshold for the treatment is sharp. A geographic boundary ensures observations that cannot "accidently" avoid the treatment, as residential parcels are also fixed in geographic space (Imbens and Lemieux 2008). Therefore, this study employs what is known as a sharp regression discontinuity design. The focus is on observations near the boundary, or a "discontinuity sample" (Angrist and Lavy 1999). Varying the size of the sample by adjusting the distance from the boundary for observations to include in the sample offers a strong robustness test (Angrist and Pischke 2009). That is the approach that is implemented in this study.

In earlier work, Brown and Geoghegan (2009) focused exclusively on measuring different beneficial impacts of the UPP partnership, including the impact on homeownership rates, property turnover, and area-wide measures of housing price appreciation, in addition to testing hypotheses concerning the capitalization effect of the partnership. In this paper, we investigate the impact of the recent accomplishments of the UPCS school district using additional, newer observations on housing sales. While this earlier work did show a capitalization effect of the University Park Partnership, our intuition was that the demographically broader-based spatial amenity associated with the public school had the potential to be a more compelling selling point for a neighborhood populated by younger families and immigrants than simply the promise of potential free college tuition.

The hedonic pricing model offers a framework for testing hypotheses about the capitalization of particular features of housing or local amenities (or disamenities). Rosen (1974) provides the theoretical underpinnings of the hedonic model and the theory of implicit markets. In the context of housing and property markets, hedonic theory suggests that the market price of housing (P) is a function of z bundled structural, site-specific, and neighborhood characteristics [$P(z)$] and is equal to the bid of the purchasing household. The theory of implicit markets asserts that the household's bid is in turn a function of how much it values the characteristics, each of which is traded in an implicit market. Each buyer will equate the marginal cost of acquiring the characteristic on the market with his or her additional willingness to pay for it.

Hedonic statistical models are influenced by both the buyer and the seller sides of the market. Information from sales prices alone is sufficient to estimate a hedonic function of the form

$$P_i = h(s_i, g_i), \tag{1}$$

where P_i is the selling price of house i, s_i is a (k) vector of parcel and structural characteristics, and g_i is a (l) vector of spatial and location variables. Because housing is a bundled good, it is unlikely that the functional form of equation (1) would be linear on *a priori* grounds, but economic theory does not suggest the correct functional form for the empirical specification. However, previous research has demonstrated that flexible functional forms, such as the Box-Cox transformation, are superior for empirical specifications of hedonic pricing models (Cropper, Deck, and McConnell 1988). That is the approach we take here.

Aside from measurable housing characteristics, this study will focus on measurable differences in neighborhood disamenities and characteristics of the site of the property. The impact of local land use amenities and disamenities has been extensively studied by economists. For example, a review of the literature on the value of local open space, such as parks, on residential land values (McConnell and Walls 2005) covered more than 60 articles, with most empirical results suggesting that these local amenities are capitalized into nearby property values. A similar review focusing on the impact of negative environmental externalities, such as brownfields, on housing prices (Boyle and Kiel 2001) also found evidence of (negative) capitalization.

This study of the capitalization hypothesis for the UPCS neighborhood exploits one feature of the program noted above: the strict geographic limit placed on key educational benefits (possible enrollment in the UPCS and potential free tuition to Clark University). The "boundary effect" has been used previously in investigations of the impact of school quality on housing values (Black 1999, Gibbons and Machin 2003) to estimate unobservable features of neighborhoods common to

two districts that may be correlated with school performance on test scores in each district. The approach pairs all houses on either side of a boundary to estimate such a nuisance parameter. This approach has come under some criticism within the literature on the economics of education (e.g., Brasington and Haurin 2006). School attendance zones can change over time and the variation over a large region containing many school districts can mean that the borders between particular school districts are not as homogenous as the method assumes. Our approach exploits the boundary effect in a different way and takes account of local (dis)amenities that would not be captured in studies covering large metropolitan areas.

In contrast with the literature discussed above that attempts to test hypotheses concerning the capitalization effect of school quality on home prices over many school districts, this paper includes only properties in close proximity to the UPCS boundary on either side in the estimation. These properties most likely share local neighborhood characteristics. As Figure 1 indicates, the boundary of the UPCS does not clearly demarcate housing types or proximity to industrial sites. The neighborhoods to the south and east are generally poorer than those to the north and west. Figure 2 identifies the locations of the 1,150 houses sold during the period within the bounds of the largest buffer used in this study—150 meters. The buffer corresponds to about two city blocks. The narrowest buffer—50 meters—includes about one city block on either side of the boundary.

