The Effect of a Large Hog Barn Operation on Residential Sales Prices in Marshall County, KY

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Abstract In this paper, we examine the economic impact of a tightly clustered complex of hog barns, a type of concentrated animal feeding operation (CAFO) on residential property in a rural area near Benton, Kentucky. The operation creates noxious and offensive odors associated with swine-raising and waste disposal activities. Theory and practice indicate that buyers would avoid purchasing a property believed to be contaminated or subject to effects of unsustainable environmental disamenities. Using hedonic regression analysis, the results show price reductions of 23%–32% for residential properties sold within 1.25 miles of the facility, and much larger losses northeast (downwind) of the facility.

In this case study, we examine the economic impact of a hog barn, a type of concentrated animal feeding operation (CAFO) on residential property. The CAFO for this case study includes a tightly clustered complex of hog barns, with capacity for several thousand hogs, which was built and opened in a rural area near the town of Benton, Kentucky in 2007. After about a full year of operations that allows the waste pit to fill, the operation created noxious and offensive odors associated with swine-raising and waste disposal activities. Theory and practice indicates that, all else being equal, buyers would avoid purchasing a property subject to effects of an environmental disamenity because of unpleasant odors, possible health risks, reduced use, difficulty in reselling the property, uncertainty, and nuisance associated with these environmental issues. Therefore, properties suffering from proximity to a hog farm can be expected to sell less frequently and at a discounted price compared with properties not so situated. The amount of the discount can be equated to the sustainability adjustment to allow the properties to transact in the marketplace.

To determine potential reductions in sales prices, we reviewed the academic literature regarding the impact of CAFOs on property values; conducted a field trip to the project location and held interviews with affected parties living nearby; reviewed odor logs maintained by residents in the case area at various dates from 2007 through 2011, and also reviewed the environmental report of an expert in odor modeling. Next, we built a data set of approximately 270 residential sales and performed a hedonic regression analysis of sales in Marshall County, Kentucky from 2002 through 2012.[1]

Our main findings indicate statistically significant reduction of 23%–32% in residential sales prices due to the presence of the hog barn and its operations within a 1.25-mile radius from the hog barn complex. Higher losses are observed northeast of the facility, consistent with wind direction and a comprehensive compilation of the order logs.

Literature

Both economic theory and empirical evidence from peer-reviewed literature indicate that real property would be negatively affected by environmental disamenities, including the repeated presence of noxious or nuisance odors from nearby commercial activities such as CAFOs, where the existence of such a history of nuisance odors would need to be disclosed to potential buyers. In a rural area, the local knowledge of potential buyers is also expected to be relatively high, because of the lack of outside interest in living in this relatively isolated area. Identification and quantification of the negative impact of noxious odors can readily be determined through one or a combination of well-established, scientifically accepted real estate analytical techniques including hedonic regression, real estate sales trends analysis, contingent valuation analysis, and sale-resale analysis, although the preponderance of the literature cited below relies on regression analysis.

Hog farms are a type of CAFO. The other main types of CAFOs include cattle and chicken farms. Smaller operations handle several hundred or a few thousand animals at a time, and larger ones can grow to 10,000 animals or more. Sometimes the facilities have a cluster of animal barns. Activities at a CAFO typically include growing, but not slaughtering or butchering the animals. The work is relatively unpleasant, and much of the animal care is automated or handled by immigrant workers. CAFOs are typically located in relatively isolated areas because of potential negative amenities, including some noise, but especially odors. The bulk of the odors usually emanate from concentrated pits of animal by-products, such as urine, feed, body fluids, feces, medicine, and dead animal parts. These pits are rarely emptied, and a typical pit may be an acre in size and 20 feet deep: a large one could be three acres and 30 feet deep (Price, 2010). The liquids contained in a hog barn pit can lead to a strong odor, including chemicals such as ammonia and hydrogen sulfide. Because industrial-sized fans are often used to dissipate the odors locally, direction of fans and wind direction can be a large factor in where the odors go, and the impacts they have on nearby property.

In a seminal quantitative study of the impact of CAFOs on proximate property values, Palmquist, Roka, and Vukina (1997) used hedonic regression to analyze 237 arms-length transactions of rural, non-farm residences in nine North Carolina counties from January 1992 through July 1993. Their analysis, which evaluated impact based on the density of swine herds (equivalent to hog farms as we use it in this article) within concentric rings at one-half mile, one mile, and two-miles from each house, found a statistically significant reduction in house prices of up to 9% for each new hog operation opened, with the greatest losses occurring in areas of previously low hog farming density.

In an article outlining the scope of potential value diminution for properties located in the vicinity of CAFOs, Kilpatrick (2001) summarized a University of Missouri study that found losses to range from 6.6% for vacant land within three miles of the CAFO to 88% for a home within 0.1 mile of the facility. He also reported the results of single-property consulting studies, which found diminution of 50% for a fruit-and-vegetable family farm located one-quarter mile from a CAFO, 50% for a horse-breeding farm/residence 1,000 feet from a pork processing facility, and 60% for a residence 700 feet from another pork processing facility. In a recent conference paper, the authors also reported newer empirical studies consistently showing property losses, including some of the papers cited below (Kilpatrick, 2013).

Isakson and Ecker (2008) used hedonic regression to analyze 5,822 single-family homes that sold between January 2000 and November 2004 in Black Hawk County, Iowa, an area which included 39 swine (hog) CAFOs. The study incorporated a measure of the effects of prevailing winds, concentric circle analysis around the CAFOs, and spatial correlation factors. Within 2 miles of a CAFO, the authors found losses of 44% for houses directly downwind and 17% for houses at an average oblique wind angle, with wind angle the most powerful explanatory variable in their model.

Using hedonic regression, Herriges, Secchi, and Babcock (2005) evaluate 1,145 rural, owner-occupied home sales (arms-length transactions) from 1992 to 2002 in five Iowa counties with an aggregate of 349 livestock facilities (98% of which were swine facilities). The authors found statistically significant property value reductions of about 15% at one-quarter mile and 9% at one-half mile downwind of a CAFO.

