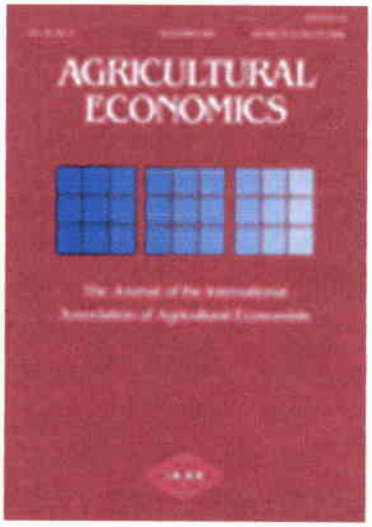


An analysis of the impact of swine CAFOs on the value of nearby houses

By

Hans R. Isakson
Department of Economics
University of Northern Iowa

Mark D. Ecker
Department of Mathematics
University of Northern Iowa

July 23, 2008

ABSTRACT

The impact of 39 swine confined or concentrated animal feeding operations (CAFOs) in Black Hawk County, Iowa on 5,822 house sales is explored by introducing a new variable that more accurately captures the effects of prevailing winds, exploring potential adverse effects within concentric circles around each CAFO, managing selection bias, and incorporating spatial correlation into the error term of the empirical model. Large adverse impacts suffered by houses that are within 3 miles and directly downwind from a CAFO are found. Beyond three miles, CAFOs have a generally decreasing adverse impact on house prices as distance to the CAFO increases.

Contact Author: Hans R. Isakson
Professor
Department of Economics
University of Northern Iowa
Cedar Falls, Iowa 50614-0129
Hans.isakson@uni.edu
Voice: 319-273-2950
Fax: 319-273-2922

Keywords: LULUs, swine CAFOs, house values, externalities, spatial correlation, hedonic analysis, maximum likelihood, concentric circles, prevailing winds, selection bias.

JEL Codes: Q51, Q53, R21

An Analysis of the Impact of Swine CAFOs on the Value of Nearby Houses

Introduction

Swine confined or concentrated animal feeding operations (CAFOs) can be and often are considered to be locally undesirable land uses (LULUs). Unpleasant odors and ground water contamination tend to be the greatest concerns of those who live near swine CAFOs. This situation has intensified since passage of the federal Pork Production, Research and Consumer Education Act (PPRCEA) in 1985, which lead to a significant increase in pork production. PPRCEA funded research into more efficient production techniques, especially CAFOs. During the late 1980s and early 1990s, two powerful influences, (1) PPRCEA funded advertising (pork, the other white meat) and (2) health concerns regarding the consumption of red meat, fueled a tremendous increase in the consumption and production of pork. Much of this increased production has been concentrated in a few, historically traditional, pork-producing states, particularly Iowa, North Carolina, Minnesota, and Illinois. As a result, nuisance complaints from those living near pork production sites, especially CAFOs, have increased. Lasley (1998) reports considerable concern with hog odors among rural Iowa residents. Van Keek and Bulley (1995) report that 95% of the nuisance attributed to farm odors can be traced back to swine CAFOs. In Iowa, some rural residences have sued nearby swine CAFOs as nuisances, and public hearings to consider new swine CAFO permits are overflowing with protesters.

The impact of proximity to swine CAFOs on housing values is a topic worthy of attention. To whatever extent swine CAFOs are the source of a negative externality deserves to be rigorously addressed, because the fears that the value of nearby homes might diminish could easily be exaggerated or overstated. Others have investigated this issue using proximity to a LULU to measure impact, implicitly assuming that any adverse effect will diminish with increasing distance from the source. However, relying solely on proximity as a measure of intensity can be problematic, because selection bias might distort the results. That is, the impact observed might be due to LULUs locating near low-valued houses. Therefore, additional measures of intensity and techniques to manage selection bias are desirable.

Spatial correlation abounds in housing sales data (Basu and Thibodeau, 1998; Isakson and Ecker, 2001; Case, Clapp, Dubin and Rodriquez, 2004) whereby two similar homes sell for a more similar price if they are closer geographically, than two homes farther apart. Omitted spatial variables and clustering of similarly priced homes are two sources of spatial correlation that, if omitted, will bias ordinary least squares (OLS) parameter estimates.

This study reviews previous studies of CAFOs, develops a spatial model for estimating the adverse affect associated with proximity to CAFOs, and applies this model to housing sales in a representative Iowa county. In particular, this study expands the approach taken in previous studies by (1) introducing a new variable that more accurately captures the effects of prevailing winds, (2) exploring potential adverse effects within concentric circles around each CAFO, (3) managing selection bias, and (4) incorporating spatial correlation into the error term of the empirical model

The organization of the paper is as follows: section 2 contains a review of the literature while the housing sales data and CAFO variables are examined in section 3. The statistical model is developed in section 4 while the results and findings are reported in section 5. The final section includes a discussion of the findings and suggests directions for further research.

Review of the Literature

Studies of the effects of a locally undesirable land use (LULU) on nearby housing values are abundant in the literature. In a meta-analysis, Simons and Saginor (2006) review 58 articles that study the impact on nearby property values of numerous LULUs, such as power lines, landfills, nuclear power plants, sex offenders, air pollution sources, and leaking underground storage tanks. They report that the adverse effect of a LULU diminishes with distance from the source.

In the earliest of the published studies of swine CAFOs, Palmquist, Roka, and Vukina (1997) examine 237 rural house sales in nine southeastern North Carolina counties, which occurred between January 1992 and July 1993. Unfortunately, due to privacy and confidentiality rules in North Carolina, the authors have no specific data for the locations of the CAFOs. Instead, they made use of data provided to them by the State Veterinarian's Office consisting of the total number of herds and capacity of swine CAFOs within three bands (0-1/2 mile, ½-1 mile, and 1-2 miles) around each of the 237 sales. From the CAFO data, the authors construct a manure index, based on the type and number of animals at the CAFO to estimate the weight of manure produced within each of the three bands. Using nonlinear least squares, they estimate that the effect of proximity is up to negative 9% of the value of a house, depending on the amount of manure produced by the CAFO.

