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Pigs in Space:

Modeling the Spatial Structure

of Interior US Hog Production from 1992-97

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Abstract: We estimate a reduced-form spatial lag model of county-level hog production and identify how sectoral agglomeration, input availability, firm productivity, market access, urban encroachment and local economic variables affect the locational pattern and intensity of hog production within 13 interior states during 1992 and 1997. We identify strong but declining agglomeration economies for both the hog sector and find that urban encroachment variables negatively (positively) affect the eastern (western) portion of the area considered.

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Introduction

Few sectors have undergone more rapid change in scale, structure and organization than has the US swine sector in the past two decades. Movement to large-scale, specialized production units reflects past trends in western cattle feeding and dairy enterprises while increasing vertical coordination of production with upstream suppliers and downstream processors resembles patterns adopted in the poultry sector several decades ago. Accompanying these changes in production has been a simultaneous change in the spatial organization of hog production within the United States. Industry analysts (Hurt, Drabenstott, Rhodes) have forwarded several stylized facts of this spatial reorganization: traditional Eastern Corn Belt states have lost in terms of national share of hog production to Southeastern, Great Plains, and Mountain states during the 1980's and 1990's as the firms offering swine production and marketing contracts attempt to locate large-scale facilities where there are few people, cheap land or cheap labor. Others have also noted that, with respect to the spatial location decision, the importance of the Corn Belt's sector-specific infrastructure, such as veterinarian services, hog buying stations and producers' cooperatives, may have retarded the adoption of innovative organizational forms which have stimulated large production increases in non-traditional hog production regions (Kliebenstein and Lawrence).

In addition to changes in the regional shares of hog production and the role of traditional sectoral infrastructure, the industry's reorganization has altered the distribution of hogs in another way: the intra-regional spatial distribution of hogs has become less uniform, leaving spatial haves and have-nots within each region (Hubbell and Welsh). The geographic consolidation of swine has consequences for localities whose hog production base changes. It affects the local supply and demand balances for key inputs and outputs, hence redistributing spatial price premiums; it alters the local economic throughput, with consequences for community economic viability; it alters the utilization of sector- and industry-specific infrastructure and services, potentially rendering infrastructure obsolete in some areas; and it concentrates nutrients from animal manure in fewer locations, which may trigger adverse environmental consequences and other externalities that may spark local community conflict. In particular the last concern has assumed greater importance in location decisions for hog production both because nutrient absorptive capacity may be the most site-specific of all necessary hog production inputs (Boehlje) and because a firm's intended siting of a large-scale hog operations often serves as a focal point for local and state discussions concerning the social efficacy of industrialized agriculture (Abdalla *et al*.). More generally, the reorganization in hog production is emblematic of the massive spatial and structural reorganization of economic activity that characterizes recent industrialization in agriculture and has potential consequences for the communities that gain new organizations or lose smaller existing operations.

To better understand the elements driving spatial change in US hog production, we posit a reduced-form model of the spatial organization of the hog production sector at the county level and estimate how numerous supply-side, demand-side and regional economic, population and policy factors have affected the spatial location and intensity of hog production within 13 interior states over the period 1992 to 1997. Our focus on spatial pattern provides a unique contribution to this literature that offers insight into which elements may shape the future of local hog production and helps to confirm and quantify many of the stylized facts forwarded in the literature. Spatial concentration is explicitly accounted for via a spatial lag model that uses centroid-to-centroid distance measures across counties to define the spatial extent of the lag. This allows us to explore whether agglomeration economies are present at the sector and industry levels by isolating the effect of neighboring hog production and other local livestock populations respectively on a county's hog production. The estimates provide strong explanatory power. By explicitly accounting for the spatial relationships among key variables that naturally arise in such spatially disaggregated models, we circumvent econometric problems that arise from non-spatial regression techniques.

The rest of the paper is organized as follows. In the next section we provide an overview of evolution of hog production and its spatial organization in the interior United States. Following this we introduce the model and then describe the data used in the analysis. We next discuss econometric methods employed in estimating the model and then present and discuss results. We conclude in the final section.

Interior US Hog Production: A Brief History

Prior to the early nineteenth century, the interior US swine sector was characterized by hog production on numerous, small, diversified farms scattered across the landscape roughly in proportion to the size of the predominantly rural, local populace. The high costs associated with herding live hogs over rutted trails to local slaughter houses, the limited possibilities for inter-regional exports due to undeveloped regional infrastructure and the relatively low fixed costs associated with the hog production technologies of this era meant that hog production was a local phenomenon. Hogs were predominantly grazed in nearby woods and fed surplus corn for several weeks before being slaughtered on farm for family consumption with modest excesses being preserved and sold locally (Towne and Wentworth).

As the 1800s progressed, interior corn production flourished and transportation costs fell with the introduction of interior canals, all-season roadways and railroads. In response, swine production systems quickly evolved from woods-based foraging systems to corn-based confinement systems. As economic location theory would suggest (see Kilkenny and Thisse for a review), when larger end-product markets emerge, but fixed costs of transportation and storage are still large, the optimal processing location moves from the location of the inputs to the location of markets. Indeed, small packing plants and slaughterhouses began to pop up in locations with favorable transit connections. Hog production began to cluster in interior states with good corn yields and in locations near to major water-based transportation systems such as Cincinnati and later near major railroad hubs such as Chicago. Midwestern pork quickly replaced eastern pork despite its lower perceived quality and initial lack of acceptance on international markets (Towne and Wentworth).

