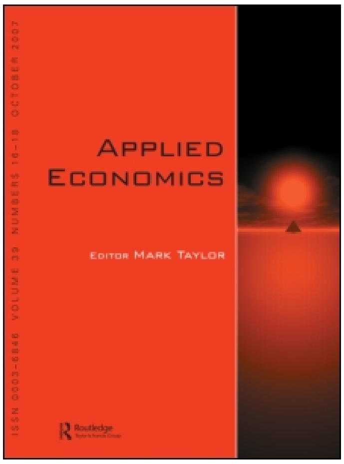

Applied Economics
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713684000

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First published on: 09 June 2010

To cite this Article Agee, Mark D. and Crocker, Thomas D.(2010) 'Directional heterogeneity of environmental disamenities: the impact of crematory operations on adjacent residential values', Applied Economics, 42: 14, 1735 — 1745, First published on: 09 June 2010 (iFirst)

To link to this Article: DOI: 10.1080/00036840701721679

URL: http://dx.doi.org/10.1080/00036840701721679

Applied Economics, 2010, **42**, 1735–1745

Directional heterogeneity of environmental disamenities: the impact of crematory operations on adjacent residential values

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A hedonic study of residential house sales in Rawlins, Wyoming, was conducted to estimate the impact of an environmental shock from a new point source upon adjacent residential property values. We use a unique data base of house sale prices and associated house attributes, including structural and neighbourhood characteristics and geographic distances and directions from the source of the shock, atmospheric emissions from a new crematory. Our data spans 27 months of house sales: 7 months before, and 20 months after the startup of crematory operations. Results indicate that proximity, measured both in terms of direction and distance from the crematory, imparts a statistically significant negative impact on average house sale prices – an increase of 0.3 to 3.6% of average sale price for every one-tenth mile increase up to one-half mile in distance away from the crematory, but depending on direction from the crematory. This distance benefit increases somewhat with calendar time only for houses located west of the crematory.

I. Introduction

Residential property values depend both on physical and locational attributes. Attributes include structural, neighbourhood and environmental characteristics, all of which may impact the selling price of a property. Indeed, housing markets are one of the few places where environmental amenities are traded in formal markets along with physical amenities. As such, for decades, economists have used hedonic property value techniques to measure monetary equivalents of a variety of environmental quality changes that affect consumers' welfare via their purchase and consumption of the good 'housing.' Recent examples include air quality (Kiel and McClain, 1995; McMillen and Thorsnes, 2003), aesthetic views (Bourassa *et al*., 2004) and proximity to other amenities or disamenities such as proximity to natural areas (Thorsnes, 2002) or landfills (Ketkar, 1992).

Hedonic property value studies are useful if they provide empirical evidence that selling prices of a heterogeneous market good reflect alternative levels of amenities (good or bad). Given the sometimes

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Applied Economics ISSN 0003–6846 print/ISSN 1466–4283 online © 2010 Taylor & Francis
http://www.informaworld.com
DOI: 10.1080/00036840701721679

elusive nature of environment-related benefits and costs, such information is particularly useful as it provides evidence that people are willing to pay more for higher levels of environmental quality.

When proximity to an environmental externality affects value, both direction and distance may matter. For example, many point sources of pollution produce either noticeable odours or airborne pollutants so that prevailing winds (or lack of air movement) create directional heterogeneity in distance effects. We demonstrate that if directional effects are present but ignored, one might observe no proximity impact on house value even though impacts are indeed present but are not the same in all directions. To date, published hedonic property value studies that employ distance measures pay little attention to direction. While some of these studies account for spatial trends (e.g. Gillen *et al*., 2001), such as spatial autocorrelation in model error terms, these studies do not specifically address distance profiles as a function of direction. Herriges *et al*. (2005) and Cameron (2006) are the only studies we are aware of which empirically examine direction and distance impacts of an environmental disamenity using a hedonic property value model. But these last two studies disregard the potential impact of spatial autocorrelation and heteroskedasticity upon their reported results. Here we account for direction and distance impacts and test for and make appropriate corrections for spatial autocorrelation and spatial heteroskedasticity.

The following section explains our approach to assessing the impacts on residential property values of proximity to the shock of exposures to atmospheric emissions from a crematory of whose start-up operations adjacent property owners had never been informed.[1] Section III describes our data and model specification, and our results and value estimates are reported in Section IV. Section V concludes.

II. Hedonic Model and Pre-Testing

This section outlines a basic hedonic model to assess the marginal impact on house sale prices of proximity to a point source, environmental disamenity shock, holding constant all other attributes important to these values. The literature has identified several empirical issues that must be addressed in order to optimize both statistical efficiency and precision of estimates using hedonic techniques. The most common and addressable issues include choice of functional form, bias due to omission of relevant explanatory variables and definition of the extent of the market to be examined (sampling).