Because the school was established only in 1997, the UPCS capitalization hypothesis can be tested using a standard difference-in-difference approach within the context of the sharp regression discontinuity design. In general, the specification of the hedonic regression thus includes time-varying estimates of the capitalization of the amenities offered by the UPCS:

$$(2)\quad \frac{p^{\lambda}-1}{\lambda} = \alpha + \sum_{k=1}^{K}\beta_k \frac{s_k^{\mu}-1}{\mu} + \sum_{l=1}^{L}\tau_l \frac{g_l^{\mu}-1}{\mu} + \sum_{t=1}^{9}\gamma_t t + \sum_{t=1}^{10}\delta_t Z_{\text{UPCS}} + \varepsilon.$$

The variable Z_{UPCS} takes on the value of one for all properties sold that are located within the catchment of the school. The time-varying coefficients (δ_t) allow for the estimated discount or premium associated with the school catchment to vary over time. To conserve degrees of freedom, ten 2-year sub-periods, which begin in 1988/89 and end in 2006/07, were chosen. This flexible specification is superior to the traditional difference-in-difference specification, since it allows for changes in information about the payoffs to a family for locating in the catchment of the UPCS to influence the sales price of a home. Inclusion of period dummy variables (t) controls for the impact of the changes in the housing market over the period that would likely be separate from the impact of the school.[7] The flexible functional form of the Box-Cox specification allows for differing transformations of the dependent variable (the sales price) and the continuous property characteristics, such as the age of the house or the floor area. It should capture any nonlinearities present in the relationship between the housing price and its covariates.

Most important, this specification of the hedonic relationship offers a direct test of the capitalization hypothesis, which is a period-specific difference-in-difference test. The capitalization hypothesis suggests that, on average, a home located within the UPCS should appreciate in value. In terms of the regression framework in equation (2), a test of the hypothesis of appreciation is equivalent to a test that the average of the period coefficients ($\delta_t s$) from after establishment of the UPCS is greater than the average from prior to establishment of the partnership [see the inequality in equation (3)]:

$$(3)\quad \frac{1}{5}\sum_{t=6}^{10}\delta_t - \frac{1}{4}\sum_{t=1}^{4}\delta_t > \varphi\,.$$

The quantitative significance of the estimated appreciation can be found using a series of Wald tests that the difference on the left-hand side of equation (3) exceeds different candidate values of the scalar φ.[8] Note that the period 1996–1997 is left out of the test, since it includes some sales

[7] The specification in equation (2) implies that the base case for the regression is a house sold in 2006–2007 located outside of the catchment of the University Park School.

[8] Strictly speaking, the null hypothesis is that the difference is less than or equal to a given value of φ.