In the second published study, Herriges, Secchi, and Babcock (2003) examine 1,145 house sales that occurred between 1992 and 2000 in five Iowa counties for the effects of proximity to 550 livestock facilities. By including more years (8) and a larger geographical area (five counties) in their analysis, these authors have many more sales and CAFOs than previous studies. The five Iowa counties selected for study include some of the highest concentration of CAFOs in the state. The authors make use of several measures of the effects of a CAFO, including distance to the nearest CAFO, the number of CAFOs within three miles of a house, the size (live animal weight) of the CAFO, a manure index, and whether the house is downwind from the nearest CAFO in warmer and colder months. Very few of these CAFO variables are statistically significant. Proximity to the nearest CAFO in the colder months for houses downwind from a CAFO shows a statistically significant loss in value depending on the size of the CAFO (their prevailing wind variable is a binary (0,1) measure). The strongest adverse effect reported is proximity to smaller CAFOs with a price-with-respect-to-distance elasticity of 0.097 during the winter and 0.112 during the summer months. Interestingly, the larger CAFOs show a smaller negative impact associated with proximity than smaller CAFOs. The authors suggest that one reason for this effect is the ability of the larger CAFOs to afford the costs of odor abatement techniques. Unfortunately, the Herriges, Secchi, and Babcock study does not estimate the effect of proximity separately from the size of a CAFO. Instead, they include interaction terms (log size times the log proximity; and the log size times the number of nearby CAFOs) without including the main effects, i.e., they do not allow for the potential for main effects alone being statistically significant by only checking if the interaction is important.

Others have also studied swine CAFOs. For example, Taff, Tiffany, and Weisberg (1996) in an unpublished paper examine 292 sales of rural, residential properties in two Minnesota counties that occurred from 1993 to 1994. These authors measure proximity to CAFOs using a series of three, one-mile rings around each sale. They also attempt to control for the size of the CAFO, wind direction, and number of CAFOs within three miles of a sale. In contrast to Palmquist, Roka, and Vukina, the authors report a positive effect associated with proximity to CAFOs. That is, houses closer to the CAFOs are reported as selling for more than those located further away, after controlling for other factors that traditionally affect housing values.

In another unpublished study, Hamed, Johnson, and Miller (1999) examine the sales of 99 rural parcels (39 with houses) in Saline County, Missouri that occurred between January 1, 1996 and December 31, 1997 for effects of proximity to CAFOs. The authors use a linear measure of distance to the nearest CAFO and find a loss of $112 per acre of land with houses and no impact on vacant land within three miles of a CAFO. In yet another unpublished study, Abeles-Alison and Connor (1990) examine housing sales surrounding eight swine CAFOs in Michigan that received multiple odor complaints during the first nine months of 1989. The primary purpose of their study is to estimate the impact on property tax revenues due to the presence of a CAFO in a township. The authors' analysis of 288 housing sales reveals that houses within 1.6 miles of a CAFO suffer a decline in value of $1.74 per animal in the CAFO. This impact is found to decrease with increasing distance from the CAFO.

The literature suggests that swine CAFOs can be a significant negative externality. Unfortunately, all previous studies suffer from at least of one of the following: the lack of data on location/intensity at the CAFO level; small sample sizes; the lack of ability to detect any effect due to wind; a model that does not account for spatially correlated data; and the lack of management of selection bias. This study uses measures of location and intensity both at the CAFO level and at the individual house level, includes a new cardinal, wind angle variable, uses larger sample sizes, manages selection bias, and incorporates a spatial correlation component into the model.

Data

This study combines two primary sources of data: (1) housing sales data and (2) swine CAFO data. The housing sales data consists of 5822 single-family sales in Black Hawk County, Iowa.[1] The number of sales in this dataset far exceeds the number of sales used in all of the previous studies. The sales data initially contained every transaction in the county from January 2000 to November 2004. These sales were refined by selecting only those transactions identified as "arms length transactions" by the county tax assessor's office. The sales were further refined by selecting only those sales with a selling price greater than $32,000 or less than $400,000, houses with at least three but less than 12 rooms, at least 500 square feet of living area, and a lot size greater than 3,000 square feet. In addition, due to limitations of the spatial model in this study, only the most recent sale, for any repeat sales, was used.

The housing sales data includes information on the following variables for each sale: date of sale, state-plane coordinates of the centroid of the property, municipal jurisdiction, year built, lot size, living area, and number of rooms. In addition to these variables, each sale includes calculations of the distance to selected points of influence; the CBDs of the two largest cities (Cedar Falls and Waterloo), the largest employer in the county (John Deere), and a large university (The University of Northern Iowa).

Information regarding CAFOs is difficult to obtain. CAFO owners are very reluctant to volunteer any data to researchers, because they fear that the information they disclose may be used against them. Thus, researchers are forced to use public records as their source of information. For each of the 39 swine CAFO sites in the county, information is obtained from the Iowa Department of Natural Resources (IDNR) on the following: state-plane coordinates of the centroid of the site, number of animal units permitted, and planned manure management techniques (method of applying manure to fields). Animal units represent a weighted sum that reflects the number and size of the animals permitted, whereby one animal unit is defined as one head of feeder cattle. Swine that weigh more than 55 pounds count as 0.4 animal units, while swine that weigh between 15 and 55 pounds count as 0.1 animal units. Animals less than 15 pounds are not counted. The manure management techniques are planned rather than actual, because the state only requires CAFO owners to report their planned, rather than their actual manure management techniques, and unfortunately, the Iowa DNR does not monitor compliance with CAFO manure management plans. Data regarding manure storage facilities and operational types are not included in this study, because this type of data is difficult to obtain, unverified, and often unreliable.