Ready and Abdalla (2005) examined the impact of agricultural land use as both an amenity and disamenity. The hypothesis was that open space has a positive impact on residential property values, while local disamenities, including landfills, high-traffic roads, airport, and large-scale animal production and mushroom production, have a negative impact. The study area was Berks County, Pennsylvania. The findings indicated that animal production facilities have a significant negative impact on the property values of 6.4% within 500 meters and 4.1% within 800 meters. Large facilities (greater than 300 AEU[2] but less than 600 AEU) have less impact on residential property values than medium-sized facilities.

As summarized in Exhibit 1, these studies indicate that it is typical to find residential property value diminution of 10% to 45%, depending on location with respect to prevailing wind direction, within two miles of swine CAFOs. Losses can amount to 50% and more for individual properties located in close proximity to CAFOs. The adverse property value impacts are greatest where swine CAFOs are introduced into areas that did not previously contain high-density hog farming operations.

Exhibit 1 | Brief Summary of Literature

Author(s)	Year	Method	Findings
Palmquist, Roka, and Vukina	1997	Hedonic	9% loss
Kilpatrick	2001	Case Study	50–83% within 0.1 mile: 7% 3 miles away
Isakson and Ecker	2008	Hedonic	44% for houses downwind and 17% for those at an average
Herriges, Secchi, and Babcock	2005	Hedonic	9% at one-half mile downwind
Ready and Abdalla	2005	Hedonic	6.4% within 500 meters and 4.1% within 800 meters
Kim and Goldsmith	2009	Spatial Lag Model	10% loss

Study Area and Sales Data

The hog barns analyzed in this study are located in a rural area of Marshall County, Kentucky, and nearby Benton, Kentucky. The main complex includes a pair of large hog barns. The area's topography is dominated by level land and slightly rolling hills and a generally warm climate, with mild winters and hot humid summers. The case area (expected to represent the area most affected) where the affected residential properties are located is within a 1.25-mile radius of the main hog barn complex. All areas outside this radius are considered control (likely unaffected) property. However, since, the empirical evidence citied above suggests that the zone of affected property may be larger: in other words, part of the control area (outside the affected zone) may also suffer from diminished property values, we also tested an area between 1.25 and 2 miles from the hog farm complex. The case area and nearby control areas were all in Marshall County within about seven miles of the hog farm complex. They contain similar types and a similar range of housing stock, and were subject to similar local economic conditions, with the exception of their proximity to the subject hog barns, throughout the study period. Exhibit 2 identifies the general locale.

Study Area Particulars

In 2006, a hog farm complex capable of handling 5,000 hogs was proposed in the predominantly rural study area near Benton, Kentucky. The facility was opened in mid-2007, and within about a year the urine/catchment pool under the facility became full. Several large fans pointing generally west-northwest move odors and heat away from the facility. According to generally available data in the popular press, hog barns are associated with noxious chemicals including ammonia and hydrogen sulfide; when inhaled, these chemicals can lead to bronchitis, asthma, nosebleeds, brain damage, and seizures (Price, 2010). An expert report that documented environmental conditions (Winegar, 2013) confirmed the presence of these chemicals in proportions large enough to be noticed, and the wind direction, and attributed them to the hog farm. These nuisance odors are consistent with