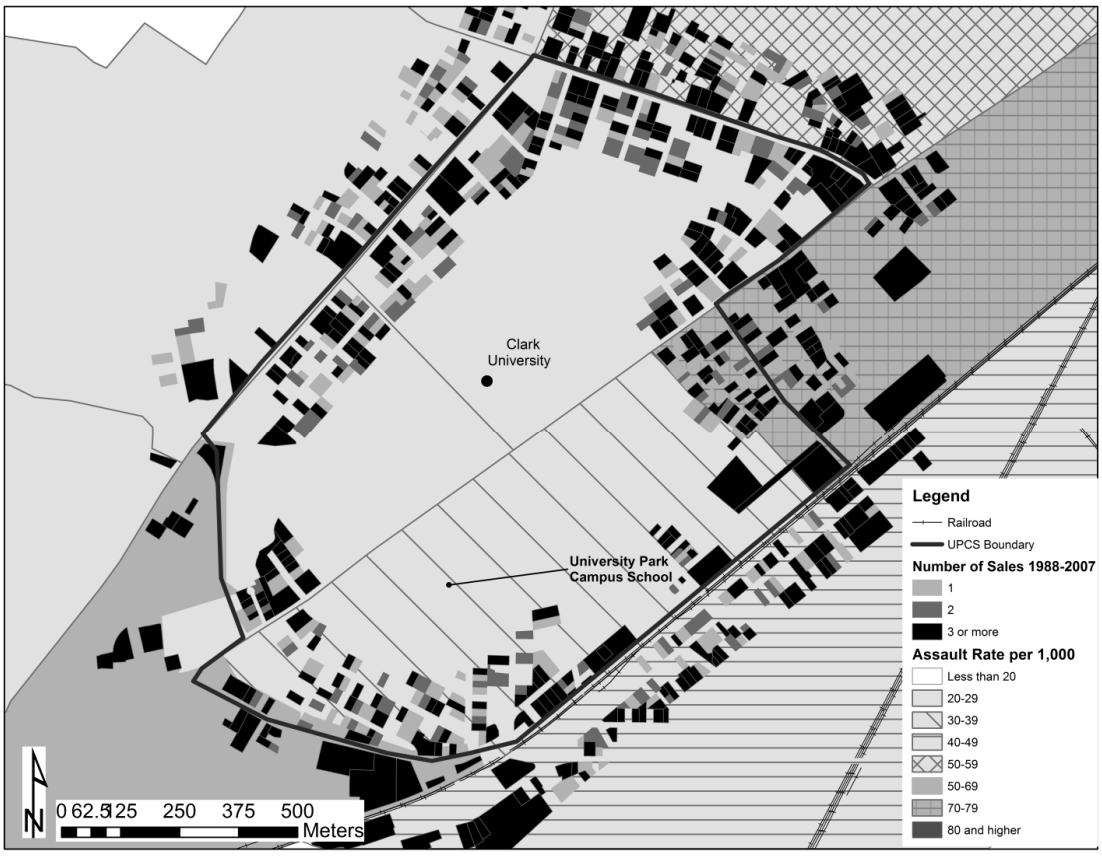

Figure 2. Crime and Sales of Houses within the 150-Meter Buffer around the University Park Campus School Catchment Boundary (1988–2007)

Source: The Warren Group for property sales data, the Worcester City Police Department for data on the assault rate, and the Population Census of 2000 for population data.

that took place after the establishment of the school.

Data Description

The parcel-level GIS data for this project were made available to us from a research project based at the Worcester Polytechnic Institute that linked parcel-level tax assessment data with other spatial data on roads, parks, and brownfields. Using information from Clark University, the City of Worcester, and the Main South Community Development Corporation, additional information was added to the database including an indicator variable for whether or not the parcel was located within the UPCS catchment. In addition, a GIS of the 57 Police Statistical Areas (PSAs) of the Worcester City Police allowed us to associate the local crime rate with each parcel.

Data for all housing sales that occurred in the city of Worcester over the period 1988 through 2007 were purchased from the Warren Group. These data include information on the location of the property, date of sale, style of the structure, lot size, and other housing characteristics. The data on sales of housing were merged with the GIS parcel data to create the foundational database used for the analysis, which focused on sales of one-, two-, and three-family houses.[9] Most of the structures sold in the neighborhood are the

[9] Condominiums were excluded because of the difficulty of placing them in the GIS and the dissimilarity in how they are priced compared to more conventional forms of housing. Buildings with four or more units were excluded.

traditional three-unit working class homes of many urban areas in New England, known as "triple deckers." Other housing styles included some single-family homes and multi-unit dwellings in various arrangements, including duplexes, side-by-side duplexes, and so forth. Dichotomous variables controlled for more than ten styles of housing.[10]

Linking the data on the sales price and attributes of houses with their geographic location within a GIS allowed us to create a unique assortment of measures of very local spatially explicit amenities and disamenities for use in the hedonic model. The location-specific variables reflect both the industrial legacy of the Main South neighborhood and current conditions arising from relatively high poverty rates. First, three distance variables were introduced for each property: distance from the central business district (CBD), distance from Clark University, and distance from the nearest railroad.[11] As with many urban areas in the United States, distance from the central business district can be viewed as an amenity, as the loss of jobs and businesses in the city center has given way to higher crime rates. Distance to Clark may be viewed as an amenity or disamenity; the further away a property is, the more costly the access to the cultural activities in the neighborhood. At the same time, the more distant parcels would less likely be located next to buildings occupied by students. Finally, the location of railroads is a key marker for the presence of older industrial buildings, most of which are now abandoned. Distance from railroads would thus constitute an amenity.