The Corn Belt solidified its historic position as the nation’s pork supplier because of its plentiful supply of corn and because of the development of reliable interregional transportation systems and has maintained this position for most of the twentieth century. However, the Corn Belt's historical dominance in hog production has begun to fade. The development of the interstate highway system has driven transportation costs even lower while efficient production technologies featuring high fixed costs have become central to firm-size considerations in the hog production sector (Rhodes). As fixed costs have increased, hog farmers have exploited economies of size to increase productivity and maintain profitability in this highly competitive sector. The profit-maximizing increase in hog farm size combined with slow growth in pork demand logically implies the net exit of individual hog farms – a perusal of any time series of hog farm numbers validates this intuition. Cheap transit costs and high fixed costs of hog production and slaughter has spurred processing to diverge from historical, urban, market-based locations and move to intermediate locations between input regions and end markets. In sum, this confluence of circumstances affords hog production firms considerable locational flexibility, implying that a wide array of factors is likely to shape the resulting spatial pattern of production.

3. Location and Hog Production

We are interested in explaining the presence of hog inventories and large-scale production in a given county. What makes a particular county a desirable place to locate hog production? An independent hog farmer might respond: a plentiful supply of feed; nearby access to several alternative slaughter outlets; a reasonably trained workforce to supplement family labor; a viable, local network of knowledgeable veterinarians, nutritionists and other swine-related professionals; low property taxes; and freedom from the interference of suburban sprawl that clogs traffic and draws protests from encroaching neighbors. Counties in which the farms are currently quite efficient with respect to swine production are often excellent candidates for expansion because they can rapidly incorporate and make profitable technological and organizational improvements that originated elsewhere, while counties in which the farmers struggle with efficiency would be less able to use these advancements without costly training.

Consider the objective of a representative farmer in county *i*:

$$(1) \qquad U(\pi_{i,t}(\mathbf{p}_{i,t}, \mathbf{w}_{i,t}) + n_i - q_i),$$

where $\pi_{i,t}$ is the per period profit from farming, n_i is the income generated from non-farm sources, q_i is the per period property tax paid, and $U(.)$ is the farmer's utility function, which is assumed to be monotonically increasing at a decreasing rate. Consider the following representation of the farmer's profit function:

$$(2) \qquad \pi_t = \mathbf{p}_i f(\mathbf{y}_i, \mathbf{x}_i, \boldsymbol{\varphi}_i) - \mathbf{w}_i \mathbf{x}_i - \mathbf{c}_i,$$

where $\mathbf{p}_i$ is a vector of output prices, $f(\mathbf{y}_i, \mathbf{x}_i, \varphi_i)$ is a multi-output production technology, $\mathbf{y}_i$ is a vector of outputs, $\mathbf{x}_i$ is a vector of inputs, φ_i is a vector of technology shifters, $\mathbf{w}_i$ is a vector of input prices and $\mathbf{c}_i$ is a vector of fixed costs associated with production and operations, e.g., fixed capital costs of new buildings and the fixed portion of the cost of meeting state environmental regulations and handling local complaints concerning operations. The supply of hogs, approximated in this paper by county hog inventory, will expand as the relative output price for hogs increases, as technology favoring hog production improves more rapidly than technology for other enterprises, as fewer resources are expended to accommodate environmental regulations and local complaints, as input prices for hog production drop, as local sector and industry infrastructure improves, and as property taxes are lowered.

We draw from the industry location literature (e.g., Bohm *et al.*; Goetz; Knapp and Graves) to formulate a general model of spatial location of hog production and production intensity. We consider several categories of variables: (i) sectoral and industry agglomeration proxies that affect $\mathbf{w}_i$ and $\mathbf{c}_i$; (ii) input availability variables that impact $\mathbf{w_i}$, (iii) firm productivity and specialization indicators that capture φ_i, (iv) market access measures that alter $\mathbf{p}_i$, (v) urban encroachment indicators that affect $\mathbf{c_i}$ and $\mathbf{w_i}$, and (vi) local economic variables that impact n_i, q_i and $\mathbf{w_i}$.

Data and Variable Construction

Agricultural data are taken from the 1997 and 1992 Census of Agriculture for 13 contiguous, interior states representing both traditional areas of hog production, namely Corn Belt and Lake states of Ohio, Michigan, Indiana, Illinois, Wisconsin, Missouri, Iowa and Minnesota, as well as areas of hog production in the Great Plains and Mountain states, including Nebraska, Kansas, Oklahoma, Colorado and Utah. Observations with missing variables are imputed rather than dropped because distance measures are used and because spatial continuity is crucial for the spatial lag model,.[1]

[1] For example, 1997 county-level hog inventories are suppressed for 86 of the 1,103 counties considered in the analysis; this represents 5.9 percent of the total hog inventories for the region. For each state with missing county-level variables, the authors calculate the number of hogs left unassigned within the Census of Ag and allocate them among the suppressed counties using several methods. First, if available, contemporaneous, county-level estimates published by state agricultural statistical services are drawn upon. Second, county-level total livestock receipts, which are rarely suppressed, are used to allocate the remaining hogs. Finally, county-level inventories from the 1992 Census of Agriculture are considered. Similar tactics are employed to impute suppressed observations in other agricultural data series.