Exhibit 2 | Study Area: Big Picture and Impacted Area

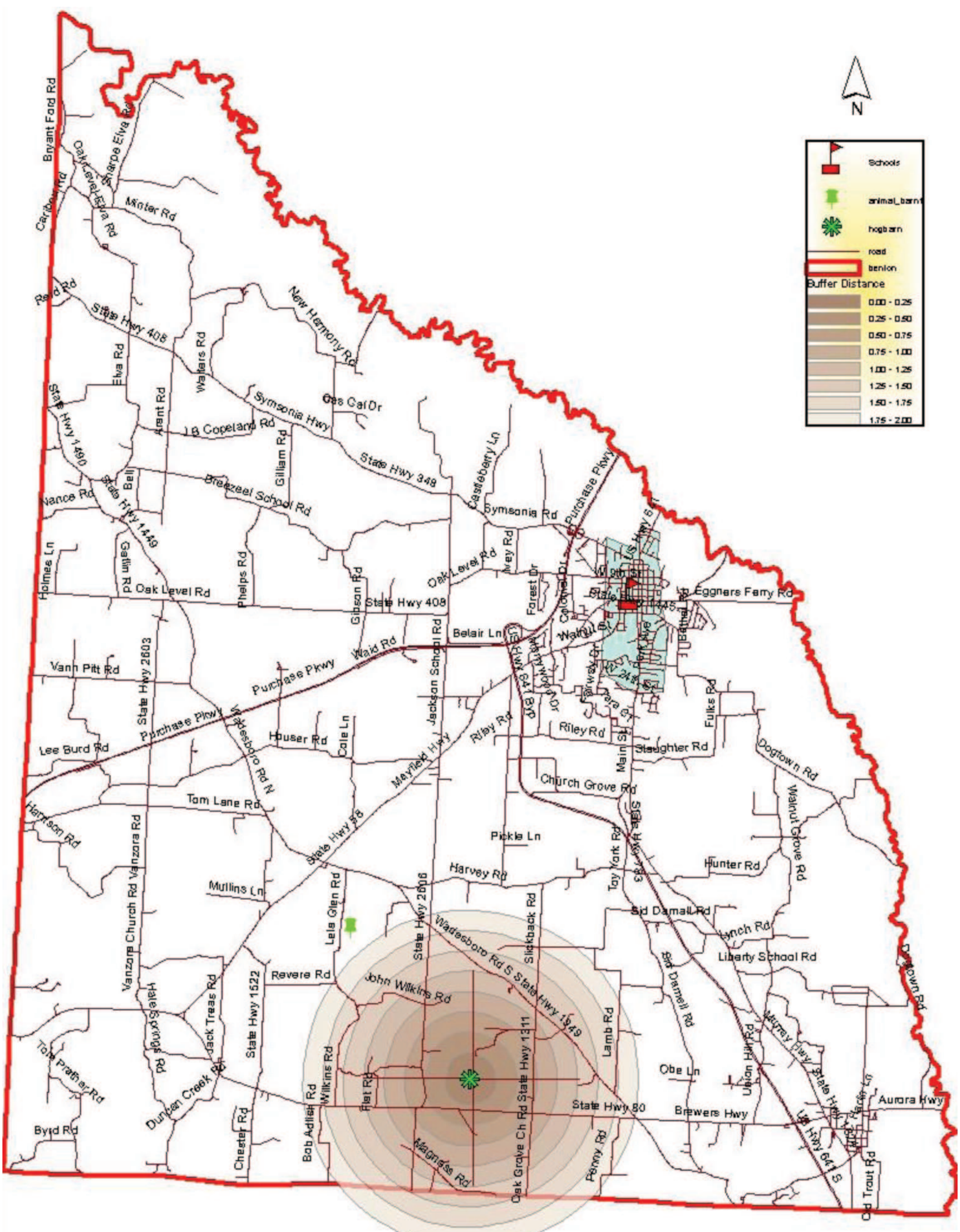
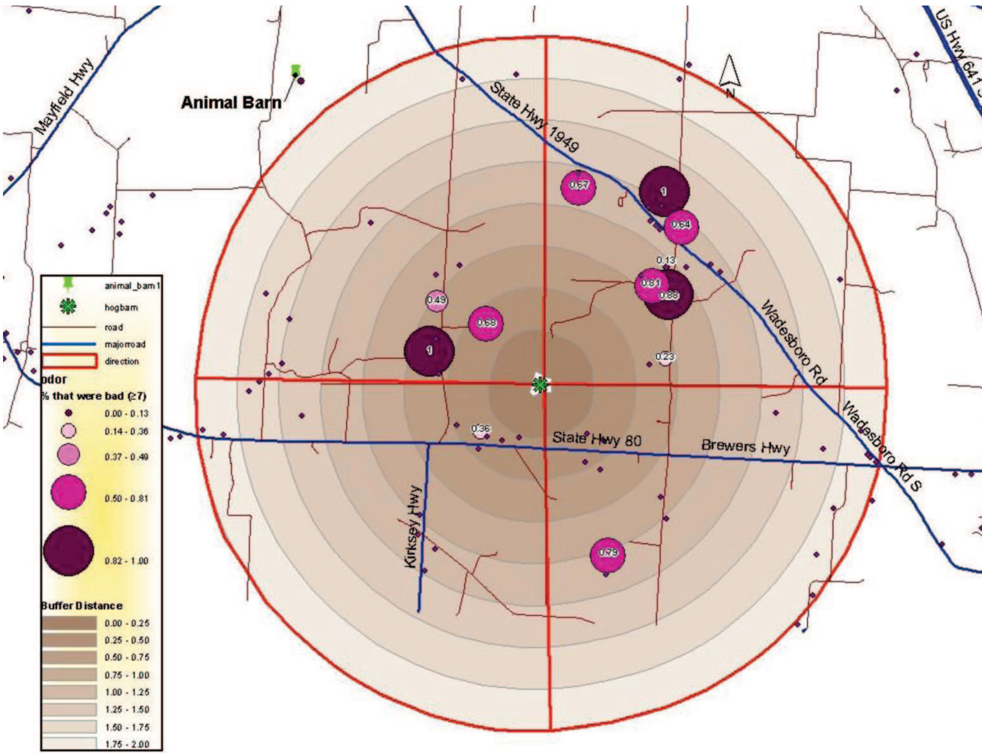


Exhibit 3 | Nearby Resident Odor Log Analysis: Severe Odor Percentages



Note: This is not a random sample of residents. Residents were involved in litigation against the hog farm operators.

those described in the peer-reviewed literature cited above. A slightly smaller hog farm operation, opened in about 2010 by the same owner, is located about 1.5 miles northwest of the main hog barns. There has also been a smaller chicken farm operation about 1/3 mile east of the main hog barns for over 15 years, and this is considered part of the baseline conditions with respect to odors. Both of these are shown in Exhibit 3. The case area includes about 300 residential properties, with about a third of the parcels being undeveloped land.

Personal interviews with a non-random sample of nearby residents confirmed that in about 2009 odors started emanating from the plant, and that they were intermittently bad to very bad in some directions from the facility (especially to the northwest), and sometimes noticeable in other directions. The odors persist until the present day.

Local Resident Odor Logs

Detailed logs of hog barn odor observations (“odor logs”) were maintained by 14 nearby residents over varying periods of time from July 2007 through August

2011. The authors had no control over who provided these odor logs, and we do not assume this is a random sample. However, the logs do support that odors are strongest towards the northeast, and thus provide valuable information for model design.

We translated these observations into a common 10-point intensity scale,[3] and then calculated, for each location, an average "odor intensity level" and a "severe-odor" percentage (i.e., the percentage of all of the observations that were rated at 7 or higher on the 10-point intensity scale).

We employed a geographic information system to plot the severe odor percentages at the residents' homes on a map of the case area, which is shown in Exhibit 3, along with recent sales. The results of this process revealed that the largest cluster of severe odor percentage observations indeed occurred to the northeast of the hog barns. Other relatively high severe odor percentages were found to the northwest and southeast of the hog barn site, while the plaintiff odor logs showed less frequent severe odors to the southwest of the barns.