The GIS also permitted creation of variables that capture localized disamenities. One important variable indicates whether or not a property lies within 30 meters of a brownfield. Most of these brownfield sites are small parcels and consist of uses such as gas stations and car repair facilities, so the variable uses GIS to capture if the housing sales observation is directly adjacent to one of these brownfield locations. We expect that proximity to a brownfield site would lower the sales price of a property. As Figure 1 indicates, brownfields are scattered around the UPCS neighborhood and the adjacent areas.

Finally, data on violent crime are available for each of the 57 Police Statistical Areas for the City, but only for the period after 1999. This study uses the assault rates per 1,000 residents (murder, assault, and sexual assault) averaged over the years 2000–2007. Rates were calculated on the basis of the population estimates from the 2000 Census of Population. As Figure 2 indicates, the area around and including the UPCS catchment spans some of Worcester's safest neighborhoods (with an assault rate below 20 per 1,000) and some of its most dangerous neighborhoods (with an assault rate of about 75 per 1,000). As the PSA boundaries were drawn independently of the boundary of the UPCS district, the district itself includes part or all of five PSAs.

We also include information on the structural characteristics of the property that are found in the original data source. They include the interior floor area of the property in square feet, the year that the house was constructed, and whether or not the property was remodeled prior to sale. The dependent variable of the regression, the recorded sales price, was deflated using the monthly consumer price index for the Boston metropolitan area.[12] The base year chosen for prices is 2007. Summary statistics for each variable for the largest sample used in the analysis (the 150-meter buffer) can be found in Table 1.

Angrist and Pischke (2009) and Imbens and Lemieux (2008) note three important specification issues relevant for an application of the sharp regression discontinuity design. First, potential nonlinearities in the relationship between the variable that measures the boundary and the outcome variable may lead to spurious identification of a boundary effect. The inclusion of controls for local disamenities (brownfields, crime, distance to unused industrial sites and to the CBD) and the flexible functional form should address this concern. The second issue is whether unmeasured differences in property and site characteristics on either side of the boundary may lead to a spurious association between the presence of the UPCS and property values. The difference-in-difference de-

[10] The single family houses included Cape Cod, colonial, conventional, ranch, raised ranch, and semi-detached houses. Multi-family dwelling types included duplexes, family flats, triple-decker, multi-unit buildings, and stacked flats.

[11] We appreciate the comments of an anonymous referee, who pointed out the necessity of modeling the location of each house within the larger urban structure of the city.

[12] The data are available at http://www.bls.gov/cpi/.

Table 1. Summary Statistics for the 150-Meter Buffer Sample

Name and Description of Variable	Mean	Standard Deviation
Price of house (in $1,000 of 2007)	$162.60	99.00
Interior square feet (1,000)	2.92	1.03
Age of the dwelling (years)	98.68	22.07
Remodeled building (0,1)	0.11	0.31
Distance to the CBD (in miles)	1.44	0.33
Distance to Clark University (in miles)	0.40	0.27
Distance to the nearest railroad (in miles)	0.36	0.24
Average assaults per 1,000 residents	39.76	16.83
Brownfield within 30 meters (0,1)	0.07	0.25
Within UPCS × sold in 2006–2007	0.06	0.23
Within UPCS × sold in 2004–2005	0.08	0.27
Within UPCS × sold in 2002–2003	0.07	0.26
Within UPCS × sold in 2000–2001	0.08	0.27
Within UPCS × sold in 1998–1999	0.05	0.23
Within UPCS × sold in 1996–1997	0.06	0.24
Within UPCS × sold in 1994–1995	0.06	0.23
Within UPCS × sold in 1992–1993	0.04	0.20
Within UPCS × sold in 1990–1991	0.03	0.17
Within UPCS × sold in 1988–1989	0.05	0.21

Note: Additional controls were included for twelve different types of housing styles. The most important of these styles (with each respective housing type's share) included triple-deckers (0.49), multi-unit building (0.17), conventional (0.12), family flat (0.09), two- and one-half floors (0.07), and duplex and semi-detached (0.015 each). The remaining styles included colonial, ranch, stack, and two-family.