Following Rosen (1974), this study uses a first-stage hedonic model, in which the hedonic price function is estimated using a sample of prices and characteristics of observed 'transacted' properties,

$$\mathrm{SALEPRICE}_i = \alpha + \sum_j \beta_j D_{ij} + \sum_k \beta_k H_{ik} + e_i \quad (1)$$

where $\mathrm{SALEPRICE}_i$ denotes nominal selling price of house i $(i = 1, \ldots, N)$, which is a function of two sets of observed variables, D and H. The j variables in D describe the house in terms of its date of sale, and distance and direction from the environmental disamenity. The k variables in H describe the house in terms of its general structure (living area, number of bathrooms, etc) and its accessibility to public facilities. α is a constant term. Expression (1) defines the hedonic price function as a locus of equilibrium points. If the property attributes observed are independent of any not observed, Bajari and Benkard (2005) show this implies the existence of a hedonic price function even if the housing market is imperfectly competitive and lacks a continuum of types.

While choice of functional form for (1) is somewhat arbitrary for the researcher, we choose a double-log specification based upon a number of preliminary regressions (not reported) and statistical testing of goodness-of-fit. The specifications reported in Table 2 emerge as clearly best in terms of statistical fit. These results are consistent with Cropper *et al*. (1988) who show that the double-log form usually performs best relative to linear, semi-log inverse semi-log, and other quadratic forms for first-stage hedonic models, both in terms of model flexibility and ability to measure marginal prices in the presence of misspecifications. Also, functional forms that are too general may not prove robust to small misspecifications (Cassel and Mendelsohn, 1985).

The hedonic technique is especially useful for determining values of general reductions in 'receptor effects,' i.e. a single disamenity 'bundle' comprising several effects such as noise, foul odours, or bothersome visual effects. When these general receptor effects dominate, identification and valuation of specific environmental impacts, which include exposures to specific contaminants, can be problematic unless detailed information is available

[1] Thus the housing market could not anticipate the likely effects of crematory operations.

on all individual effects in the disamenity bundle (see e.g. Palmquist *et al*., 1997). Since individual effects within the bundle are plausibly correlated, omission of any one or a subset of effects from the hedonic regression will bias the predicted impacts of remaining disamenities accounted for in the regression. However, if assessment of general effects is the focus, windfall losses to receptors will equal to the total decline in predicted property values (Polinsky and Shavell, 1976; Palmquist, 1991). These losses are often expressed in terms of proximity to the disamenity source. Losses due to proximity to an environmental disamenity are larger if the proximity-related decline in property value also includes a slowing of appreciation rates (Mitchell and Carson, 1986). Our goal is to assess the decline in predicted residential property values associated with proximity to a newly installed crematory, of whose planned installation and start-up adjacent property owners were unaware. Proximity (distance and direction) is assumed to capture general receptor effects associated with living near the environmental shock from the atmospheric emissions of the new crematory operation. To assess the proximity-related change in predicted values fully, we also assess the value impact of emitter effects on house price appreciation rates.

While assessment of general proximity effects greatly simplifies model specification and data requirements, other potential estimation problems linger. For instance, if an environmental disamenity affects a large area, and/or there are multiple sources of changed emissions, hedonic price functions can shift, implying that the total predicted change in aggregate property values serves only as an upper bound for the true change in value (Bartik, 1988). That is, marginal changes in property values as measured by the slope of a hedonic price function need not equal that aggregate change in value which is determined by general equilibrium adjustments involving induced relocations and changes in population and housing supply. We limit our analysis to marginal changes since the externality we consider is localized relative to the size of the housing market.

Sample selection bias represents another potential estimation issue because, say, more expensive homes might more likely be offered for sale when confronted by a disamenity shock. We believe this issue to be insignificant for this study since residences in the neighbourhood subjected to the shock are very nearly all middling in their attributes and residents. Also, Jud and Seaks (1994) conclude that ignoring the sample selection issue leads to an average error of only 1% in housing price change estimates.