Residential Sales Data Set

The real estate market in this part of Kentucky has been resilient, and has largely avoided the economic downturn that has affected the rest of the United States. Although there is a mix of housing in the study area, from mobile homes on ¼-acre rural lots to newer mansions on 10+ acres, a typical house is a 2,000 sq. ft. ranch or bi-level, 15 years old, on 5–10 acres of land, and located along a rural road. Benton (population about 4,400) and Murray (home of Murray State University with a population of about 18,000) are the nearest towns, while Paducah, Kentucky and Nashville, Tennessee, TN would provide air links. Mineral Mounds State Park is about 45 minutes east of the area by car. In short, Benton is a rural area not convenient to urban life.

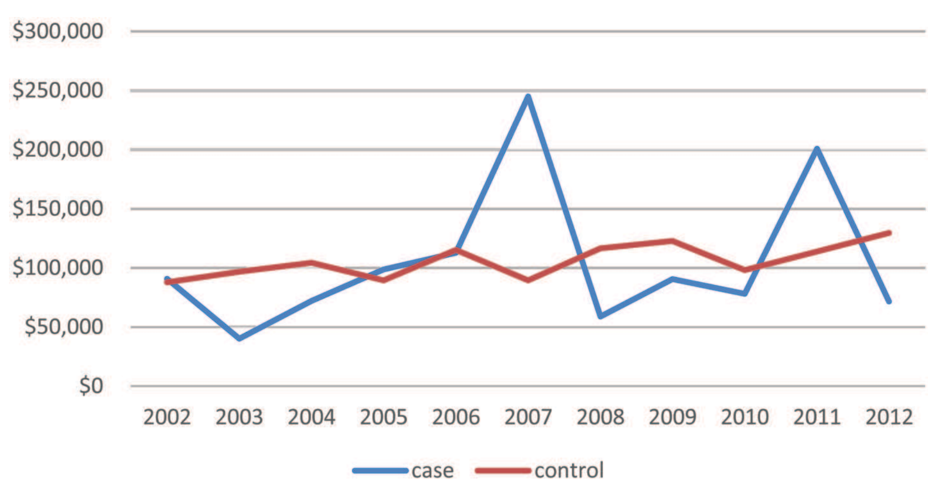
Exhibits 4a and 4b show local area housing sales price trends. While the balance of the U.S. was mired in the great recession due in large part to the foreclosure crisis, the study area was generally experiencing a continuation of steady growth in sales prices and transaction amounts (note in particular control area price trends in Exhibit 4b). Case area prices vary widely in some years, due to a small number of sales.

The initial database used to create the regression data set is a mix of local property valuation data (PVA) and the local multiple listing service (MLS), and included all (the population of) 305 single-family home sales from both the case and control areas, which transacted between 2002 and 2012. Based on information in the accompanying deeds and detailed MLS reports, 12 sales were deleted because they did not appear to be "arm's length." We also deleted 15 sales that were not able to be properly geocoded, leaving 278 transactions. Because this is a rural area, this is a relatively small data set, but represents the vast majority of sales in the affected area and nearby. Hence, the case and nearby control areas are generally comparable, and subject to the same economic trends.

Exhibit 4a | Sales Activity and Average Prices for Case and Control Area: 2002–2012

	All Sales		Sales in Case Area		Sales in Control	
Sale Year	# of Sales	Average Price	# of Sales	Average Price	# of Sales	Average Price
2002	26	$88,265	4	$90,875	22	$87,791
2003	23	$89,443	3	$40,200	20	$96,830
2004	25	$96,524	6	$72,083	19	$104,242
2005	30	$90,600	4	$98,725	26	$89,350
2006	24	$115,075	2	$112,700	22	$115,291
2007	27	$100,870	2	$245,000	25	$89,340
2008	19	$110,407	2	$58,750	17	$116,485
2009	18	$119,106	2	$90,400	16	$122,694
2010	21	$93,405	5	$78,040	16	$98,206
2011	24	$132,028	5	$200,800	19	$113,930
2012	34	$115,990	8	$71,500	26	$129,679

Exhibit 4b | Average Sales Price Trends



The real estate public sales dataset was corroborated with MLS records where available, and contained virtually all of the variables required for a regression analysis. Continuous variables (unless otherwise noted) included property address (needed for geocoding distance and direction from the source of the odors), sale amount (the dependent variable) and year (a dummy variable), interior square footage of the building, porch size, garage/carport spaces, year built, bedrooms, number of barns and outbuildings, bathrooms, and lot size. Dummy variables were created for private swimming pool, home style (stick-built vs. mobile homes), topography, property and site conditions, special sale types (bank sales, land contracts, etc.), and a few other property characteristics. We deleted two non-arms-length properties owned by employees of the hog farm owner.

We retained all sales observations with complete data, and therefore deleted seven observations that were missing essential data. With this dataset, we also transformed certain variables to comply with functional form, consistent with theory and/or prior published regression research (e.g., Simons, Bowen, and Sementelli, 1997; Simons, Winson-Geideman, and Mikelbank, 2001). For technical reasons, we utilized year dummy variables for sales from 2002 to 2012, as well as seasonal variables. We used the logarithmic forms of the age and sales price variables.

All properties that were successfully geocoded enabled us to attach locational variables to each sale. The key variables were to place each sale in a distance band from the hog farm complex, and also to place it in one of four directional variables (NE, SE, SW, and NW) relative to the facility. We also added the ''major road'' variable in the model that is the dummy variable for sales within 0.1 mile (using a distance buffer ring) of a major road, as previous studies in the peer-reviewed literature have revealed that properties close to a major street tend to sell at lower prices due to traffic noise [Asabere, et al., reviewed in Simons (2006)]. Finally, we applied a dummy variable to sales outside 1.25 miles but inside 2 miles from the hog barn facility, to control for secondary proximity outside the designated case area.

We considered other location variables: schools, distance to downtown Benton, and other animal barns. As shown in Exhibit 2, there are two schools in the study area: Benton Elementary and Benton Middle School. These schools are located close to each other in downtown Benton. Models with these variables, schools, and distance to downtown Benton indicated that these variables are not statistically significant,[4] so they did not make the final models. We also had a variable for the newer hog barn facility that opened in 2010, but the result was not statistically significant. The chicken barns are explicitly modeled.