sign suggests that this would be a problem if the unmeasured characteristics changed in a way that was consistent with an appreciation of properties inside the boundary *after* the establishment of the school. The saturated regression specification, which includes dummy variables for all housing types and multiple location controls, should allay some of these concerns. In addition, the results of a preliminary assessment of the degree to which the boundary may also demarcate differences in measured characteristics and nearby amenities for the smallest of the samples is provided in Table 2. The table includes the means and standard deviations of the measured neighborhood and structural characteristics for each of these buffer samples by exposure to the treatment of access to the University Park Campus School ("Within UPCS Catchment" and "Outside of UPCS Catchment") for periods 1 through 4 (1988–1995) and 6 through 10 (1998–2007). The final column shows the relative change in the variables (the difference in difference) over the two periods. As expected, the real price of properties sold within the UPCS rose substantially. A comparison of the structural characteristics of the houses suggests no change in the floor area or extent to which they were remodeled. After the establishment of the school, the houses sold within the catchment were relatively older than those that sold in the same area before the establishment of the school. The locational information does not show a consistent pattern. Finally, the incidence of local disamenities (brownfields and high crime rates) was relatively *higher* for houses sold within the catchment after the school was established. The absence of a consistent pattern among the several measured characteristics reduces some of the concern about other unmeasured characteristics that may have changed in a way that correlates with the temporal and spatial changes implied by the test in equation (3).

Table 2. Evaluating the Sample for Discontinuities within 50 Meters of the UPCS Boundary: Means and Standard Deviations of Property Values and Characteristics

	Sold 1988–1995		Sold 1998–2007		
Variable	Within UPCS Catchment x_{i1}	Outside of UPCS Catchment x_{o1}	Within UPCS Catchment x_{i2}	Outside of UPCS Catchment x_{o2}	Difference in Difference $\Delta x_i - \Delta x_o$
Real price (in $1,000 of 2007)	96.7 (76)	135 (117)	222 (107)	180 (99)	+80.3
Interior square feet (1,000)	3.00 (1.14)	2.83 (1.11)	3.32 (0.84)	2.95 (0.86)	0
Age of the dwelling	87.6 (18)	98.7 (9.02)	102 (13.6)	96.4 (34.4)	+16.7
Remodeled building	0.11 (0.32)	0.17 (0.38)	0.10 (0.30)	0.16 (0.37)	0
Share triple-deckers	0.60 (0.49)	0.47 (0.51)	0.72 (0.45)	0.57 (0.50)	+0.02
Share other multi-family	0.17 (0.38)	0.19 (0.40)	0.13 (0.45)	0.16 (0.37)	-0.01
Distance to the CBD (in miles)	1.58 (0.35)	1.34 (0.34)	2.44 (0.55)	1.99 (0.43)	+0.21
Distance to Clark University (in miles)	0.45 (0.15)	0.39 (0.15)	0.69 (0.19)	0.65 (0.12)	-0.02
Distance to the nearest railroad (in miles)	0.29 (0.19)	0.44 (0.24)	0.25 (0.20)	0.36 (0.25)	+0.04
Average assaults per 1,000 residents	37.1 (18)	51.6 (12.4)	38.7 (17.8)	48.4 (13)	+4.80
Brownfield within 30 meters	0.02 (0.14)	0.31 (0.47)	0.07 (0.26)	0.13 (0.34)	+0.23
N	53	36	101	79	

Notes: Standard deviations are in parentheses. "Difference in difference" refers to the change in the value of the variable over two periods (prior to the creation of the UPCS and after the creation of the UPCS).

Source: Warren Group sales data and the GIS of the Main South neighborhood.

The final specification check for a sharp regression discontinuity design is to examine whether results across different bandwidths in the neighborhood of the discontinuous variable are consistent. It is an empirical question of how close the observations have to be to the boundary to ensure that the properties are similar in all structural and neighborhood characteristics except for the treatment. This study used GIS techniques to create subsamples of the sales of all one-, two-, and three-family houses within 50, 75, 100, and 150 meters on either side of the UPCS boundary line. The 50-meter buffer yields a sample size of about 290 observations, and the widest buffer—150 meters—yields a sample size of 1,150 observations. The larger buffers result in more precision in the estimates of parameters, but that may be at a cost of increasing the unmeasured heterogeneity of the surrounding neighborhood.