One of the major contributions of this study is the introduction of a non-linear, cardinal variable called *wind angle* that measures the extent to which a house is downwind from a nearby CAFO; see Figure 2. Prevailing winds data during the study period obtained online from the National Climatic Data Center is used to determine the prevailing (most frequent) wind directions, which are from the northwest in the colder months (135 degrees from the X-axis) and from the south-southeast in the warmer months (300 degrees from the X-axis). The variable wind angle is defined as zero for all homes upwind of the CAFO, because one would anticipate no (additional) wind effect for homes in a 180 degree field upwind from the nearest CAFO. Wind angle is 90 for houses directly downwind from the nearest CAFO. One would anticipate that the more directly downwind from a CAFO a particular house is (at a fixed distance from the CAFO), the greater the intensity of any airborne pollutants, such as obnoxious odors[2]. This wind effect may play an even stronger role in affecting home prices than just proximity to the confinement building when the source of the odor is a large area of land, such as the fields in the immediate vicinity of the CAFO where manure has been applied. The model also includes a seasonal binary variable indicating warmer or colder months based on the date of sale, and a binary variable that identifies on which side (north or south) of the prevailing winds the house is located. Lastly, a wind angle – season interaction variable is included to account for potential seasonality of the prevailing winds, i.e., to distinguish being downwind in the warmer versus the colder months.

The problem of selection bias in the data deserves attention. Selection bias can result when CAFOs and lower priced homes are clustered or concentrated in the same geographic area of the county, i.e. the low land prices attract CAFO owners as well as home buyers looking for inexpensive homes. One way to explore for selection bias is to examine house sales just before and right after a CAFO is opened and operating. This sort of event study is rarely performed and, moreover, establishing causality is extremely difficult since the observed price change could be due to the new CAFO or due to some other event. None of the previous studies of swine CAFOs make a direct attempt to manage selection bias, although Herriges, Secchi, and Babcock do so unintentionally by including the number of CAFOs within close proximity (three miles) of each sale. Munneke and Slawson (1999) manage selection bias in their study of mobile home parks by using a two-stage, random-effect, correction variable derived from a PROBIT analysis. Unlike covariates in standard (hedonic) regression models, their correction variable is not a fixed-effect; it has variability (sampling distribution/error) that is not accounted for in their final model. In the present study, selection bias is managed primarily by including a fixed-effect variable directly into the mean structure of the model to capture the extent of CAFO clustering (rather than a two-stage approach). If CAFO owners locate their operations near low valued houses, then one should observe clusters of CAFOs in very close proximity to low valued houses. Therefore, this study includes, for each sale, the count or number of CAFOs within a very close (1.5 mile) distance of each sale. If selection bias were present, then one should find more CAFOs located near lower valued houses (than located near higher-valued houses), i.e., the count variable will be statistically significant and negative. In addition to this count variable, this study also manages selection bias within an error term that accounts for spatial correlation, as seen in the next section.

Table 1 contains summary statistics of the 5822 sales and 39 CAFOs. Figure 2 contains a map of the locations of the sales, CAFO sites as well as the municipal boundaries of the major cities in the county. Most of the sales occur within the jurisdictional boundaries of five incorporated cities, while 254 of these sales occur within the unincorporated (rural) areas of the county. On average, houses in the dataset are four miles from the nearest CAFO, and one out of forty (146/5822) houses has a CAFO located within 1.5 miles. The wind angle varies from zero to 90, with an average of 33.95, and about 20 percent of the sales occurred during one of the colder months.

The 39 CAFOs are permitted for an average of 977.5 animal units and range in size from 156 to 2005 animal units. About one-fourth of them (11/39) indicate that they plan to apply manure to fields in the vicinity of the confinement building using the older, traditional broadcast method. The rest intend to use newer methods, such as injection or knife methods.

Statistical Models and Methodology

This study starts with a hedonic regression model of house price that includes independent variables to control for factors that traditionally influence house prices, including size and age of the dwelling, as well as, a set of variables that can capture the potential adverse effects of proximity to a CAFO. Specifically, let,

P = the selling price of the house,
S = lot size in acres,
t = the time of the sale,
C = a vector of site level characteristics of the house that typically affects selling price,
L = a vector of site level spatial measures of proximity to other points of influence,
J = a vector of binary variables representing the jurisdiction in which the house is located
D = the distance to the nearest CAFO,
AU = the number of animal units permitted at the CAFO,
CT = the number of CAFOs within 1.5 miles of the home,
PW = the degree (0 to 90) that the house is downwind from the nearest CAFO,

WS = a binary variable representing the season (0 = summer; 1 = winter), and

$PWS = PW * WS$, a wind direction – season interaction variable.

then the selling price of a house can be expressed as,

$$P = \kappa S^{\rho} A U^{\pi} e^{\chi D + \phi t + \varphi \mathbf{C} + \gamma \mathbf{L} + \eta \mathbf{J} + \alpha CT + \beta PW + \delta WS + \lambda PWS} \varepsilon \tag{1}$$

where the Greek letters represent parameters of the model to be estimated from the data. The site specific variables in **C** include living area, the number of rooms in the house and the year the house was built. The spatial variables in **L** include the distance to the CBD of two large cities (Waterloo and Cedar Falls) and distances to the two largest employers in the county (John Deere and the University of Northern Iowa) that dominate the labor markets in the county. This model includes independent variables to capture any adverse effect of CAFOs, including the size, wind-angle, and distance to the nearest CAFO.