After cleaning the data to include only complete, arms-length transactions, 271 sale observations are available for the model. Descriptive characteristics of the data set used are presented in Exhibit 5. The typical house sale had a sales price of $104,400, on a 7.6-acre lot, with 2.9 bedrooms, and 1.7 full bathrooms. A total of 16% of the properties were sold within the case area (with 9% sold after 2008 in the case area); 10% of the transactions involved bank sales (i.e., sales of previously foreclosed properties back into the marketplace), and 9% involved properties with a mobile home as the residence. Sales prices ranged from $2,000 to $650,000 throughout the study period. Sales prices in the study area were stable, with a low average annual sales price of $88,300 in 2005 and a high of $132,000 in 2009.

Exhibit 5 | Descriptive Statistics

Variable	Label	Min.	Max.	Mean	Std. Dev.
ln_hp	Log of house price	7.601	13.385	11.315	0.733
Hp	House price	2,000	650,000	104,369	79,367
ln_acres	Log of acres	−0.952	5.150	1.054	1.224
Acres	Acres	0.386	172.441	7.643	18.333
ln_livtot	Log of living area	6.238	8.328	7.337	0.315
Bsmt__SF	Basement SF	0.000	1,620	115.82	356.86
ln_age	Log of age	−2.303	4.466	3.237	0.966
cond_good	Dummy for good condition	0.000	1.000	0.251	0.434
cond_avg	Dummy for average condition	0.000	1.000	0.734	0.443
cond_poor	Dummy for poor condition	0.000	1.000	0.011	0.105
site_good	Dummy for site good	0.000	1.000	0.059	0.236
BR	Bedrooms	1.000	5.000	2.856	0.619
BA	Bathrooms	1.000	4.000	1.683	0.605
Space_Equi	Garage space equivalent	0.000	5.000	1.321	1.046
Garage_SF	Garage size	0.000	2,808.000	447.620	492.880
No__of_Bar	Number of barns	0.000	5.000	0.173	0.512
topo_level	Dummy for topology (level)	0.000	1.000	0.731	0.445
topo_rolling	Dummy for topology (rolling)	0.000	1.000	0.240	0.428
topo_steep	Dummy for topology (steep)	0.000	1.000	0.030	0.170
Bank_Sale	Dummy for bank sales	0.000	1.000	0.100	0.300
Porch_SF	Porch SF	0.000	768.000	143.539	147.201
Road_Front	Road frontage	0.000	3,118	344.56	431.82
O_B_SF	Outbuilding SF	0.000	6,400	309.38	722.65
Out_Bldgs	Number of outbuildings	0.000	4.000	0.675	0.846
Mobile	Dummy for mobile homes	0.000	1.000	0.089	0.285
d_out_after	Sales 1.25–2 miles from hog barns after 2008	0.000	1.000	0.055	0.229
d_spring	Dummy for spring	0.000	1.000	0.310	0.463
d_summer	Dummy for summer	0.000	1.000	0.280	0.450
d_fall	Dummy for fall	0.000	1.000	0.203	0.403
d_winter	Dummy for winter	0.000	1.000	0.207	0.406
d_2002	Dummy for 2002	0.000	1.000	0.096	0.295
d_2003	Dummy for 2003	0.000	1.000	0.085	0.279
d_2004	Dummy for 2004	0.000	1.000	0.092	0.290
d_2005	Dummy for 2005	0.000	1.000	0.111	0.314
d_2006	Dummy for 2006	0.000	1.000	0.089	0.285
d_2007	Dummy for 2007	0.000	1.000	0.100	0.300

Exhibit 5 | (continued)

Descriptive Statistics

Variable	Label	Min.	Max.	Mean	Std. Dev.
d_2008	Dummy for 2008	0.000	1.000	0.070	0.256
d_2009	Dummy for 2009	0.000	1.000	0.066	0.250
d_2010	Dummy for 2010	0.000	1.000	0.078	0.268
d_2011	Dummy for 2011	0.000	1.000	0.089	0.285
d_2012	Dummy for 2012	0.000	1.000	0.126	0.332
Land_Contr	Dummy for land contract	0.000	1.000	0.037	0.189
buf_animal	Dummy for within 1.0 mile of pre-existing modest sized chicken feeding operation.	0.000	1.000	0.136	0.344
Case_before	Dummy for sale in case area prior to 2009	0.000	1.000	0.070	0.256
case_af	Dummy for sales after 2008 within case area	0.000	1.000	0.081	0.274
case_af09101112	Dummy for sales after 2009 within case area	0.000	1.000	0.074	0.262
case_af101112	Dummy for sales after 2010 within case area	0.000	1.000	0.066	0.250
case_af1112	Dummy for sales after 2011 within case area	0.000	1.000	0.048	0.214
case_af_nw	Dummy for sales after 2008 in northwest quadrant	0.000	1.000	0.007	0.086
case_af_ne	Dummy for sales after 2008 in northeast quadrant	0.000	1.000	0.037	0.189
case_af_sw	Dummy for sales after 2008 in southwest quadrant	0.000	1.000	0.022	0.147
case_af_se	Dummy for sales after 2008 in southeast quadrant	0.000	1.000	0.015	0.121
case1_af	Dummy for sales after 2009 in case 1 (0.75 miles from barns)	0.000	1.000	0.026	0.159
case2_af	Dummy for sales after 2009 in case 2 (0.75–1.25 mile radius)	0.000	1.000	0.048	0.214

Model and Results

General Form of the Models

Our analysis of residential property sales employed standard hedonic regression techniques (Rosen, 1974; Jackson, 2001; Colwell, Heller, and Trefzger, 2009;

Simons, Bowen, and Sementelli, 1997; Simons, Winson-Geideman, and Mikelbank, 2001; and Seo and Simons, 2012). The dependent variable is the log of housing sales prices. The independent variables include a number of control variables, plus one that isolates the effect odors (Eq. 1). We hypothesize that, after the opening of the hog barns, homes within a 1.25-mile radius of the facility have sold at lower prices than those in the control area.