Results and Discussion

The outcomes of the hedonic regressions are presented in Table 3 for all one-, two-, and three-family houses sold during 1988–2007. The results are presented in one column for each of the four buffers around the UPCS boundary. The estimated parameters, including the transformation parame-

Table 3. Results of Hedonic Estimation of Sales Prices of Properties Near the Boundary of the UPCS for Four Sizes of Buffers: One-, Two-, and Three-Familyi Houses (1988–2007)

Variable	50-Meter Buffer	Predicted Impact on Price (in $1,000)†	75-Meter Buffer	100-Meter Buffer	150-Meter Buffer
Estimated λ	0.536 (10.43)		0.545 (13.08)	0.642 (22.07)	0.641 (22.12)
Estimated μ	NA		0.670 (2.30)	-0.018 (0.05)	-0.364 (-1.55)
Interior square feet (1,000)	1.14 (1.16)	12.21	2.60 (2.48)	6.05 (3.83)	2.29 (3.38)
Age of the dwelling	0.04 (0.64)	9.57	0.20 (0.89)	1.07 (1.18)	0.01 (0.61)
Remodeled building	2.17 (1.33)	23.50	1.74 (1.46)	2.21 (2.70)	1.88 (1.57)
Distance to the CBD (in miles)	-1.71 (-0.60)	-6.32	0.69 (0.23)	3.54 (1.51)	2.51 (1.47)
Distance to Clark University (in miles)	10.84 (1.80)	17.61	2.54 (1.15)	0.51 (0.42)	1.81 (0.71)
Distance to the nearest railroad (in miles)	7.35 (1.94)	18.15	2.78 (1.77)	1.53 (2.87)	7.95 (4.16)
Average assaults per 1,000 residents	-0.06 (-1.52)	-10.79	-0.22 (-2.47)	-1.79 (-1.45)	-0.06 (-2.21)
Brownfield within 30 meters	-2.77 (-1.34)	-30.00	-1.11 (-0.74)	-1.41 (-1.04)	-5.07 (-2.88)
Within UPCS × sold in 2006–2007	3.84 (1.31)	41.59	1.94 (1.04)	1.15 (0.46)	1.98 (0.99)
Within UPCS × sold in 2004–2005	3.15 (1.39)	34.11	1.72 (0.83)	1.45 (0.84)	4.70 (2.10)
Within UPCS × sold in 2002–2003	4.41 (1.39)	47.76	1.34 (0.56)	2.25 (1.31)	1.49 (0.75)
Within UPCS × sold in 2000–2001	-0.11 (-0.06)	-1.19	-1.32 (-0.71)	-2.72 (-1.42)	-1.41 (-0.94)
Within UPCS × sold in 1998–1999	2.40 (1.40)	25.99	1.46 (1.00)	1.83 (1.17)	1.49 (0.92)
Within UPCS × sold in 1996–1997	-0.48 (-0.23)	-5.20	0.02 (0.02)	-0.08 (-0.05)	-0.06 (-0.04)
Within UPCS × sold in 1994–1995	-4.91 (-1.98)	-53.18	-2.87 (-1.25)	-3.63 (-2.06)	-2.05 (-1.32)
Within UPCS × sold in 1992–1993	-8.95 (-1.39)	-96.93	-7.14 (-2.17)	-6.63 (-2.09)	-8.81 (-2.72)
Within UPCS × sold in 1990–1991	1.92 (0.71)	20.79	-0.43 (-0.14)	3.13 (1.03)	0.34 (0.10)
Within UPCS × sold in 1988–1999	-6.27 (-1.63)	-67.90	-2.95 (-0.95)	1.18 (0.27)	1.41 (0.39)

cont'd.

Table 3 (cont'd.)