Dependent Variables

Dependent variables considered are the natural logarithm of a county's total hog inventory, the natural logarithm of the average number of hogs per farm and the change in the natural logarithm of hog inventories.[2]

Agglomeration Variables

Smith and Marshall both recognized that, along with economies of scale that are exclusively beneficial to a particular firm, there existed economies of scale that are external to the firm but internal to a particular sector or to an entire industry. Existence of such 'localization economies' would imply that the performance of a single swine operation improves when other hog operations are located nearby. Such spillovers may arise because the presence of other operations facilitates a local, industry-specific infrastructure of service individuals and information, which enhances the performance of each individual operation through lower transactions costs and improved diffusion of financial, production and marketing information (for modern treatments of these concepts see Eberts and McMillen or Krugman). We capture localization economies within the hog sector by including a spatial lag (*Spacelag*) in the model which accounts for the number of hogs in neighboring counties within a given distance of the county of interest. We suspect the benefit of neighboring hog production decreases with distance; hence the lag weighs hogs from locations further away from the county in an inverse fashion, e.g., the number of hogs from a county 50 miles away is given a weight of 1/50.

Agglomeration economies can also arise from having a more general infrastructure in place that facilitates industry-wide production. Such benefits may arise

[2] We add one to all inventory and inventory per farm numbers before taking the natural logarithm to avoid problems of an undefined number for counties with zero values.

because, when many related industries locate near to one another, they can often draw from the same pool of laborers, technicians and services suppliers whose skills are specific to the livestock industry rather than to the swine sector in particular. As a proxy for industry-level agglomeration economies, we construct a variable that measures the county's receipts of all livestock except hog production (*Agglom*).

Input Availability

We include from the Census of Agriculture the county's corn (*Corn*) and soybean (*Soybean*) harvest in bushels as a proxy for local prices of raw feed ingredients. Given that the bulky nature of these inputs dictates relatively high transportation costs we hypothesize that greater local grain availability variables will be associated with larger hog inventories in a county and per farm. *Commfeed* is the ratio of total dollars expended in the county for commercially mixed feed for all types of livestock to the total dollars expended on all livestock feeds. This could approximate the availability of large-scale feed processing facilities within a county and may be correlated with lower input prices than counties without such facilities. On the other hand, very large and efficient operations may hire their own nutritionists and mix their own feed, hence reducing the amount of commercially mixed feed used. Hence we do not forward a prior expectation on the sign of *Commfeed*.

One of the most frequently mentioned stylized facts in the hog sector industrialization literature is that new, large hog production firms seek locations with plentiful, cheap land. Larger counties should be able to physically accommodate a larger total hog population. Furthermore, it may be easier to locate a large-scale facility in a larger county merely because there may be more tracts of land available for purchase;

i.e., there may simply be more places to choose from in a larger county, hence more degrees of freedom in the siting process. Hence, we include a measure of a county's total land mass (*Land Area*) and hypothesize a positive affect both for hog inventories and production intensity.

The quality and availability of local labor may also have an impact on the ability of larger hog operations to locate and operate efficiently in a given locale. We include measures of the 1990 and 1996 county unemployment rate (*Unemployment*) and data from the 1990 Census on the percent of county population with a high school degree or higher (*Education*). We expect higher unemployment to be favorable to hog production as more persons would be available to work. While a formally educated workforce is not necessary for hog production, it may improve the quality of workforce available. We hypothesize that areas with many highly educated individuals attract industries that require more formal education than does hog production, while counties with a populace lacking formal education may not supply enough individuals meeting a base level of education needed to manage hog operations and fill positions in hog production. Hence, areas with either a very high or a very low percentage of individuals with a high school degree may not be conducive to large hog operations.

We also consider the average participation by county farm operators in non-farm occupations (*Nonfarm Occ*). As a farm-based population becomes more involved in non-farm occupations it suggests the opportunity cost of farm operators' labor and management increases. We hypothesize that management of large-scale hog operations becomes less likely in counties with large proportions of farmers working off farm. However, smaller scale production may be compatible with off farm employment.

Hence, we do not forward a prediction for the effect of non-farm occupation participation on the level of all hog production.

Firm Productivity and Specialization

To control for local technological factors, we construct several variables from data reported in the Census of Agriculture. The first, *Turnover*, is a measure of productivity and equals total hog sales divided by total hog inventory. We hypothesize that counties populated by farms with newer facilities and superior management will show faster rates of gain in hog finishing operations and will report a higher *Turnover*. More productive breeding operations will produce more pigs per sow and also report a higher *Turnover*.