More importantly, since unobserved or omitted variables in hedonic regressions are often locationally correlated, 'spatial autocorrelation' is frequent in hedonic regressions. Though spatial autocorrelation does not bias ordinary least squares coefficient estimates and thus benefit measures (Leggett and Bockstael, 2000; Kim *et al*., 2003; Neill *et al*., 2007), estimates can be inefficient, which leads to biased SEs and inaccurate hypothesis tests.[2] We conducted a series of Kelejian and Robinson (1992) tests to check for any significant presence of spatial autocorrelation in the data of our case study. These tests failed to confirm spatial autocorrelation in all our Table 2 model specifications. However, White (1980) tests failed to reject spatial heteroskedasticity in these specifications. Therefore, the results presented in Table 2 discussed below, use White's (1980) heteroskedasticity consistent covariance matrix to address potentially biased SEs in our ordinary-least-squares (OLS) estimates.

Finally, heterogeneity in distance effects with respect to direction from an environmental disamenity can potentially obscure what might otherwise be a clear price–distance relationship. With directional diffusion of airborne pollutants, one would naturally expect prevailing winds to exacerbate effects for some neighbourhoods while virtually eliminating effects from others, even where distance to the upwind area from the pollution source is considerably less. Also, direction-specific geographic features such as hills and forests can enhance or counter the impact of prevailing winds. If distance and direction are correlated, omission of direction from the hedonic model will result in omitted variable bias of the coefficient estimate for distance. Their direction of drift plausibly affects the impact of mobile pollutants on property values. Surprisingly, almost all published hedonic property value studies that employ distance-to-source as their proximity measure do not include information on orientation of a property to the pollution source. Palmquist *et al*. (1997), Gillen *et al*. (2001), Herriges *et al*. (2005) and Cameron (2006), are the sole exceptions we have been able to identify. But the first two, while acknowledging 'importance' of direction, do not formally consider its effects in

[2] Even if spatial correlation were present, an assumption that any spillovers among neighbouring sites are strictly pecuniary would permit the coefficient on the pollution variable in an OLS hedonic price regression to be interpreted as the complete marginal effect of pollution on house value (Small and Steimetz, 2006). Strictly pecuniary effects imply that the value of neighbouring sites affects the sale price of a particular site but does not affect the amenities of that site.

their empirical framework. This leaves only the latter two studies that explicitly account for distance with directional heterogeneity by combining distance and direction (in the form of upwind and downwind siting for Herriges *et al.*, and of polar coordinates for Cameron) into the hedonic property value model. Our data lack sufficient detail on direction to implement the Cameron (2006) framework. However, we know the location of each sample property within one of eight possible 45° regions (N, NE, E, SE, etc). This enables us to establish a reasonable estimate of the combined influence of distance and direction effects by introducing dummy variables for direction to account for directional interactions in our hedonic OLS regressions.

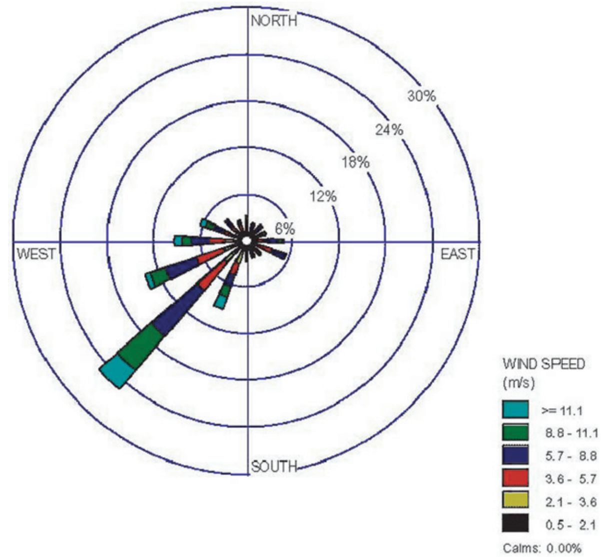

Fig. 1. Rawlins, Wyoming wind rose

III. Data

Our data consists of all 372 single family home transactions in the city of Rawlins, Wyoming, between January 2004 and March 2006. These sales are dispersed throughout the Rawlins city limits. Rawlins, population 8538 in 2000, and 8633 in 2004, is located in Carbon County in South Central Wyoming. Only one settlement with more than 1000 people lies within 100 miles, and that one settlement is nearly 40 miles distant. Rawlins covers approximately 7 square miles and has a population (housing) density of 1153 (521) per square mile. Thus the community's small population and its geographical isolation make treating it as a unified housing market a reasonable assumption. After deletion of 29 properties with missing attribute data, our total sample consists of 343 transactions.

Figure 1 presents a wind rose compiled for the geographical center of Rawlins (NEPA, 2006). The length of each 'spoke' around the circle is the annual frequency the wind blows from a particular direction. These spokes are further broken down into discrete frequency categories indicating the percentage of time the wind blows within a certain speed range from the indicated direction. Each concentric circle represents a different annual frequency, emanating from zero at the center to the highest annual frequency at the outer circle.