Variable	50-Meter Buffer	Predicted Impact on Price (in $1,000)†	75-Meter Buffer	100-Meter Buffer	150-Meter Buffer
Sold in 2004–2005	1.97 (0.70)	21.34	1.10 (0.49)	1.86 (0.76)	0.76 (0.36)
Sold in 2002–2003	-3.14 (-0.79)	-34.01	-3.33 (-1.36)	-5.20 (-1.94)	-5.45 (-2.91)
Sold in 2000–2001	-11.61 (-4.58)	-125.74	-10.18 (-5.42)	-12.33 (-4.97)	-16.96 (-9.77)
Sold in 1998–1999	-15.89 (-5.64)	-172.09	-15.45 (-8.58)	-19.51 (-9.63)	-25.10 (-12.53)
Sold in 1996–1997	-15.63 (-5.37)	-169.27	-16.77 (-9.28)	-20.44 (-9.90)	-26.17 (-11.89)
Sold in 1994–1995	-15.02 (-5.31)	-162.67	-15.34 (-6.30)	-19.54 (-7.41)	-26.43 (-13.33)
Sold in 1992–1993	-9.36 (-1.47)	-101.37	-10.30 (-3.33)	-14.29 (-4.23)	-17.73 (-6.95)
Sold in 1990–1991	-10.52 (-3.57)	-113.93	-10.06 (-4.76)	-16.81 (-5.63)	-17.54 (-8.25)
Sold in 1988–1989	-1.65 (-0.70)	-17.87	-0.60 (-0.25)	-5.45 (-1.20)	-6.85 (-2.16)
Constant	24.38 (2.58)		29.44 (3.39)	35.04 (4.68)	37.19 (7.52)
Adjusted R^2	0.58		0.56	0.56	0.57
N	289		487	684	1150

† Calculated for a one-standard deviation increase in the variable. Dichotomous variables were increased by one. The price used for calculations is $170,000.

Notes: The dependent variable is the value of the real price transformed according to the Box-Cox formula:

$$\frac{(price^{\lambda} - 1)}{\lambda}.$$

Additional dummy variables controlled for the diverse range of styles in the sample, which included only those properties zoned as one-, two-, or three-family homes. The single-family houses included Cape Cod, colonial, conventional, raised ranch, and semi-detached houses. Multi-family dwelling types included duplexes, family flats, three-decker, multi-unit buildings, and stacked flats. *z*-statistics are in parentheses.

Source: Results of bootstrap regression estimation for four buffers along the boundary of the University Park Campus School catchment.

ters λ and μ, and the associated *z*-statistics, are reported in the first two rows of Table 3. For most of the Box-Cox specifications, the results suggest that a transformation of both the dependent variable and the continuous independent variables was required. Likelihood-ratio tests led to the rejection of the hypothesis that the μ parameter on the continuous independent variables was equal to one except for the 50-meter buffer. Likelihood-ratio tests likewise rejected a logarithmic transformation of the sales price, which is commonly used in the hedonic literature. The estimated transformation was instead about equal to 0.5. The remainder of Table 3 reports the estimated coefficients from bootstrap regressions, which were conditional on the estimated λ and μ. As expected, the parameter estimates have smaller estimated standard errors as the buffer width and

sample sizes increase. At the same time, the explanatory power of the specification remains about the same regardless of the width of the buffer. The strongest influences on housing prices were the period of sale, the distance to the nearest railroad, the violent crime rate, and the square footage of the building.

The results of the Box-Cox transformation can obscure the quantitative impact of the independent variables. To give an illustration of the impact, we calculate the impact of a one standard deviation increase in the independent variable on the predicted market price for houses or the smallest (50-meter) buffer, which can be found in the third column of Table 3.[13] For example, for this buffer, a remodeled house sold for an estimated $23,000 premium; high crime reduced the sales price by $10,000; a house within 30 meters of a brownfield site sold at a discount of $30,000. Finally, the coefficients for the impact of the University Park Campus School on property prices (δ_t) show a consistent pattern. The steep discounts that were often observed from the late 1980s through the mid-1990s gave way to premia after 2001. For the narrowest buffer, the predicted impact of a location inside the school district boundary changed from a substantial (and often significant) discount prior to 1998 to a premium of $35,000 to $47,000 by the end of the sample period. It may not be coincidental that the success of the first graduating class of the school (in 2003) and the attention it garnered had an impact on the public's perception of the amenity associated with the school.