FF is an index of a county's lack of specialization in production between the breeding and finishing components of hog production and equals the sum of farms reporting sales of feeder pigs and farms reporting sales of 'other pigs' divided by the number of farms reporting the sales of any type of pig. For example, a county in which all farms specialize in one facet of production or the other would have a value of one while a county in which all farms participate in both farrowing and finishing would score a two. The hog production sector is evolving toward larger, specialized units that focus either in breeding or in finishing hogs (Kliebenstein and Lawrence). We hypothesize that counties populated with a higher percentage of specialized operations reflects a county that has more fully embraced industrialized production and, hence, will have a larger hog production sector as these specialized operations tend to rely on economies of scale to maximize profits. To see if one of these specialized segments (feeder pig production or feeder pig finishing) is associated with larger total hog populations, we consider the variable *%Sows*, which equals the ratio of sow inventories to all hog inventories. A county with a high percentage of sows may suggest that the cost of feeder pigs, which are inputs for the specialized finishing farms, will be lower and attract more total hogs. However, highly efficient operations will yield more pigs per sow, hence requiring fewer sows to meets it reproductive needs. Hence we do not forward a hypothesis on the sign of *%Sows*.

Market Access Measures

To approximate local hog demand conditions we calculate several measures of local hog slaughter capacity. These measures are based on the location of 73 large-scale hog slaughtering facilities located in 68 counties in the continental United States as identified by the National Pork Producers' Council (NPPC 1999); each facility was reported to have a daily slaughter capacity of 250 hogs or more in either 1992 or 1997.[3]

For each county we measure the straight-line distance from the county's geographical center to the geographical center of the closest county holding one of the 73 facilities (*MinDistance*) and expect more hog production in counties nearer to a slaughter plant.[4] We also measure the capacity of all plants located in the closest county with processing (*CapNear*) and expect a positive affect on hog production and intensity.

To allow for possible spatial competition among packing plants we also include a count of the total processing capacity in counties within 500 miles (*Cap500*) as well as a count of the number of counties with processing facilities within 500 miles (*Plant500*).[5]

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[3] Capacity data are published by NPPC starting in 1995. Capacities for 1992 are assigned by the 1995 published value except in the case of processing plants that exited operation between 1992 and 1995; for these cases NPPC staff estimated individual plant capacity (2000, personal communication).

[4] For counties that contain one of the 73 plants the distance was calculated as one-half of the square root of the county's land area; i.e., its assumed hogs will travel roughly half the distance across county to reach the plant.

[5] We chose 500 miles because it roughly represents a reasonable day's drive from farm to plant.

We hypothesize that more hogs will be located in counties with more plants and greater capacity within 500 miles of the county because spatial competition for hogs should be more intense.

Urban Encroachment and Population Characteristics

The existence and size of cities are typically explained by positive external benefits that are generated by the spatial concentration of businesses and households within a local economy. These externalities, also known as urbanization economies, may result from businesses sharing non-excludable inputs, such as public infrastructure, technical knowledge, and a common labor pool (Eberts and McMillen) or from demand and supply linkages within a large local market between producers and consumers (Krugman). These positive externalities imply increasing returns to spatial concentration, which lead to urban growth.

Certain sectors, however, may not reap the general external benefits of urbanized areas due to negative production externalities. For example, many authors have highlighted potential incompatibilities between large-scale hog production and human populations (Rhodes, Abdalla et al.) due to traffic, air and water externalities that may emerge and cause conflict between residential populations and hog production. In addition, localities experiencing rapid growth may exert more resistance to the siting or expansion of large-scale hog operations. Lastly, as population grows and as more land is converted from farmland into housing developments, there exist fewer acres to site hog production and, perhaps more importantly, to grow the bulky corn and soybean inputs. For these reasons, we hypothesize that diseconomies of urbanization exist with respect to hog production. We use county population (*Pop*) and the rate of county's population growth (*Popgrowth*) as proxies for this urbanization effect and expect both the absolute population and rate of population growth to negatively affect hog production in a county. To gauge the specific effect of land conversion, we include the per capita number of building permits issued in 1992 and 1997 (*BuildPermit*) as reported by the US Economic Census.[6]

Certain ethnic and cultural characteristics of the local population may also affect the prevalence of hog production. Specifically, the succession practice of some ethnic backgrounds, such as the traditional yeoman farmer cultures associated with German or Dutch ancestry, of seeking to accommodate the wishes of all children from a family that desire to stay in farming (Salamon). In farm families from other heritages, such as English or Yankee ancestry, it is common to accommodate only the oldest son's desire to farm while other children must pursue such enterprises on their own volition (Salamon). One method of developing the farm operation to accommodate the entry of multiple heirs in agriculture is to intensify production via livestock enterprises such as hogs. This minimizes the need for land, which is often difficult to obtain due to the lumpiness of transactions, and allows setup of the new operations within geographic proximity of existing family. We use 1990 US Census data and create an ethnic homogeneity variable that equals the percent of the county population to claim German or Dutch ancestry (*EthnicHomog*). We expect this variable to be positively related to county-level hog populations.

[6] 1992 and 1997 building permit numbers may not be directly comparable as the sampling technique used to develop these estimates are based upon a slightly larger universe of populated places in 1997.

Local Economic Conditions

Local economic conditions may affect the likelihood of hog production within a county. All else equal we would expect higher property taxes within a county to discourage new location of hog facilities. We include a measure of a county's average per capita property tax bill (*PropTax*). Counties experiencing low levels of economic growth may also be more apt to recruit large-scale operations and provide preferential tax or infrastructure alterations. To control for such counties we include a measure of the percent of the county's populace in poverty (*Poverty*).