Figure 1 shows the Rawlins wind blowing primarily from the southwest; the longest spoke indicates that 25% of all hourly winds emanate from the direct southwest, and roughly 12% of the time from the west and west/southwest. The highest recorded wind velocities are also from the southwest (greater than 11.1 m/s). The upper right-hand quadrant of the rose indicates that wind rarely blows from the northeast or south/southeast, however, roughly 12 % of all hourly winds do blow from the east and east/southeast, albeit at low velocities (0.5 to 2.1 m/s).

The subject crematory is surrounded by residential developments to its north, west and southwest, with commercial development to its southeast. The landscape around the crematory and adjacent residential area has some notable attributes. In particular, a ridge (approximately 200–300 feet in elevation) embraces the residential area to the southwest, west and north of the crematory, forming a continuous, inverted 'J' around this area. The diameter of this area is approximately 0.9 miles. No residential development is located directly west, northwest and north of the J-shaped ridge, nor directly northeast of the crematory.[3]

In March 2004, the Rawlins City Planner issued a building permit to the subject mortuary to install a 40 ton, two-chamber, natural gas-fired Millennium II crematory in a vehicle storage garage adjacent to the mortuary building. Controversy remains as to whether this Planner was authorized to issue a permit for this expanded, nonconforming use of an

[3] This may seem to contradict our data, which indicates (in Table 1) a good deal of housing sales activity in the region northeast of the crematory. However, these homes are located further (about 1 mile on average) northeast of the crematory; open fields, a cemetery and school athletic fields occupy much of the nonresidential area directly northeast of the crematory.

Table 1. Variables, definitions and descriptive Statistics ($N = 343$)

Variable	Definition	Mean	SD
T	Number of months after 31 December 2003 the house was sold.	14.6122	7.0846
AGE	Age of house in years as of 2006.	51.1166	26.3047
SQFT	Square footage of house that is aboveground.	1293.8430	553.4636
SQFTBSMT	Square footage of basement if house has a basement.	666.6531	480.0317
BEDROOMS	Number of bedrooms.	3.2507	1.0123
BATHS	Number of bathrooms.	1.8674	0.6165
FINBSMT	House has a finished basement; 1 = yes; 0 = no.	0.2945	0.4565
TOWNHOUSE	1 if townhouse; 0 otherwise.	0.0583	0.2347
ATTACH2	House has attached 2-car garage; 1 = yes; 0 = no.	0.2653	0.4421
ATTACH3	House has attached 3-car garage; 1 = yes; 0 = no.	0.0058	0.0763
ATTACH4	House has attached 4-car garage; 1 = yes; 0 = no.	0.0058	0.0763
DETACH2	House has detached 2-car garage; 1 = yes; 0 = no.	0.2157	0.4119
DETACH3	House has detached 2-car garage; 1 = yes; 0 = no.	0.0146	0.120
DETACH4	House has detached 2-car garage; 1 = yes; 0 = no.	0.0087	0.0932
DISTANCE	Distance (in tenths of 1 mile) house is located away from crematory.	10.4924	7.8914
DOWNTOWN_MINUTES	Travel distance (in minutes by car) house is located away from the Rawlins downtown area.	2.417	1.763
SALEPRICE	Sale price of house in thousands of nominal dollars.	99.2185	49.8136
North	House is north of the crematory; 1 = yes; 0 = no.	0.0321	0.1764
South	House is south of the crematory; 1 = yes; 0 = no.	0.0262	0.1601
East	House is east of the crematory; 1 = yes; 0 = no.	0.035	0.184
West	House is west of the crematory; 1 = yes; 0 = no.	0.0496	0.2174
Northeast	House is northeast of the crematory; 1 = yes; 0 = no.	0.4227	0.2174
Northwest	House is northwest of the crematory; 1 = yes; 0 = no.	0.1662	0.3728
Southeast	House is southeast of the crematory; 1 = yes; 0 = no.	0.1808	0.3854
Southwest	House is southwest of the crematory; 1 = yes; 0 = no.	0.0875	0.2829