We fit the hedonic model, equation (1), using a concentric circles statistical modeling approach, in which seven hedonic regression models are fitted for all sales that have a CAFO within 2, 2.5, 3, 3.5, 4, 4.5, and 5 miles of the house. An eighth hedonic regression model is fitted using all 5822 sales. Obviously, the results of the two mile hedonic regression analysis, with $n_1 = 309$ sales, will have an impact upon the results of the 2.5 miles analysis, with $n_1 + n_2 = 507$ sales, due to the common $n_1 = 309$ sales. However, we choose the concentric circles analysis over a ring analysis (of solely the $n_2 = 198$ sales between 2 and 2.5 miles from the nearest CAFO) because the concentric circles analysis provides a more continuous and smooth look at how proximity to a CAFO affects selling prices, i.e., we explore how the independent variables change in both interpretation and statistical significance with proximity to the nearest CAFO. Ring analysis often results in a smaller sample size, produces much more variable results and is beset with highly influential sales. These effects can be smoothed out using concentric circles.

In addition, we include a spatial correlation component in the hedonic regression model, equation (1), by modeling the error term, ε, in a geostatistical manner (see Cressie (1993); Isakson and Ecker (2001); and Ecker (2003)), in lieu of the traditional OLS error term. Spatial correlation implies that, all things otherwise equal, two homes will sell for a much more similar price if they are closer geographically, compared to two otherwise similar homes much farther apart. Specifically, we model

$$\ln(\varepsilon) \sim N(0, \tau^2 + \sigma^2), \quad (2)$$

where τ^2 is referred to as the "nugget" effect (a measurement error or micro-scale variability) in the geostatistical literature. The sum of the parameters $\tau^2 + \sigma^2$ in (2) represents the spatial variability of the spatial process or "sill", i.e., the variability of the home prices after adjusting for individual home characteristics. Lastly, for two home sales with errors ε_i and ε_j, we model the spatial correlation as a function of their Euclidean distance apart, d_{ij}. Specifically,

$$\mathrm{Corr}(\ln(\varepsilon_i), \ln(\varepsilon_j)) = \exp(-\phi d_{ij}) \quad (3)$$

where ϕ controls the strength of the spatial correlation and is called the "range" parameter. The range indicates the distance beyond which home prices are (essentially) uncorrelated. Spatial correlation models, (2) and (3), are random effects models designed to "mop up" extra variability not captured in the mean structure in equation (1). In particular, unobserved variables and any selection bias not fully captured by the count of

CAFOs within 1.5 miles of the home sale are managed by adding spatial correlation components, (2) and (3), to the model.

The spatial correlation parameters, the range, sill and nugget in (2) and (3), along with the site level mean structure parameters in (1), are estimated simultaneously, within each concentric circle, using a maximum-likelihood, iterative fitting technique.[3] Reasonable starting or seed values of the spatial correlation parameters are needed to ensure timely and accurate convergence of the fitting algorithm. These starting values for the range, sill and nugget for each concentric circle are obtained by fitting an exponential theoretical variogram model to an empirical variogram constructed from the residuals of an ordinary least squares (a non-spatial correlation) hedonic regression model.[4]

Results and Findings

The results of the eight, maximum-likelihood regressions are reported in Table 2 where the Goodness of Fit statistics indicates that as one adds more data in the larger diameter concentric circles, the model fits better. All of the house specific or structure variables have coefficients that are highly statistically significant, of reasonable magnitude and sign, and are very stable from one concentric circle to the next. Of the time variables, the date of sale is statistically important in all concentric circles, while the season variable is only important in the 4 mile concentric circle (in which, homes sold in warmer months sell for more that those sold in colder months). The date of sale coefficient shows lower rates of annual appreciation (3.7%) for those sales that are close to a CAFO. In the larger concentric circles, the annual rates of appreciation are higher (about 5%).

None of the distance variables are statistically significant in any concentric circle. It is not surprising that the CBDs of both cities are not strong points of influence, since they are not a major destination point for county residents. The employment and retail sites within the county are well disbursed, rather than concentrated at any particular point.

Very few of the city binary variables are statistically significant. Within the smaller concentric circles, no sales are present in some of the cities. Where the city variables have statistically significant coefficients, these coefficients suggest that houses sell for more within the two major cities. Higher house values within a city, as opposed to a rural area, are not a surprise.

The coefficients of the spatial correlation variables are fairly stable for all concentric circles except for the range parameter in the smallest concentric circle. This range coefficient suggests that the spatial correlations diminish rapidly beyond about two thirds of a mile (0.35 = 3500 feet). The nugget value is consistently about 0.02 and represents about 40% of the total variability. Thus for parcels located within about two thirds of a mile from each other, OLS techniques would unnecessarily use the entire sill for explanation and prediction, i.e. the covariance for closer parcels is as much as 60% less than the total variability.

The pattern of statistical significance and insignificance for the CAFO variables reveals considerable insight into which characteristics of a CAFO most adversely affect nearby house values. The count variable, minimum distance and the manure application variables are all statistically not significant. Thus, there appears to be no evidence for selection bias, nor are houses affected by the planned method of manure management. (The actual method, if it were known, could be more important than the planned method of manure management.) The lack of significance for the distance variable indicates that just being close to a CAFO, all by itself, does not greatly affect house prices (more than wind-angle or size of the CAFO, as seen below).

The CAFO variables animal units and wind angle exhibit statistical significance within several of the concentric circles. For a house located at 3 miles or closer to a CAFO, how much the house is directly downwind from a CAFO is the most important (most statistically significant) CAFO variable. Beyond 3 miles, the size of the nearest CAFO in animal units is the only statistically significant CAFO coefficient. For houses that are five miles or more from the nearest CAFO, those that are north of being directly downwind from a CAFO sell for more than those that are south.