Estimation Models and Procedure

A distinguishing feature of our model is the inclusion of spatial interaction among county-level hog production that stems from hypothesized intra-sector agglomeration economies. However, because hog production levels across counties are determined simultaneously,[7] these variables are endogenous and therefore, including them as regressors would lead to biased results. Similar to the approach taken in time series models, a standard means of addressing this problem in spatial econometrics is to parameterize the spatial lag structure by means of a spatial autocorrelation parameter and a spatial weights matrix (Anselin). A spatial weights matrix specifies the spatial relationship between each pair of values using a weighting scheme in which each element of the matrix corresponds to the relative magnitude of the spatial dependence between

[7] The actual process is likely to be recursive; however, because our data is limited to two snapshots in time, 1992 and 1997, we are unable to estimate a recursive structure and therefore treat the interaction as simultaneous.

pairs of observations. Formalizing the explicit spatial interaction among the dependent variable in this way produces a model of the general form:

(3) $y = \rho Wy + X\beta + \varepsilon$,

where y is an $Nx1$ vector of endogenous hog production variables in each of the N counties for a given time period, ρ is the scalar spatial lag coefficient, W is an NxN spatial weights matrix, X is the Nxk matrix of exogenous explanatory variables described in the previous section, β is a $kx1$ parameter vector to be estimated and ε is an $Nx1$ vector of normally distributed error terms with zero mean and variance σ^2.

A variety of different assumptions regarding the structure of the spatial weight matrix are possible. For the case at hand, the dependence is assumed to be a decreasing function of distance between any two locations. The weights are assigned by means of an inverse distance function, $w_{ij} = 1/d_{ij}$ where d_{ij} = distance between i and j measured in miles. At some distance, the effect of distant hog production should no longer affect local activity. Therefore an upper distance is typically chosen as a point beyond which all weights equal zero. The appropriate upper distance is an empirical issue; the models presented in this paper are estimated using several weight matrices and the weight matrix with the upper distance providing the best fit of the data is the one used in the estimation results reported in the paper. As Table 1 reveals, for two of the models used in this paper the upper distance of 200 miles provides the smallest Akaike's Information Criterion statistic while providing the second best fit in the other three models. To maintain consistency and comparability, we use a spatial weights matrix with an upper distance of 200 miles when estimating all models presented in this paper, although the results are quite robust to the particular weights matrix chosen.

In models featuring units of observation of different physical size (e.g. counties) and because the upper limit of total hog production is eventually limited by land area, intuition suggests errors may be correlated with the geographic size of the observation – in this case, county land area (*Land Area*). Hence we test for heteroskedasticity in an additive form using a spatially adjusted Breusch-Pagan test statistic that is distributed as a chi-square with one degree of freedom (Anselin).

We suspect that spatial dependence may also arise in the error terms; that is, residuals of counties near to one another may be correlated. Such correlation arises from data measurement errors. In cases for which the boundary of the spatial phenomena differs from the boundaries by which the unit of observation is defined, measurement error will produce errors that are spatially correlated. This would be true, for example, if a town's population is imperfectly measured and the boundary of one or more towns overlaps with more than one county. A second source of error is from omitted variables that are spatially correlated.

For each model we test for spatially correlated errors using a LaGrange multiplier test distributed as a chi-square with one degree of freedom (Anselin). The presence of spatial correlation of errors implies that the parameter estimates are unbiased but inefficient.

A maintained hypothesis of the model postulated in (3) is that the spatial location of hog production matters, but that the influence of space is constant across the geographic extent of the sample. However, the stylized facts of hog production suggest different patterns have emerged in the western portion of the sample. To test for such differences we estimate a spatial regimes model for several of the models; it takes the following form:

$$(4) \qquad \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \rho W \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} + \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix},$$

where y_j is an N_j *x* 1 vector of endogenous hog production variables in the N_j counties in the j^{th} portion of the sample ($N_1 + N_2 = N$), X_j is an N_j by k matrix of explanatory variables for the j^{th} portion of the sample, β_j is a k *x* 1 vector of parameters for the j^{th} portion of the sample and ε_j is an N_j *x* 1 vector of error terms. Classical hypothesis tests (an F-test) are then used to determine if parameters differ across spatial regimes.

All models are estimated via maximum likelihood methods. The exact variables used in estimation include those described in the previous section as well as the square of each variable; the use of squared terms allows us to capture non-linearity of a variable's effect on the endogenous variable while also allowing non-monotonicity of the effect. Squared terms are dropped from the model when clearly insignificant or when the squared terms are thought to create problems with collinearity.

Results and Discussion

Overall the model (Table 3) appears to fit the data quite well: the psuedo-R^2's reported for the two models, constructed as the degree of correlation between the predicted and actual hog inventories in each county (Anselin), are 0.75 and 0.67 for the 1992 and 1997 models, respectively. The residuals show no signs of spatial dependence nor do they reveal heteroskedasticity with respect to the variable *Land Area*.