existing funeral home facility in an area zoned for residences since the 1970s. None of the residents in adjacent neighbourhoods were ever notified of plans for the crematory. Cremation operations began in August 2004. Soon after, citizens began complaining to City and State authorities about the crematory with its glaring, all-night illumination, noise and – most notable – noxious odor, which permeated residents' houses, making them feel ill and 'devaluing' (Morton, 2005) their properties. Starting in October 2004, and continuing through the time interval of our data set, the local daily newspaper updated the community on the status of the issue and printed numerous letters from citizens giving their views. In January 2005, the Wyoming Department of Environmental Quality ordered an emissions test and determined that the crematory had emissions comparable to its state permit request with several notable exceptions: annual ambient cadmium and dioxin/furan concentrations at the crematory property boundary exceeded National (and Wyoming) Air Quality Standards, by approximately 205 and 2200%, respectively (URS, 2006). Hydrogen chloride concentrations at this boundary exceeded the one-hour US Environmental Protection Agency's 'remediation goal' by 797%, with sulfur oxide, nitrogen oxide, chromium, and mercury concentrations being from 43 to 74% of the Agency's National Standard or remediation goal. Cadmium, chromium, dioxin/furans, hydrogen chloride and mercury are toxins for which any positive concentration may have human health impacts (Wexler, 2005).

No other new or substantially changed sources of (dis)amenities appeared in Rawlins residential neighbourhoods during our data time interval. Our data includes information on a variety of housing and neighbourhood characteristics typically used in the hedonic property valuation literature to explain variation in single family house selling prices. These data also contain variables describing direction from and distance to the crematory. Our data is deficient in its lack of information on lot size. This omission may detract somewhat from the explained sum of squares of our regressions; however, since our data contains detailed information on the number of attached and detached garages, following Boxall *et al*. (2005), we assume lot size to be captured at least in part by the presence (as well as extent) of transportation-related or other (e.g. maintenance- or recreation-related) vehicle storage structures beyond the livable area of the

Table 2. Parameter estimates with ln(SALEPRICE) as the dependent variable

	Specification			
	1		2	
Variable	Coefficient	t-Value	Coefficient	t-Value
CONSTANT	0.71441*	1.811	0.67640*	1.698
T	0.01874**	3.999	0.01975**	4.368
Ln(AGE)	−0.16206**	− 7.958	− 0.15841**	− 7.916
Ln(SQFT)	0.46158**	8.337	0.46870**	8.534
Ln(SQFTBSMT)	0.04026**	5.802	0.03971**	5.925
Ln(BEDROOMS)	0.35161**	4.950	0.33811**	4.912
Ln(BATHS)	0.09943	1.482	0.10991*	1.665
Ln(DOWNTOWN MINUTES)	0.11815**	2.278	0.03896	0.666
FINBSMT	0.06881*	1.929	0.06107*	1.759
TOWNHOUSE	−0.21317**	−3.526	−0.18906**	−3.068
ATTACH2	0.26031**	6.394	0.25692**	6.643
ATTACH3	0.31041*	1.658	0.33981**	2.326
ATTACH4	0.24196*	1.734	0.21615**	2.149
DETACH2	0.13376**	2.750	0.14521**	3.124
DETACH3	0.43269**	5.336	0.41962**	4.594
DETACH4	0.35251*	1.654	0.44466**	1.986
ln(DISTANCE)	0.06320**	2.060	0.08960**	2.820
$[\ln(\text{DISTANCE})]^2$	−0.01873**	−2.458	−0.01803**	−1.970
ln(DISTANCE) × T	−0.00375*	−1.883	−0.00897**	−3.126
ln(DISTANCE) × North × T			0.00818**	3.327
ln(DISTANCE) × South × T			0.00403	0.810
ln(DISTANCE) × East × T			−0.00345	−0.697
ln(DISTANCE) × West × T			0.01480**	3.651
ln(DISTANCE) × Northeast × T			0.00582**	2.941
ln(DISTANCE) × Northwest × T			0.00289	1.158
ln (DISTANCE) × Southwest × T			0.00771**	3.402
χ^2 (White's homoscedasticity test)	91.13	104.96		
Adjusted R^2	0.7143	0.7326		
F-statistic	48.51	38.48		
Number of observations	343	343		

Notes: * Significant at less than 10%; ** Significant at less than 5%.

house – as indicated by number of attached and/or detached garage spaces.[4]

As for other plausible but unobserved influences upon residential sale prices, we assume them to be independent of the influences we do observe, thus implying the existence of a hedonic price function (Bajari and Benkard, 2005). Distance to schools is a prominent observed influence in numerous hedonic price studies. We lack house-by-house data on it. In the Rawlins case, however, nearly all residences are within walking distance of an elementary school.[5] Variable definitions and descriptive statistics are presented in Table 1.

Variables used to measure D_{ij} include distance in tenths of a mile from the crematory (DISTANCE), and directional dummy variables indicating which of the 45° regions (from the crematory as point of origin), N, S, E, W, NE, SE, SW, NW, contains the sample house. To account for revisions in people's expectations about the Rawlins residential property market, a time trend variable, T, measures the number of months after 31 December, 2003 each

[4] Our data indicates a higher correlation between multiple vehicle storage structures and distance away from the downtown area, implying larger lot sizes are most prevalent among residences located at the outer edge of the Rawlins city limits, well beyond the areas plausibly affected by crematory emissions.