The CAFO coefficients from the concentric circle analysis paint a picture showing that the prevailing winds play a much more important role for houses within three miles of a CAFO, while the size of the nearest CAFO plays a more important role in influencing home prices for houses that are further away. Note that the sign and magnitude of the animal unit coefficient for very close sales (within 2 and 2.5 miles) is consistent with the signs and magnitudes in the larger concentric circles. Thus, lack of significance for animal units at close distances might be attributed to the relatively few sales in the smaller circles. Lastly, the wind angle – season interaction is not significant for any concentric circle, suggesting that the effect of being downwind from a CAFO in the warmer months is no different than in the colder months. In the smaller three concentric circles (2, 2.5 and 3 miles), wind angle is a more powerful (more statistically significant) explanatory variable than any of the other CAFO variables. Houses directly downwind and within two miles of a CAFO can suffer as much as a 44.1 percent loss in value (but, only one house is essentially (89.1 degrees) directly downwind and within 2 miles of a CAFO; the rest are no more than 60 degrees downwind). At the average wind-angle (33.95 degrees), the loss in value for houses within two miles of a CAFO is slightly over 16.6 percent. If a house is within 2.5 miles of a CAFO, the maximum loss in value is 15.3 percent, while at the average wind-angle, the loss is 5.8 percent. Houses directly downwind within three miles of a CAFO (holding CAFO size constant) suffer a maximum loss in value of 9.9 percent, while at the average wind angle they suffer a 3.7 percent loss in value. Beyond three miles, wind-angle is not as important (statistically significant) as the size of the CAFO. Within three miles of a CAFO, the elasticity of house price with respect to CAFO size (measured in animal units) is -0.1370, which on average, suggests about a 6.85 percent loss in value for a 50 percent increase in CAFO size. For all sales, the elasticity of house price with respect to CAFO size is -0.0668, which on average, suggests about a 3.34 percent loss in value for a 50 percent increase in CAFO size.

Analysis of the sales data indicates that houses within very close proximity (3 miles or closer) to a CAFO can suffer a substantial loss in value, especially if the house is directly downwind from a CAFO. Further away from a CAFO (beyond three miles), houses suffer diminishing adverse effects as one moves further away from the CAFO. Generally, the rate of appreciation in house values is higher for houses further away from a CAFO.

Summary and Conclusions

This study improves our understanding of how and to what extent swine confined animal feeding operations (CAFOs) impact the value of nearby houses by (1) using concentric circles to increase sample sizes, (2) introducing a new variable that captures the effects of prevailing winds, (3) using a model that accounts for spatially correlated data, and (4) managing the problem of selection bias. The study finds large adverse impacts suffered by houses that are very close (within 3 miles) to and directly downwind from a CAFO. Beyond three miles, CAFOs have an adverse impact on house prices, but this impact, in generally, diminishes with increasing distance from a CAFO.

This study also separates the effects of proximity, size, and prevailing winds, demonstrating for the first time that prevailing winds play a dominant role for houses within 3 miles of a CAFO, while size (animal units) plays a dominate role for houses beyond 3 miles from a CAFO. Additionally, this study finds that the impact of swine CAFOs is farther reaching than previous studies report; CAFOs can reduce the value of houses, albeit by a small amount, as far as six miles away.

Additional research remains to be done. In particular, the impact on houses located very close (within two miles) to a CAFO is extremely difficult to determine, because so little data are available. In fact, the impact could be so dramatic on these very close houses that they do not sell, due to the lack of willing buyers and/or the owner refusing to accept an offer that is a fraction of what its house specific variables would otherwise suggest. In addition, a comparison of the total loss in house values to the cost of odor abatement is also worth study. It might be less expensive for CAFO owners to compensate home owners for their loss than to implement odor abatement techniques. If transaction costs are sufficiently low, assigning tradable externality-free rights to homeowners or externality-creation rights to CAFO owners represent market-based solutions that could be implemented to help mitigate the negative impacts associated with swine CAFOs.

Finally, the techniques developed in this study can easily be adopted by others who also study the impact of a particular land use on the value of nearby properties. The management of selection bias will always improve the results. Building spatial correlation into the error term will also help reduce biases in the estimates of the coefficients. The concentric circles technique can help deal with the problem of small sample sizes and influential observations. The wind angle measure introduced in this study could be adopted by others who study the impact of any sort of phenomenon that is carried and influenced by prevailing winds.

References

Abeles-Allison M and Connor, L (1990). An analysis of local benefits and costs of Michigan hog operation experiencing environmental conflicts. Department of Agriculture Economics, Michigan State University, East Lansing.

Basu, S. and Thibodeau, T.G. (1998). Analysis of Spatial Autocorrelation in House Prices. *The Journal of Real Estate Finance and Economics.* 17 61-85.

Case, B, Clapp, J, Dubin, R. and Rodriquez, M. (2004). Modeling Spatial and Temporal House Price Patterns: A Comparison of Four Models. *The Journal of Real Estate Finance and Economics.* 29 167-191.

Cressie, N (1993). *Statistics for Spatial Data.* New York: John Wiley and Sons.

Ecker, M.D. (2003). Geostatistics: Past, Present and Future. In *Encyclopedia of Life Support Systems (EOLSS)* . Developed under the Auspices of the UNESCO, EOLSS Publishers, Oxford, UK. [available at: www.eolss.net].

Hamed, M., Johnson, T.G., and Miller, K.K. (1999). The impacts of animal feeding operations on rural land values. Social Studies Unit, College of Agriculture, Food and Natural Resources, University of Missouri-Columbia, Report R-99-02.

Herriges, J.A., Secchi, S., and Babcock, B.A. (2005). Living with hogs in Iowa: The impact of livestock facilities on rural residential property values. *Land Economics,* 81(4): 530-546.