County-level hog inventories are affected by variables from all five categories outlined above. The importance of agglomeration economies, both at the swine sector (*Spacelag*) and livestock industry (*Agglom*) levels, is confirmed for both periods, though the effect of neighboring swine production has a much larger elasticity. An one percent increase of hog inventories in the counties within a 200-mile radius is associated with more than a two percent increase in own county hog populations both in 1992 and 1997; a one percent increase in all other livestock receipts within the same county is associated with 0.1 percent larger hog inventories. Imposing the 1992 parameter value for the spatial lag onto the 1997 data results in a significant restriction as measured by a chi-square test statistic reported in the last column of Table 3; hence, it appears that the importance of sector-level agglomeration economies is increasing during the 1990's. That is, hog production is more spatially concentrated across counties in 1997 than it is in 1992. No such time trend is identified with respect to industry-level agglomeration economies, however.

A couple of interpretative notes are in order concerning spatial concentration. First, because our unit of observation is the county, our results apply only to inter-county spatial concentration patterns of hog production and one can draw no conclusions about the spatial concentration within a given county. The logical implication of work by Abdalla *et al*. is that, due to co-emergent nutrient concentrations from manure, individual farms may find it necessary to spread out from one another. We suspect that our unit of observation is too coarse to capture the full effect of such activity, if it does indeed exist.

Second, it is constructive to compare the definitions of spatial concentration used in this study to the Hubbell and Welsh definition of spatial concentration. Note that

Hubbell and Welsh employ an entropy measure and that such measures are not spatially articulate -- distances between individual units of observation are never considered. Rather, entropy measures represent the equality of distribution of a given level of hog production across heterogeneous units without regard to the spatial pattern of these units, which, particularly for the purposes of gauging environmental consequences of distribution, is crucial.[8]

Variables representing the availability and quality of inputs to production are associated with moderate elasticities. For example, as intuition and history suggest, the availability of corn within the county is a key spatial determinate: a one percent increase in county corn harvest in 1997 is associated with a 0.45 percent larger in hog population. Though some have noted the separation of feed production and livestock production enterprises (Breimyer) and suggested that local availability of corn is no longer a limiting factor for siting large hog operations (Abdalla *et al.*), the data suggests that it is still quite important and that this importance has, in fact, increased significantly from 1992 to 1997. The availability of soybeans is also a positive influence on hog populations though it is not a significant variable in 1997 and has a much smaller elasticity than corn during both periods. A county's feed processing capacity, as approximated by the reliance of a county's livestock industry on commercially mixed feed, is also positively related to hog inventories.

Sheer land mass of a county exhibits an initially increasing quadratic effect in which a one percent decrease in available land area in a county in 1992 is associated with

[8] For example, if two counties in a state held all the hogs they would yield the same entropy measure of concentration whether the two counties are adjacent or whether the two counties are on opposite ends of the state. The former (latter) pattern would result in a positive (negative) spatial lag measure using the techniques of this paper.

a 0.59 percent decrease in hog inventories when evaluated at sample means. The 1997 elasticity is significantly smaller, perhaps reflecting the reduced reliance on home raised corn, particularly in western states.

Cheap labor is often cited as a reason for hog expansion in the Southeastern US. With respect to labor inputs in this sample of interior states, the elasticity with respect to unemployment is positive at the means in 1992 and calculated from statistically significant coefficients. The coefficients reveal that hog inventories are initially increasing with unemployment up to the six percent mark (slightly above the simple sample average) and then decreasing thereafter. In 1997 the same elasticity is negative though calculated from insignificant coefficients. With respect to quality of labor, approximated by the percent of the county population with a high school education or higher, 1992 displays a positive elasticity while 1997 displays a negative elasticity. The coefficients for each year suggest a quadratic relationship in which counties with very high and very low populations of formally educated individuals house fewer hogs than those with an average number of individuals with high school diplomas or more.

Counties in which a higher percentage of farmers declare a non-farm occupation as a primary livelihood are associated with lower hog populations; this is significant in both time periods and features a similar elasticity in each period. In these areas the opportunity cost of the labor and management skills of farm operators may be so high that intensive operations such as hog production are less attractive.

The model also reveals several important productivity and specialization measures as significant predictors of county-level hog populations. Counties in which hog farms feature a high *Turnover* ratio tend to have more hogs, though this relationship is not significant in the 1992 data. Hence counties that are endowed with certain physical capital or that have a history of certain management organization that makes them productive, in terms of hogs marketed per unit of inventory, tend to attract larger hog inventories. Interestingly, counties in which farms do not specialize in either feeder pig production or hog finishing, but rather engage in farrowing and finishing enterprises (which is associated with a larger *FF* variable) are associated with larger total inventories both in 1992 and 1997. Hence, counties with specialized herds do not attract larger populations in general.[9] However, if a county's inventory has a larger percentage of sows, it is associated with smaller total county population of hogs. Farrowing operations are more labor intensive and, given a fixed resource base, a county with a high percent of hogs may be able to sustain fewer total hogs.