[5] Adding covariates to a hedonic price function to avoid omitted variable bias has a cost. If the added covariate is imperfectly measured in the sense that it does not correspond exactly to that feature which the market actually values, measurement error will increase. As more covariates are added, the measurement error bias will increase, thus increasing the noise-to-signal ratio. Atkinson and Crocker (1987) and Graves *et al.* (1988) use the Bayesian diagnostics of Leamer (1978) to demonstrate that measurement error bias appears to be a more serious problem in hedonic price studies than does omitted variable bias.

house was sold. Thus our sample includes properties sold as much as 7 months before and up to 20 months after the environmental shock to the crematory's residential neighbours from its August 2004 start-up. The average T for our sample is 14.61 months; our sample contains a few houses that have sold more than once over our 27-month sampling period. Variables used to measure H_{ik} include house age in years (AGE), square feet of living space both above-ground (SQFT) and below ground (SQFTBSMT), number of bedrooms (BEDROOMS) and bathrooms (BATHS), whether the house has a finished basement (FINBSMT), whether the house is a townhouse (TOWNHOUSE), travel time (by car) in number of minutes from house to downtown Rawlins (DOWNTOWN_MINUTES), and categorical covariates indicating whether or not the house has each of several numbers of attached or detached garage spaces (ATTACHED, DETACHED). ATTACHED_1 and DETACHED_1 are the excluded Table 2 categories, implying that the valuation impacts of the coefficients for the included categories are relative to the valuation impacts of these exclusions.

IV. Results

Table 2 reports OLS estimates of two specifications of the hedonic property value equation. Examination of the covariates in Table 2 indicates that, for both specifications, nearly all estimated coefficients have the correct signs, are statistically significant, and have very similar and plausible magnitudes across specifications when transformed to dollar values. For example, an additional square foot of living space (above ground) is worth roughly \$36 in the average house. An additional bedroom is worth slightly over \$10 300, while a finished basement contributes about \$6250 to the price of an average home.[6] These estimates are very close to the values found in other studies (see e.g. Palmquist *et al.*, 1997; Boxall *et al.*, 2005). Reported at the bottom of the Table 2 are White's (1980) chi-square test statistics of the null hypothesis of homoskedasticity, which clearly reject the null hypothesis at less than the 1% level. Asymptotic SEs used to calculate all Table 2 t-statistics are from White's (1980) heteroskedasticity-consistent covariance matrix. Finally, the reasonably high adjusted R-squared and F-values reported at the bottom of Table 2 indicate that the regressions, as specified, both have adequate fit, and explain a substantial portion of the total variation in observed home sale prices.

Turning to distance effects, specification 1 gives model parameter estimates accounting for time of sale and for distance from the crematory, but with no direction-specific terms. The predicted distance benefit as derived from specification 1 is:

$$\frac{\partial \ln(\text{SALEPRICE})}{\partial \ln(\text{DISTANCE})} = \underset{(2.060)}{0.0632} - \underset{(-1.883)}{0.00375}T - \underset{(-2.458)}{0.0375}\ln(DISTANCE) \quad (2)$$

Accounting for direction-specific heterogeneity, the predicted distance benefit derived from specification 2 is:

$$\frac{\partial \ln(\text{SALEPRICE})}{\partial \ln(\text{DISTANCE})} = \underset{(2.820)}{0.0896} + [\beta_j(\text{direction}_j) - \underset{(-3.126)}{0.00897}]T - \underset{(-1.970)}{0.036}\ln(\text{DISTANCE}) \quad (3)$$

The first term in expression (3) accounts for any nondirection-specific and time-invariant distance benefit. The bracketed terms in (3) account for direction- and nondirection-specific distance benefits, both time varying (in expression (2) all direction-specific benefit terms are assumed zero). The final right-hand-side term in (3) accounts for the distance benefit which is also distance-specific but nondirection-specific and time invariant. A series of F-tests confirms Table 2 specifications 1 and 2 as the clear best-fit benefit hedonic specifications for the Rawlins data. We summarize these tests as follows. First, we introduced and tested for the statistical significance of distance-specific distance coefficients which were time varying and/or direction-specific [we likewise tested in specification 1 for the significance of a time varying, distance-specific coefficient for expression (2)]. All these coefficients were individually and jointly nonsignificant. Second, we introduced and tested for the significance of direction-specific coefficients which were nondistance-specific and time invariant (i.e. direction-specific differences applying to the first term in expression (3)). These coefficients were likewise individually and jointly nonsignificant. Finally, though not applicable to the distance benefit expressions in (2) and (3), we also tested for any direction-specific differences associated with