The regression results suggest substantial appreciation of housing values within the University Park School district, even after accounting for structural and locational characteristics. Table 4 reports the results of the formal test of the capitalization hypothesis found in equation (3). The Wald test statistic for a significant difference in the premium or discount associated with a property located just inside the border of the district is distributed χ^2 with one degree of freedom. As it is a one-sided test, the results are reported for a range of potential values for the amount of the appreciation (φ) between the first (1988–1995) and second (1998–2007) periods.[14] The results are striking and are strongest for the 50- and 75-meter buffers, which involve houses that sold that were at most located two blocks from each other. For the two narrowest buffers, the test rejects an appreciation smaller than $10,000 at a 5 percent level of significance and smaller than $15,000 at a 10 percent level of significance. For the 150-meter buffer, the test rejects the hypothesis of no appreciation ($\varphi \leq 0$) at a 5 percent level of significance and an appreciation smaller than $10,000 or less at a 10 percent level of significance. The results for the 100-meter buffer are not as strong, but they do reject a *depreciation* of $10,000 at a 10 percent level of significance.

Overall, the evidence from this application of a sharp regression discontinuity model to test for a spatial amenity reveals significant changes in housing prices in response to the introduction of a neighborhood amenity, a high-quality school. By 2006–2007, housing prices averaged about $230,000 outside of the UPCS. The premium for being within the UPCS could represent an increase in value compared to this price on the order of 4 or 5 percent. The stability of the premium since 2003 is even more remarkable given the overall downturn in housing prices that began in the spring of 2006.

Conclusions

The hedonic pricing model results emphasize the value that participants in the housing market place on parcel-level, spatially explicit local amenities and disamenities associated with the Main South neighborhood. By focusing on the sales prices of houses in close proximity to the boundary of the UPCS school district, we can more directly compare properties in similar neighborhoods that differ only by the treatment effect of being within the school district. This approach exploits to great advantage the power of micro-level, spatially explicit data on market transactions. The results show that once other locational and structural attributes are controlled for, the benefits of access to the UPCS have been capitalized into higher property values.

[13] The estimate for dichotomous variables is for a value of one rather than a standard deviation. The estimated impacts are for a house valued at $170,000. Similar calculations could be done for the other buffers, but they are qualitatively similar.

[14] The results of the Box-Cox estimation mean that multiplying φ by $10,000 yields an estimated appreciation of about $10,000$\varphi$.

Table 4. Difference-in-Difference Tests for the Impact of the University Park Campus School on the Sales Price of Housing

	Predicted Average Change after Establishment of the UPCS							
Buffer Size (in meters)	φ=-1	φ=0	φ=0.25	φ=0.5	φ=0.75	φ=1	φ=1.5	φ=2
50	17.29***	13.37***	12.47***	11.60***	10.76***	9.95***	8.43***	7.04***
75	9.92***	6.58***	5.85**	5.16**	4.52**	3.92**	2.84*	1.94
100	3.42*	1.65	1.31	1.01	0.74	0.52	0.19	0.02
150	8.55***	5.43**	4.76**	4.13**	3.55*	3.02*	2.07	1.31

Notes: *** is significant at the 1 percent level, ** is significant at the 5 percent, and * is significant at the 10 percent level. The value in each cell is the χ^2 test statistic distributed with one degree of freedom. It is the result of the Wald test that

$$\frac{1}{5}\sum_{t=6}^{10}\delta_t - \frac{1}{4}\sum_{t=1}^{4}\delta_t > \varphi ,$$

where φ is the net change in the discount or premium associated with a location within the catchment of the University Park Campus School. The amount of the premium implied by φ is about $10,000φ.

Source: Results of bootstrap estimation of the housing price hedonic function.

While the use of GIS and spatial analysis has greatly increased in use in areas of environmental and natural resource economics, especially within studies of land use and land use change (see Geoghegan and Gray 2005a, 2005b), much of this focus has been on the development of spatial variables to control for features of the landscape and spatial econometric techniques to control for issues such as spatial autocorrelation in the residuals that can arise when using spatial data. In this application, we demonstrate another powerful aspect of spatial data and spatial analysis: where the specific spatial characteristic of a particular policy is used to test hypotheses concerning the effects of the policy. There are likely many other applications of this methodology throughout environmental and natural resource economics that could use this spatial difference-in-difference approach, such as analysis of conservation reserve districts, the location of locally undesirable land uses, and air and water quality regulations.

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