Market access variables are significant predictors of county hog populations. The distance to the nearest county with a major slaughter facility is significant and negative, though it decreases at a decreasing rate in both time periods. For both time periods a one percent increase in straight-line distance to the nearest county with a large-scale slaughter facility decreases hog population by about 0.8 percent. The capacity of this nearest slaughter facility is significant in the 1997 data only, but it has a very strong effect during this time period: a one percent increase in capacity is associated with a nearly four percent increase in total hog inventory.

Not only is the nearest slaughter plant important for predicting hog inventories but also is the number and capacity of plants within a 500-mile radius of the county is also predictive. In 1992 the total capacity in this radius is not significant but a one percent

[9] Another possible explanation may exist. Farms may have separate, specialized units operating in the same county but reporting inventories under the name of the same farm. Hence, the variable may not be

increase in the number of plants is associated with county hog populations that are 1.4 percent larger. In 1997 we see a richer pattern emerge: the number of plants within 500 miles is associated with larger hog numbers but greater slaughter capacity is associated with smaller hog numbers. This means that, holding the number of plants within 500 miles constant, larger hog inventories are associated with smaller processing capacity; e.g., larger inventories are observed if a county is serviced by two plants with a total daily slaughter capacity of 6,000 than if it were serviced by two plants with capacity of 12,000. In fact, these figures would suggest that merely adding one plant with a daily slaughter capacity of 15,000 hogs within the 500-mile radius of the average county would actually be associated with a hog inventory that's nearly 14 percent smaller. This result may stem from the presence of large-scale slaughter facilities where some portion of the capacity is reserved for captive supplies. In such a case, available capacity is overstated and thus would be associated with smaller total county inventories. If we extend the previous example of adding one plant with a daily slaughter capacity of 15,000 hogs such that this additional plant is now a county's nearest plant and the minimum distance to slaughter decreases by 20 miles, our model would predict a 72 percent increase in hog inventories.

The model substantiates that urbanization variables significantly impact the spatial pattern of hog production. Verifying anecdotal evidence and common intuition, human population within a county is negatively associated with hog inventories both in 1992 and 1997 and the strength of the association is increasing over time. In 1997 this negative association is quadratic and does not turn positive until a county's human population surpasses 3.6 million. In 1997 a one percent increase in human population is associated with 0.11 percent fewer hogs. The preceding period's population growth rate

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fully capturing the extent to which specialized production units exist.

does not retard hog inventories; on the contrary higher human growth rates are associated with higher hog populations. However, per capita building permits do significantly hinder hog inventories: a one percent increase in per capita building permit issuance is associated with 0.3 percent fewer hogs. In sum these variables suggest urban encroachment steadily drives down a county's hog population. For example, comparing the average county with one that has a one percent larger population, a one percent higher human population growth rate and one percent more building permits per capita predicts that the later county will have 8.9 percent fewer hogs. Later we will see that these figures vary in magnitude and sign between the eastern and western counties in this dataset.

The presence of a highly homogenous population with German and Dutch ancestry is strongly associated with higher hog populations. Both during 1992 and 1997 the model predicts counties with one a percent more homogenous population carry inventories of greater than one percent more hogs. Hence it appears that local farm operator culture and patterns of succession associated with ethnic heritage may have a strong influence on the pattern of hog production.

Local economic variables also influence the spatial pattern of hog production. The average per capita property tax bill has a significant, negative association with inventories though this reverses for property tax rates about two standard deviations higher than average. A one percent larger tax burden is associated with about a 0.59 percent smaller hog population suggesting that hog production is responsive to local policy variables. Counties with higher poverty rates are associated with larger hog populations in 1997 though for poverty rates of 17 percent (13.8 is the simple average poverty rate) hog inventories begin to decrease, all else equal.

Spatial Regimes

Stylized facts suggest that the share of hog production contained in traditional Corn Belt and Lake states has decreased during the last two decades while production in the Great Plains and Mountain states, fueled by the entry of large, horizontally contracted and vertically aligned facilities, has increased in relative size. This suggests that the eastern states within our sample are involved in a more organic, or perhaps more atomistic, evolution of the industry while western state's growth is dependent upon the decisions of a smaller number of key economic agents. To analyze these stylized differences between the two regions we estimate a model that segments the 13 states into two spatial regimes: eastern states (Ohio, Indiana, Michigan, Wisconsin, Illinois, Iowa, Minnesota, Missouri) and western states (Nebraska, Kansas, Oklahoma, Colorado and Utah).

Table 4 lists the estimates from the spatial regimes model for the 1997 data and, in virtually all spheres of variables, sharp differences across the two regions appear. Indeed a likelihood ratio test confirms that pooling the data across the regimes is a significant restriction of the model (χ^2 (30) = 108.68, $p < 0.001$).

Agglomeration economies across other livestock industries are positive and significant for both regions with a significantly stronger effect in eastern counties. This is consistent with Kliebenstein and Lawrence's observation that traditional areas of production rely more heavily upon existing infrastructure. Areas of new, rapid growth, such as the western states, may instead rely upon infrastructure transplanted by the coordinated players in the sector. Such a characterization appears to hold for the general livestock arena as well – other species of livestock are more attractive to hog inventories in eastern states. This may also suggest less inter-species competition for feed inputs and nutrient capacity in the east.