Isakson, H. and Ecker, M.D. (2001). An Analysis of the Influence of Location in the Market for Undeveloped Urban Fringe Land. *Land Economics,* 77(1): 30-41.

Lasley, P. (1999). Iowa farm and rural life poll: 1999 summary report. Ames, Iowa: Iowa State University Extension 1-12.

Munneke, H.J. and Slawson, V.C., Jr. (1999). A housing price model with endogenous externality location: A study of mobile home parks. Journal of Real Estate Finance and Economics, 19(2), 113-131.

National Climatic Data Center, National Oceanic and Atmospheric Administration, Asheville, NC.

Palmquist, R.B., Roka, F.M, and Vukina, T. (1997). Hog operations, environmental effects, and residential property values. *Land Economics*, 73(1): 114-124.

Simons, Robert A. and Saginor, Jesse, D (2006). A meta-analysis of the effect of environmental contamination and positive amenities on residential real estate values. *Journal of Real Estate Research*, 28(1): 71-104.

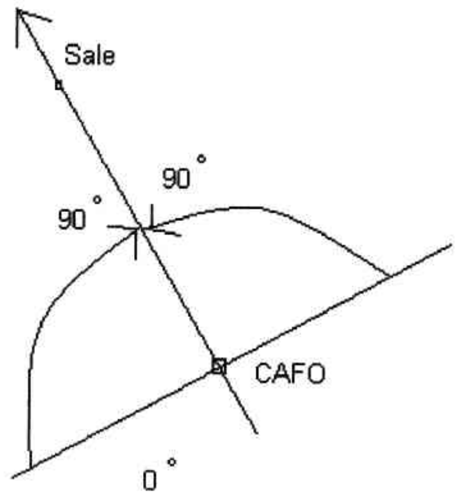
Taff, S.j., Tiffany, D.G., and Weisberg, S. (1996). Measured effects of feedlots on residential property values in Minnesota: A report to the legislature. Department of Applied Economics, College of Agricultural, Food, and Environmental Sciences, University of Minnesota, Staff Paper P96-12.

Acknowledgements

We thank the Black Hawk County Board of Supervisors for providing the housing sales data used in this study. We are also grateful to the participants of the Economics Department Workshop at the University of Northern Iowa. Lastly, we thank two anonymous reviewers who greatly improved the quality of this paper.

Figure 1 Definition of Wind Angle Variable

Warmer Months: March 22 to December 2 – SSE Predominate Wind Direction:



Colder Months: December 1 to March 21 – NW Predominate Wind Direction

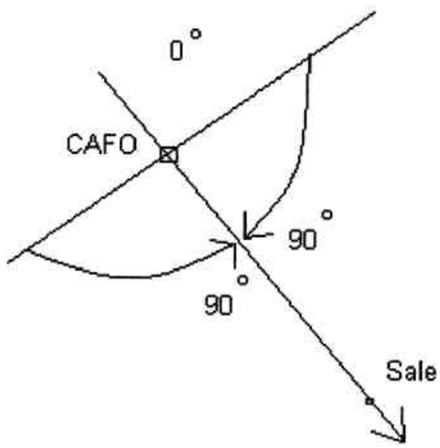


Figure 2 Locations of Sales, CAFOs, and City Boundaries

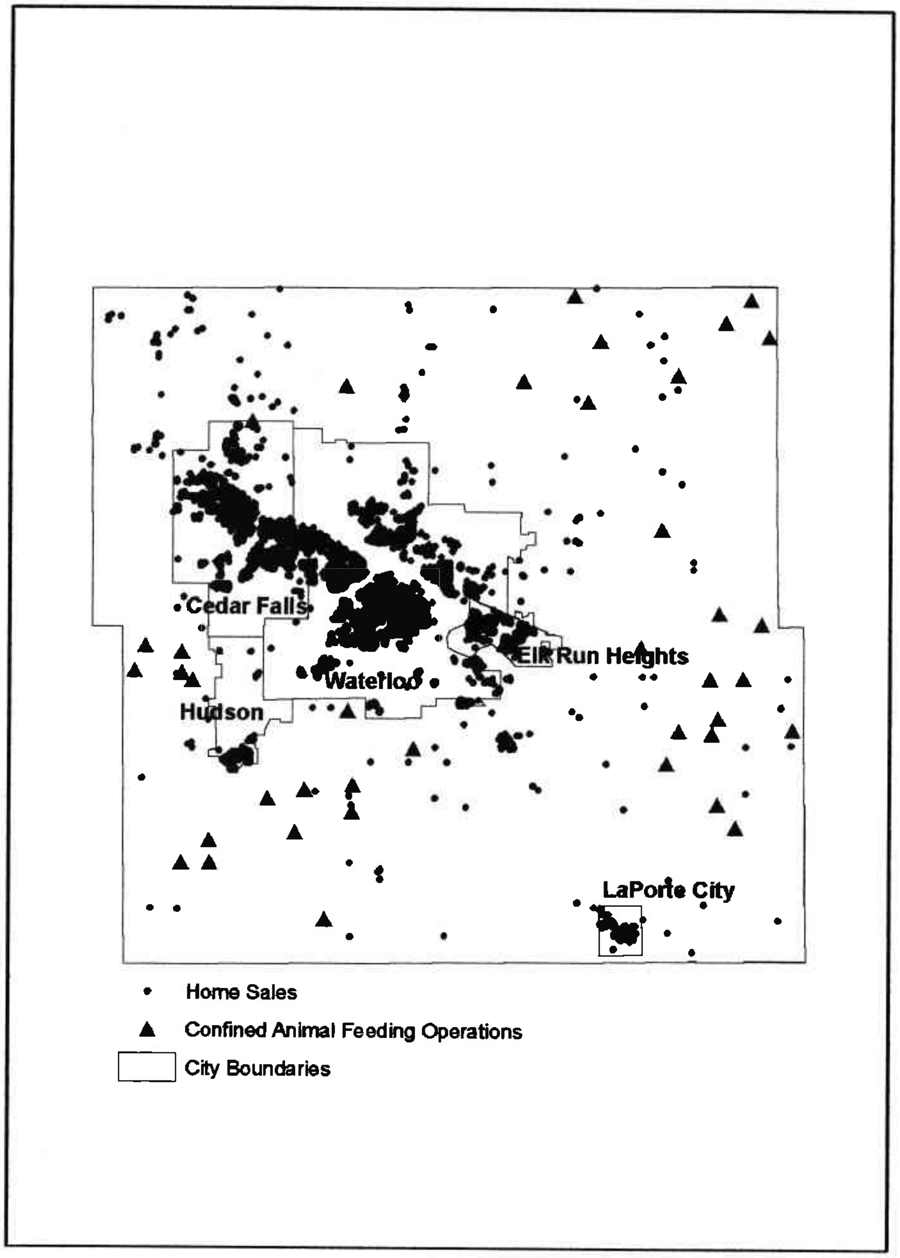


Table 1 Summary Statistics of Data

Variable	Mean	Std Dev	Minimum	**Maximum**
Sales Price	108456.38	60919.30	32208.96	399512.37
Structural:				
Living Area	1182.67	442.2736094	502.7032320	3904.95
Year Built	1953.08	25.9301497	1852.0	2003.0
N. Rooms	5.4905531	1.2581963	4.0000000	11.000000
Lot Size	3.0445554	18.499110	0.0706512	365.0374679
Time:				
Date of Sale	2.6873789	1.3821553	0	4.88
Season	0.2006183	0.4004974	0	1
City:				
Cedar Falls	0.2858124	0.4518393	0	1
Waterloo	0.5879423	0.4922477	0	1
Hudson	0.0197527	0.1391611	0	1
Elk Run H.	0.0475782	0.2128902	0	1
LaPort City	0.0204397	0.1415110	0	1
Distance to:				
Cedar Falls	7.1481845	3.6729565	0.1600000	25.5900000
Waterloo	3.7208159	2.8765304	0.1600000	17.9400000
John Deere	6.5147149	2.5233630	0.4400000	20.2500000
University	5.5595706	3.5354120	0.4700000	23.7100000
CAFOs:				
Count	0.0269667	0.1771941	0	4.0
Distance	4.0029612	1.0978247	0.1600000	6.5900000
Wind Angle	33.952926	30.803978	0	89.989
Animal Units	977.5385	508.9314	156.0	2005.0
North	0.709550	0.454009	0	1
Manure App	0.2821	0.4559	0	1

NOTES:

a. Sales Price is measured in dollars
b. Living Area is measured in square feet
c. N. Rooms represents the number of rooms in the house
d. Lot Size is measured in acres
e. Date of Sale is measured in years beginning at Jan. 1, 2000
f. Season = 1 for colder months (Dec. 1 thru March 21); 0 for warmer months
g. City variables are bi-variant (0,1)
h. Distance to variables are measured in miles to the center of each destination
i. Count measures the number of CAFOs within 1.5 miles of the house
j. Distance represents the distance to the nearest CAFO
k. Wind Angle represents the extent to which a house is downwind from the nearest CAFO
l. North = 1 for sales north of being downwind from the nearest CAFO; 0 if south
m. Manure App = 1 for broadcast; 0 otherwise (injection, etc.)

Table 2 Maximum Likelihood Coefficients and p-values (statistically significant values, at the 0.1 level, are in **bold**)