To check for spatial autocorrelation in housing sales prices (Kim and Goldsmith, 2009), we used the Lagrange Multiplier (LM) test for lag, for error, RobustLag for lag, and RobustLM for error. None of the test results indicated spatial autocorrelation was a concern.[5]

Two models plus an examination of the effects of the hog farm over time are presented: a baseline model including all sales in the case area from 2009 onward; a space model focusing on wind direction; and a series of interactive models over time and space that allows us to identify variations in price impact over varying time periods, based on a case property's direction from the hog barn complex. All models are generally specified as follows:

$$Ln\_HP = \beta_0 + \beta_1 HC + \beta_2 LOC + \beta_3 TIME + \beta_4 CASE\_AF + \varepsilon, \quad (1)$$

where:

Ln_HP = The (log of the) sale price of each home that sold in our dataset;
β_0 = The model intercept;
HC = A matrix of physical housing characteristics;
LOC = A matrix of dummy variables for sales within 0.1 mile of a major road, outside the case area;
$TIME$ = A matrix of year and season dummy variables;
$CASE\_AF$ = The effect on sales price of location within the case area after the hog barns became fully operative, which can take different forms as discussed below; and
ε = The error term.

Results: Baseline Model

The results from our baseline model are presented in Exhibit 6. We checked for multicollinearity, and the VIF statistics shown in the far right-hand column are low, outside the concern of generally accepted cutoffs. We also tested for normality and heterogeneity using the Kolmogorov-Smirnov test, which indicated that there is no normality problem with the dataset. The value of K-S D is 0.07, which is statistically significant at the 99% confidence interval. Similarly, application of the Breusch-Pagan test found no heteroscedasticity.[6]

The model's adjusted R^2 value at 69.67 is satisfactory, indicating that the variables used in the model explain about 70% of the variation in sales price. Likewise the

Exhibit 6 | Baseline Model: Case Area from 2009 Onward

Variable	Estimate	Std. Dev.	*t*-Value	Pr > |*t*|	VIF
Intercept	10.6080	0.2052	51.69	<0.0001	0.00
Acres	0.0109	0.0015	7.34	<0.0001	1.22
Total_SF	0.0001	0.0001	2.63	0.0092	1.88
ln_age	−0.1239	0.0328	−3.77	0.0002	1.67
cond_good	0.0042	0.0672	0.06	0.9503	1.41
cond_poor	−1.1989	0.2455	−4.88	<0.0001	1.10
site_good	0.1324	0.1167	1.13	0.2577	1.26
BR	0.1125	0.0512	2.20	0.0290	1.66
BA	0.1233	0.0633	1.95	0.0528	2.43
Space_Equi	0.1157	0.0276	4.19	<0.0001	1.38
No__of_Bar	0.1696	0.0554	3.06	0.0025	1.34
topo_rolli	0.0231	0.0622	0.37	0.7104	1.17
topo_steep	−0.4038	0.1578	−2.56	0.0111	1.19
*Bank_Sale_*	−0.4758	0.0860	−5.53	<0.0001	1.10
Porch_SF	0.0002	0.0002	1.16	0.2469	1.39
O_B_SF	0.0002	0.0000	4.35	<0.0001	1.26
d_spring	0.1407	0.0753	1.87	0.0631	2.02
d_summer	0.0858	0.0752	1.14	0.2548	1.90
d_winter	0.1164	0.0806	1.44	0.1500	1.77
d_out_after	−0.1052	0.1208	−0.87	0.3844	1.27
mobile	−0.8050	0.1057	−7.62	<0.0001	1.50
d_2003	−0.0755	0.1214	−0.62	0.5345	1.90
d_2004	0.0701	0.1170	0.60	0.5496	1.91
d_2005	−0.0440	0.1168	−0.38	0.7064	2.23
d_2006	0.1102	0.1184	0.93	0.3530	1.88
d_2007	0.2184	0.1188	1.84	0.0671	2.10
d_2008	0.1179	0.1263	0.93	0.3518	1.73
d_2009	0.2301	0.1301	1.77	0.0781	1.74
d_2010	0.2449	0.1281	1.91	0.0570	1.95
d_2011	0.1729	0.1224	1.41	0.1591	2.01
d_2012	0.2371	0.1150	2.06	0.0404	2.41
case_before	0.0643	0.1058	0.61	0.5441	1.21
maj_road	−0.1481	0.0595	−2.49	0.0135	1.41
Land_Contr	0.0518	0.1376	0.38	0.7070	1.12
BUF_ANIMAL	0.0115	0.0764	0.15	0.8803	1.14
case_af09101112	−0.2662	0.1090	−2.44	0.0153	1.35

Notes: The number of observations is 271. The adjusted R^2 is 69.67. The *F*-statistic is 18.72.

F-statistic is 18.72, satisfactory but consistent with statistical analysis with a limited number of sales.

The coefficients on the housing characteristic control variables are generally as expected by theory, at over a 90% level of confidence. The variables for lot size, porch size, square footage of living area, number of bedrooms, and number of baths have the expected positive signs and possess significantly high *t*-values. Housing and site condition dummy variables are as expected and statistically significant. Bank sales (−0.48) show the expected negative and statistically significant effect on sales prices, as does the mobile home variable (−0.81). The locational variable (major road) shows the predicted negative effect and is statistically significant. We used the year 2002 as the base year; the coefficients for sales in the years 2003 and 2005 have negative signs but are not statistically significant; the coefficients for sales in the years 2007, 2009, 2010, and 2012 reflect statistically significant differences from the base year in the order of a 20% increase, stable since 2007, which is contrary to the national trend of a downward cycle, consistent with the figures in Exhibit 4.