[6] Interpretation of dummy variable coefficients in Table 2 requires a slight correction. For example, the correct marginal impact on SALEPRICE of the coefficient for FINBSMT is $\exp(\beta_{FB}) - 1$, where β_{FB} is the coefficient estimate for FINBSMT reported in Table 2 (Halvorsen and Palmquist, 1981).

the time coefficient, T; these tests (for specifications 1 and 2) confirmed a single coefficient estimate for T common to all Rawlins regions as most appropriate.[7]

Table 2 specifications 1 and 2 clearly demonstrate that failure to account for directional heterogeneity in Rawlins leads to omission of some important and possibly misleading benefit assessment information. The direction-specific terms in specification 2 are highly significant jointly as well as nearly all individually significant. Table 3 sheds some light on the benefit assessment implications of omission of directional heterogeneity for the Rawlins crematory example. Columns 2–4 of Table 3 provide a breakdown of mean values of DISTANCE, T, and SALEPRICE for all ($N = 343$) Rawlins homes sold between 31 December 2003 and 28 March 2006, along with various subsample means of Rawlins homes sold within a specified proximity (distance and direction) to the crematory. As one works down the columns of Table 3, DISTANCE to the crematory declines from a maximum radius of 0.5 to 0.1 miles. Column 5 gives the mean benefit for successive one-tenth mile DISTANCE increases away from the crematory conditional upon direction from the crematory; and column 6 expresses this mean benefit as a percentage of mean SALEPRICE for the particular subsample of homes in question. For example, the subsample of 43 homes located north of and within a distance of 0.2 to 0.3 miles from the crematory would gain an average of \$5006.59 if they were to lie within 0.3 to 0.4 miles. The first row of the topmost block in Table 3 provides the mean nondirection-specific DISTANCE benefit for the entire Rawlins sample; the next three rows show the mean distance benefit for all Rawlins homes located North, West and Southwest of the crematory. Each block below this first block presents similar calculations for sample homes within a given distance from the crematory. Benefit expression (2) is used to calculate all nondirection-specific (All Directions) estimates; expression (3) is used to calculate the direction-specific estimates appearing in the last three rows of each block. Absent an accounting of directional heterogeneity in the sample, the average Rawlins home SALEPRICE benefit associated with a 1-tenth mile DISTANCE increase away from the crematory for the period of 31 December 2003 to 28 March 2006, is −\$754.08. With directional heterogeneity accounted for in the sample ($N = 343$), Rawlins homes located North, West and Southwest of the crematory reveal a mean DISTANCE benefit of \$534.51, \$3 659.76 and \$243.58. Column 6 shows these estimates amount to roughly 0.5, 3.6 and 0.3% of average SALEPRICE for homes in these directions.

As one moves down Table 3, estimates based on benefit expression (2) clearly demonstrate that a ‘classical concentric circles’ approach to DISTANCE in a hedonic assessment of the Rawlins data–accounting for distance to but not direction from the environmental disamenity–severely understates the assessed benefit associated with home location further away from the disamenity. At the bottom of Table 3, benefit expression (2) finally reveals a positive mean DISTANCE benefit associated for homes lying within a one-tenth mile radius of the crematory. This benefit amounts to \$3657.88, or 4.89% of mean SALEPRICE as calculated from the seven sample homes sold in this area. However, expression (2) says that homes located anywhere up to 0.4 miles outside this radius suffer from not being closer to the crematory and its emissions.

Table 3 estimates based on benefit expression (3) reveal a much larger positive and increasing hedonic benefit function with distance for homes North, West, or Southwest of the crematory. Columns 4 and 5 in the table show that homes North and West of the crematory exhibit the highest benefit, ranging from 2% of mean SALEPRICE for homes within the 0.4 to 0.5 mile DISTANCE radius to over 30% of mean SALEPRICE (roughly \$19 400 to \$27 700) for homes within a 0.1 mile radius. The DISTANCE benefit increases slightly with time (approximately 0.0058% per month) for homes located West of the crematory, but does not appear to increase with time for homes located North or Southwest of the crematory. Homes Southwest of the crematory exhibit more modest benefit increases of 0.5 to 4.7% of mean SALEPRICE (roughly \$490 to \$4400) as DISTANCE declines from maxima of 0.5 to 0.1 miles. These estimates would be consistent with the Rawlins wind rose data given in Fig. 1 (e.g. prevailing winds sometimes blow from the east), if the ‘J-shaped’ ridge causes Southwesterly winds to swirl in North and then in West or Southwesterly directions, or if the ridge

[7] Our Table 2 coefficient estimates of 0.018–0.019 for T are not an estimate of the average monthly appreciation rate for Rawlins houses over the time span of our data. This estimate captures an ‘embodied’ figure, reflecting both Rawlins-specific appreciation and the discount rate; the two cannot be separated (Kiel and McClain, 1995b).