Distance:	2 miles n = 309	2.5 miles n = 507	3 miles n = 1024	3.5 miles n = 1754	4 miles n = 2616	4.5 miles n = 3900	5 miles n = 4783	All n = 5822
House	**Specific**	**Variables**						
Ln Living Area	**0.3757** **(0.0001)**	**0.3726** **(0.0001)**	**0.3489** **(0.0001)**	**0.3555** **(0.0001)**	**0.3660** **(0.0001)**	**0.3593** **(0.0001)**	**0.3596** **(0.0001)**	**0.3625** **(0.0001)**
Number of Rooms	**0.0540** **(0.0001)**	**0.0616** **(0.0001)**	**0.0580** **(0.0001)**	**0.0612** **(0.0001)**	**0.0650** **(0.0001)**	**0.0591** **(0.0001)**	**0.0612** **(0.0001)**	**0.0616** **(0.0001)**
Year Built	**0.0072** **(0.0001)**	**0.0074** **(0.0001)**	**0.0061** **(0.0001)**	**0.0058** **(0.0001)**	**0.0051** **(0.0001)**	**0.0056** **(0.0001)**	**0.0059** **(0.0001)**	**0.0058** **(0.0001)**
Ln Lot Size	**0.0427** **(0.0229)**	**0.0444** **(0.0009)**	**0.0551** **(0.0001)**	**0.0637** **(0.0001)**	**0.0671** **(0.0001)**	**0.0757** **(0.0001)**	**0.0759** **(0.0001)**	**0.0701** **(0.0001)**
Time	**Variables**							
Date of Sale	**0.0367** **(0.0001)**	**0.0391** **(0.0001)**	**0.0401** **(0.0001)**	**0.0432** **(0.0001)**	**0.0456** **(0.0001)**	**0.0473** **(0.0001)**	**0.0501** **(0.0001)**	**0.0509** **(0.0001)**
Season	-0.0442 (0.2754)	-0.0102 (0.7648)	-0.0176 (0.3734)	-0.0222 (0.1990)	**-0.0249** **(0.0857)**	-0.0133 (0.2836)	-0.0159 (0.1657)	-0.0155 (0.1544)
Spatial I	**Distance**	**Variables**						
Cedar Falls	0.0267 (0.4545)	0.0105 (0.8052)	0.0518 (0.1523)	0.0293 (0.3894)	0.0132 (0.6484)	0.0216 (0.3988)	0.0190 (0.4190)	0.0254 (0.3337)
Waterloo	-0.0153 (0.7341)	-0.0009 (0.9853)	0.0307 (0.4456)	0.0082 (0.8158)	0.0001 (0.9962)	0.0124 (0.6255)	0.0111 (0.6224)	0.0105 (0.6728)
John Deere	0.0063 (0.8500)	0.0157 (0.6605)	-0.0068 (0.8262)	0.0009 (0.9742)	0.0166 (0.4950)	0.0110 (0.6122)	0.0124 (0.5322)	0.0070 (0.7513)
UNI	-0.0282 (0.4985)	-0.0172 (0.7169)	-0.0640 (0.1078)	-0.0378 (0.3065)	-0.0270 (0.3958)	-0.0358 (0.1998)	-0.0335 (0.1860)	-0.0396 (0.1601)
City	**Binary**	**Variables**						
Cedar Falls Binary	-0.1464 (0.2293)	-0.1051 (0.4855)	0.0913 (0.4828)	0.1180 (0.3078)	0.1181 (0.2551)	0.1381 (0.1010)	**0.1408** **(0.0553)**	0.1129 (0.1210)
Waterloo Binary	-0.0280 (0.8723)	0.0927 (0.5280)	0.1018 (0.4333)	0.1094 (0.3328)	0.0583 (0.3260)	**0.1126** **(0.0969)**	0.0999 (0.1149)	0.0482 (0.4332)
Hudson Binary	0.0674 (0.6693)	0.0832 (0.5703)	0.0794 (0.5786)	0.1272 (0.3778)	0.1337 (0.3260)	0.1444 (0.2682)	0.1184 (0.3479)	0.0840 (0.5268)
Elk Run H. Binary	NA	NA	NA	NA	0.2397 (0.3017)	-0.0239 (0.8585)	-0.0722 (0.5361)	-0.0778 (0.4873)
La Porte City Binary	NA	NA	NA	NA	NA	NA	-0.2236 (0.3428)	0.0822 (0.5626)

Table 2 Maximum Likelihood Coefficients and p-values (continued)

Distance:	2 miles n = 309	2.5 miles n = 507	3 miles n = 1024	3.5 miles n = 1754	4 miles n = 2616	4.5 miles n = 3900	5 miles n = 4783	All n = 5822
CAFO	**Related**	**Variables**						
Ln Animal	-0.0682	-0.1173	**-0.1370**	**-0.0992**	**-0.1137**	**-0.0967**	**-0.0656**	**-0.0668**
Units	(0.3845)	(0.1049)	**(0.0292)**	**(0.0800)**	**(0.0229)**	**(0.0123)**	**(0.0150)**	**(0.0028)**
Manure	0.0851	0.0671	0.0390	0.0040	-0.0132	-0.0238	-0.0186	-0.0496
Application	(0.4612)	(0.4692)	(0.6062)	(0.9559)	(0.8395)	(0.6688)	(0.7090)	(0.2111)
Ln Min	0.0026	0.0300	0.0482	0.0217	0.0425	0.0216	0.0023	-0.0486
Distance	(0.9722)	(0.7046)	(0.5077)	(0.7479)	(0.4878)	(0.6925)	(0.8946)	(0.3392)
Count	0.0191	0.0351	0.0293	0.0279	0.0251	0.0182	0.0067	-0.0161
	(0.7187)	(0.5415)	(0.6048)	(0.6208)	(0.6475)	(0.7284)	(0.8946)	(0.7514)
Angle Wind	**-0.0049**	**-0.0017**	**-0.0011**	-0.0006	-0.0004	0.0002	0.0001	0.0002
	(0.0016)	**(0.0847)**	**(0.0213)**	(0.1089)	(0.1831)	(0.4455)	(0.5760)	(0.4180)
Season*	0.0028	0.0009	0.0004	0.0003	0.0002	-0.0010	-0.0004	-0.0003
Wind Angle	(0.4961)	(0.6746)	(0.8322)	(0.8265)	(0.8619)	(0.2262)	(0.5341)	(0.5476)
North	-0.01149	0.0288	0.0309	0.0204	0.0133	0.0260	**0.0303**	**0.0289**
	(0.8081)	(0.4586)	(0.2361)	(0.3967)	(0.0234)	(0.1634)	**(0.0525)**	**(0.0504)**
Spatial	**Correlation**	**Variables**						
Nugget	0.0201	0.0280	0.0251	0.0275	0.0269	0.0280	0.0280	0.0299
Sill	0.0407	0.0538	0.0580	0.0616	0.0586	0.0539	0.0505	0.0535
Range	0.0446	0.3307	0.3325	0.3880	0.3412	0.3452	0.3510	0.4575
Goodness	**of Fit**	**Statistics**						
-2 Residual Log Likelihood	57.9	-11.0	-271.7	-511.6	-900.3	-1452.4	-1887,7	-2184.3
BIC	74.9	7.6	-251.0	-489.3	-876.7	-1427.6	-1862.3	-2158.3

Endnotes

[1] The authors thank the Black Hawk County Board of Supervisors for providing the house sales data used in this study. The opinions expressed in this paper should not be interpreted as representing the opinions of the Black Hawk County Board of Supervisors.

[2] The effects of proximity to the second, third, etc. closest CAFO are not addressed in this study.

[3] Specifically, the PROC MIXED procedure in SAS is used to fit all of the models.

[4] Specifically, S-Plus is used to derive the seed values for the range, sill, and nugget in each model.