We include the variable *case_before*, which covers the subject area prior to the CAFO beginning operations. The coefficient is insignificant from zero, showing that prior to the CAFO, the subject area prices moved similarly to the surrounding areas, ceteris paribus.

We initially employed the commonly-used distance-rings approach in the hedonic model to estimate the effect of location within the case area.[7] Using the 1.25-mile distance ring, we identified sales in the case area from 2009 onward; the coefficient for the corresponding variable (*case_af09101112*) shows a coefficient of −0.27, or an estimated loss of 23%[8] (Halvorsen and Palmquist, 1980) after performing log transformation, and this figure is statistically significant at a level of more than 95%. In other words, this baseline regression model reveals that the marginal effect of a home's location within the case area (i.e., within a 1.25-mile radius of the subject hog barns after December 31, 2008, there is a 23% reduction in sales price, holding all other factors constant).[9]

Space Model Results: Direction and Time within Case Area

As noted above, the analysis of odor observation logs kept by a non-random sample of nearby residents at varying times from 2007 through 2011 demonstrated that hog barn odors appeared to be somewhat stronger and more prevalent at locations to the north and northeast of the hog barns than in other portions of the case area. As per Winegar (2013), prevailing winds in southwestern Marshall County tend to blow more often and with greater intensity from south and southwest of the hog barn complex. Accordingly, in our space model we explored the marginal effect on sales price of a home's location within the four cardinal wind directions from the hog farm facility. The case area is split into four directions, with the reference category defined as outside in the case area. The sample sizes are limited, but there is particular interest in the northeast quadrant of the case area (i.e., at headings between 0° (north) and 90° (east) from the hog barns), during the period beginning January 1, 2009. The corresponding variable is *case_af0912_ne*. The results of the regression model are presented in Exhibit 7.

The adjusted R^2 value and F-statistic in the space model are slightly higher than those in the baseline model, at 71.54 (indicating that the space model explains about 72% of the variation in sales price among all sales in the dataset) and 18.86, respectively. The signs of the variable coefficients in this hedonic regression model are similar to those in the baseline model. The coefficient of the interactive variable (*case_af0912_ne*) is statistically significant (at a level greater than 99%) and negative, indicating that the marginal effect of a property's location within the northeast quadrant of the case area, after December 31, 2008, is a reduction in sales price of 49%,[10] holding all other factors constant. This clearly shows that for these data, properties located northeast of the hog barns have sustained larger-than-average losses.

However, due to the relatively small number of sales (the number of sales in this NE quadrant is 13), caution is advised in putting too much weight on the magnitude of the parameter estimate, which seems quite large. Also, the other wind quadrants had only a handful of sales or less, and none of their parameter estimates were statistically significant. Hence, prudence indicates that we can only say that wind direction matters.

Alternative Runs Over Time and Space

In this sensitivity analysis, we explored a number of additional variations, including varying start time of the effects, and splitting distance rings within the case area. For start time, we varied the starting year, going from 2008 when the stench pit was filling up, to 2009 and 2010, through 2012 in all cases. It's important to watch the number of sales dwindling: the strongest results are when the model contains at least 15 sales.

We also took a closer look at distance rings. We attempted three rings: within 0.75 miles of the hog barns, 0.75–1.25 miles, and 1.25–2.0 miles. We ran into sample size issues again: the 0.75–1.25 miles from hog barns (referred to as case2) had over 15 sales, enough to report, and the losses there were higher than average for the entire case area.[11] The close-in ring did not have enough sales to find significant results. Exhibits 6 and 7 do not show a statistically significant effect outside the 1.25-mile range. However, there were only 15 sales, which is a small number for statistical reliability in these models.

We also conducted several additional model runs with five outliers (high and low sales prices) removed. Results continued to show significant reductions on property sales prices after 2009, about 15% lower than the full model. The space model still had significant higher losses northeast of the hog farms, but at a magnitude 25%–30% lower than the baseline model. Thus the model appears to have potentially influential outliers, but caution is again advised because the number of sales is smaller still. It can be concluded that the magnitude of the main results vary somewhat but not their statistical significance.

Exhibit 7 | Space Model Case Area (Northeast Quadrant) from 2009 Onward

Variable	Estimate	Std. Dev.	*t*-Value	Pr > |*t*|	VIF
Intercept	10.5958	0.1989	53.28	<0.0001	0.00
Acres	0.0107	0.0014	7.43	<0.0001	1.23
Total_SF	0.0001	0.0000	2.22	0.0271	1.91
ln_age	−0.1249	0.0319	−3.92	0.0001	1.68
cond_good	0.0192	0.0654	0.29	0.7688	1.42
cond_poor	−1.1710	0.2379	−4.92	<0.0001	1.10
site_good	0.1375	0.1131	1.22	0.2252	1.26
BR	0.1179	0.0497	2.37	0.0185	1.67
BA	0.1382	0.0613	2.25	0.0252	2.43
Space_Equi	0.1127	0.0269	4.19	<0.0001	1.40
No__of_Bar	0.2103	0.0546	3.85	0.0002	1.38
topo_rolli	0.0392	0.0604	0.65	0.5168	1.18
topo_steep	−0.4251	0.1532	−2.78	0.0060	1.19
*Bank_Sale_*	−0.4764	0.0832	−5.73	<0.0001	1.10
Porch_SF	0.0002	0.0002	1.27	0.2046	1.39
O_B_SF	0.0002	0.0000	5.12	<0.0001	1.30
d_spring	0.1198	0.0732	1.64	0.1032	2.03
d_summer	0.0753	0.0731	1.03	0.3037	1.91
d_winter	0.1030	0.0784	1.31	0.1899	1.78
d_out_after	−0.1367	0.1172	−1.17	0.2446	1.27
mobile	−0.7621	0.1029	−7.40	<0.0001	1.52
d_2003	−0.0737	0.1176	−0.63	0.5315	1.90
d_2004	0.0722	0.1134	0.64	0.5247	1.91
d_2005	−0.0558	0.1132	−0.49	0.6224	2.24
d_2006	0.1033	0.1148	0.90	0.3691	1.89
d_2007	0.2098	0.1151	1.82	0.0696	2.11
d_2008	0.1362	0.1233	1.10	0.2704	1.76
d_2009	0.1860	0.1269	1.47	0.1441	1.77
d_2010	0.3172	0.1258	2.52	0.0123	2.00
d_2011	0.1001	0.1194	0.84	0.4028	2.04
d_2012	0.2247	0.1115	2.02	0.0450	2.42
case_before	0.0607	0.1026	0.59	0.5544	1.22
maj_road	−0.1317	0.0588	−2.24	0.0259	1.47
Land_Contr	0.1613	0.1353	1.19	0.2346	1.15
BUF_ANIMAL	0.0201	0.0746	0.27	0.7877	1.16