Table 3. Direction- and nondirection-specific benefit estimates for Rawlins, WY

Region	Mean DISTANCE (in tenths of 1 mile) from the crematory	MeanT (number of months after 31.December 2003 house was sold)	Mean nominal SALEPRICE	Mean benefit for one-tenth mile DISTANCE increase away from the crematory	Mean benefit as percent of mean nominal SALEPRICE
Full sample estimates ($N=343$)					
Estimates using benefit expression (2)					
All directions	10.4924	14.6122	99,218	−754.08	−0.76
Estimates using benefit expression (3)					
North	4.5462	15.4615	$104 831	$534.51	0.51
West	3.8667	16.8667	101 627	3 659.76	3,6
Southwest	4.6933	15.9333	83 420	243.58	0.29
Subsample homes located within 0.4 to 0.5 miles of crematory ($N=94$)					
Estimates using benefit expression (2)					
All directions	3.1043	16.2766	93 770	−1 217.83	−1.3
Estimates using benefit expression (3)					
North	2.3444	15.4444	$95 422	$1 914.41	2.0
West	2.1538[a]	18.4615[a]	104 262[a]	8 210.55[a]	7.87[a]
Southwest	3.7526	17.3158	91 758	489.06	0.53
Subsample homes located within 0.3 to 0.4 miles of crematory ($N=72$)					
Estimates using benefit expression (2)					
All directions	2.65	16.431	92 384	−1 218.85	−1.32
Estimates using benefit expression (3)					
North	2.125	14.75	93,600	$2 251.10	2.4
West	2.1538	18.4615	104 262	8 210.55	7.87
Southwest	2.8111	18.2222	108 111	1 124.89	1.04
Subsample homes located within 0.2 to 0.3 miles of crematory ($N=43$)					
Estimates using benefit expression (2)					
All directions	2.0302	16.6512	92 241	−1 172.07	−1.27
Estimates using benefit expression (3)					
North	1.120	13.0	74 260	$5 006.59	6.74
West	1.9364	19.1818	102 491	9 402.24	9.17
Southwest	2.220	18.40	110 200	1 862.57	1.69
Subsample homes located within 0.1 to 0.2 miles of crematory ($N=18$)					
Estimates using benefit expression (2)					
All directions	1.2333	16.6111	93 797	−528.96	−0.56
Estimates using benefit expression (3)					
North	0.675	15.250	57 200	$7 796.74	13.63
West	1.30	19.40	108 180	16 081.95	14.87
Southwest	1.40	9.0	93 000	4 388.07	4.72
Subsample homes located within 0.1 miles of crematory ($N=7$)					
Estimates using benefit expression (2)					
All directions	0.5714	15.0	74 814	3 657.88	4.89
Estimates using benefit expression (3)					
North	0.3333	13.0	54 367	$19 434.39	35.75
West	0.7	24.0	80 000	27 698.32	34.62
Southwest[b]	–	–	–	–	–

Notes: [a]No West-region homes with 0.5 miles > DISTANCE > 0.4 miles.
[b]No Southwest-region homes with DISTANCE < 0.1 miles.

inhibits air movements so as to increase odour for homes located West and Southwest of the crematory. The fact of the matter is that nearly all of the complaints about crematory emissions issue from these three directions.

V. Conclusions

The lack of studies involving direction as well as distance to a pollution source is startling, particularly in light of the widespread application of the hedonic technique to assessing damages associated with airborne and other mobile pollutants. This article takes advantage of a unique data set to evaluate the impact of a direction-sensitive environmental shock on residential property values in a small, isolated Wyoming community. The regressions included structure, neighbourhood and location variables. Results reveal that control for directional heterogeneity increases the estimated impact of distance from the source of the shock upon residential property values; this impact appears strongest for sample houses North, West and Southwest of the source. Failure to control for directional heterogeneity results in the implausible conclusion that distance undifferentiated by direction from the point emission source has a positive impact on selling price for houses located very close (within 0.1 miles) to the disamenity source, while houses located two to five times farther away experienced reduced sale prices.

Acknowledgement

Helpful comments and suggestions by an anonymous referee are gratefully acknowledged.

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