Exhibit 7 | (continued)

Space Model Case Area (Northeast Quadrant) from 2009 Onward

Variable	Estimate	Std. Dev.	*t*-Value	Pr > |*t*|	VIF
class_af_ne	−0.6782	0.1476	−4.60	<0.0001	1.37
class_af_nw	−0.1167	0.2919	−0.40	0.6898	1.11
class_af_se	0.1540	0.2103	0.73	0.4648	1.14
class_af_sw	0.2270	0.1722	1.32	0.1886	1.14

Notes: The number of observations is 271. The adjusted R^2 is 71.54. The *F*-statistic is 18.86.

Exhibit 8 | Compilation of Several Alternative Runs

Model	Case Area 2008–2012	Case Area 2009–2012	Case Area 2010–2012	Case Area 2009–2012 NE of Hogs	Case Area 2009–2012 NE of Hogs	Case 2 2009–2012 0.75–1.25 miles
Parameter Est.	−0.20	−0.27	−0.32	−0.68	−0.78	−0.56
T-stat.	−1.94	−2.47	−2.76	−4.60	−5.13	−4.09
Model Adj. R^2	69.52	69.81	70.00	71.54	72.11	71.04
# of Sales	22	20	18	10	9	17

Conclusion

Hog farms are generally associated with a reduction in nearby residential sales prices, and our results support this expectation. Our hedonic regression analysis found a statistically significant average reduction in property value averaging almost 23% across the subject area within 1.25 miles of the facility for sales transacting from 2009 through 2012, holding other factors constant. Results from our regression models indicate that this negative impact on affected area property values is increasing, as the regression analysis disclosed an average property value diminution of 27% for sales from 2010 onward. We also found a substantially higher diminution in value for properties located in the northeast quadrant of the subject area, which suffer from the most prominent prevailing winds in the area. The discount allows properties that otherwise would not sell to be transacted in the market place, and thus represents a ''sustainability adjustment.''

The peer-reviewed professional literature reports that it is not unusual to find property value losses of 10% to 45% within 2 miles of CAFOs, with the effects being largest and most pronounced downwind of the facilities and in areas that do not already have high densities of existing CAFOs. The subject area fits this latter category, as the subject hog barns and a smaller, related facility are the first swine CAFOs to be established in Marshall County. The peer-reviewed literature also contains examples of property value losses in the range of 50% to 60% for individual homes in close proximity to CAFOs, with higher-valued properties sustaining particularly large percentage losses in value. Our results match closely with Isakson and Ecker's (2008) findings concerning the magnitude of losses and importance of wind direction.

With respect to time effects, we found increased impacts over time, with limited effects in the transitional year when the swill pits on the hog farms were filling up and increasing over the next several years. We conclude that wind direction is more important than pure distance in determining the magnitude of the effects on residential property values, but qualify this with our limited number of sales.

Endnotes

1 The senior author was retained as an expert witness by the plaintiffs in a legal case related to this study in 2013.

2 AEU is animal equivalent unit.

3 Many of the residents' observations were recorded on such a 10-point scale of odor intensity, but others were in the form of verbal descriptions.

4 The *t*-value is −0.53 for the distance to downtown Benton variable, and R-squared is slightly lower than the model without this variable.

5 Spatial results were: 0.09 (0.764) for LM lag, 0.09 (0.760) for LM error, 0.43 (0.513) for Robustlag, and 0.43 (0.512) for Robust LM error, respectively. The numbers in parentheses are the *p*-values. All results are below threshold levels.

6 We also examined the dataset for heteroscedasticity by visual inspection of a scatterplot of sale price and model residuals, and no fanning pattern was evident.

7 Simons and Seo (2011) found a positive externality of a religious facility campus on neighboring housing sale prices. They used hedonic regression analysis using 2,500 sales in Ohio, and identified sales within quarter-mile distance buffers. A similar distance ring approach was taken by Smolen et al., Reichert, and Nelson in their analyses of the negative amenity from proximity to landfills [in Simons (2006, p. 96)].

8 Percentage log transformation of dummy variables, $[(e^{0.2662}) - 1] * 100 = 23\%$.

9 As additional interpretive context for this result, note that the coefficient for the variable *case before* is positive but not statistically significant. In other words, over the time period before the odors became apparent covered by the dataset (i.e., 2002–2007), the sales data do not allow us to conclude that the marginal effect on sales price of location within the ''future'' area that would be affected by odors was other than zero. Thus, the sales performance of homes within the case area did not significantly differ from homes throughout the entire study area. That is, the observed diminution in value of case area homes after 2009 represents a genuine and abrupt change in their sales performance relative to a multi-year pre-existing pattern in which such homes statistically matched the sales performance of homes in the surrounding areas of southwestern Marshall County.

10 Percentage log transformation of dummy variables, $[(e^{0.6782}) - 1] * 100 = 49\%$.

11 In the outlier-free models reported just below, case2 had significant losses equivalent to the entire case area: hence no model shows closer-in sales with higher losses.

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