Among input variables the most glaring difference is that the western state's hog inventories are attracted to counties with greater land areas, which confirms anecdotal evidence forwarded in the literature. One percent more land implies 1.04 percent more hogs while land area is an insignificant determinant of eastern counties' hog inventories.[10]

A different reliance upon local feed supplies is also uncovered. Eastern inventories are more sensitive to local grain harvests, with corn and soybean elasticities being at least twice that of western elasticities, though the parameter estimates are not significantly different. Western counties' hog inventories are significantly determined by commercially mixed feed usage while eastern counties' are not. This paints a traditional picture of eastern production; feed is grown in nearby fields and fed to local animals while western production is located near commercial feed mixing facilities that may import raw grains in from other regions for processing and sale to larger facilities.

The spatial regimes model also reveals a different relationship between hog production and non-farm occupations between eastern and western states in the sample. No significant relationship is found in the eastern states while in the western states counties with higher rates of non-farm employment have significantly fewer hogs. This may be due to the prevalence of very large operations in western states; such operations may preclude off-farm participation by the operators. Eastern operators may manage one

[10] This result is not merely an artifact of larger western counties; western states have larger counties on average (1129 square miles vs. 614), but there is considerable range in both subsamples' land area (ranges of 7,670 and 6,480 for west and east, respectively).

or two large hog finishing units while either operating a diversified farming operation or working in a non-farm occupation.

The efficiency factor of *Turnover* has no significant association with hog inventories in western states but is significantly and positively related to larger hog inventories in the Corn Belt states. This reinforces a vision of atomistic devolution in eastern states: only the most efficient operations remain. However, current efficiency may not be a necessary precursor for future growth in hog production in the western states due to the siting of larger operations that bring with them much of the specialized equipment and management advice to foster productivity.

Market access variables are significant in both regions. The distance to the nearest processor is of key importance in both regimes but exhibits an elasticity of greater than one only in the western states. Capacity of this nearest processing center is significant and positive for eastern states while, somewhat surprisingly, negative for western states. This may stem from the emerging pattern of a few, intense, isolated production sites in the western portion of our sample. A new, large slaughter facility may be built to accommodate intense production in a few counties. However, these few, intense counties are often surrounded by many low hog production counties that also count the new slaughter facility as the counties' closest processing and cause the coefficient on nearby slaughter capacity to be negative.

Perhaps one of the most compelling differences between the two regions is the interaction between hog production and the local human population variables. In the eastern sample, human population is a significant negative influence on hog inventories, while in the west, larger human populations are associated with larger hog inventories.

Population growth has a similar, significant, positive effect on hog populations in both regions. Only in the eastern counties, however, does per capita building permit activity have a significant negative effect on hog inventories. Hence, the western states appear more accommodating to hog expansion with respect to urban encroachment; not only are there fewer people in most western counties but sheer population numbers are a positive influence on hog production in all but the largest of counties and building activity does not crowd out hogs, perhaps because there is less dependence upon local grain stocks. The positive effect of population on hog production may stem from the need for some minimum amount of infrastructure (e.g., roads) to support production; in the western counties such infrastructure may be positively associated with human populations. The east is more uniformly populated and has a more uniform coverage of land by roads; here too many people simply crowd out hog production. Finally, ethnic homogeneity is insignificant in the western states but significant in eastern states, suggesting the effect of yeoman farm culture is principally an eastern phenomenon.

With respect to local economic variables, property tax has a negative elasticity in the western states and retains a negative effect on hog production for nearly the entire universe of observed property tax rates. In the east, property taxes retard hog inventories once property tax rates exceed the average property tax; i.e., all else equal, the highest hog inventories can be expected at average property tax rates. Similarly, in the east, counties with average poverty rates have, *ceteris paribus*, the largest hog inventories; western states' hog inventories are monotonically increasing in poverty though the coefficients are insignificant.

Modeling County-Level Changes in Hog Inventories

A model of the change in the natural log of hog inventories from 1992 to 1997, for the entire sample as well as the eastern and western samples, is presented in Table 5. This model yields a weaker fit of the data and reinforces many of the patterns revealed in the models of inventory levels in 1992 and 1997. Several unique insights do emerge from this model, however.

First note that in both the full sample and in the spatial regimes model of change the spatial lag coefficient is negative, which is opposite of the positive values found in the levels models presented above. Though the spatial lag estimates do not quite reach the 10 percent level of statistical significance, we believe this underlines an emerging tendency for increases in hog production to be negatively correlated in space. That is, while the spatial pattern is still clustered, the changes in inventories are negatively correlated across space. This may simply underscore the emerging story of spatial haves and have-nots. Production is spatially clustered due to historical artifacts and due to agglomeration economies. However, consolidation of production implies that production will concentrate in fewer locations, so that increases in hog production must occur unevenly across neighboring counties that have historically high production levels.

In the western subsample, the agglomeration variable for other livestock species is negative and nearly significant, suggesting that counties targeted for increases in hogs may attempt to avoid other livestock species, perhaps in an attempt to reduce spatial competition for feed inputs and nutrient absorption capacity.

Another unique aspect of the model of inventory change is the inclusion of the 1992 level of county hog inventories and hog intensity as regressors. The beginning level of inventories had no significant effect on the overall model of change or on the eastern states' model, but is significant and negative with respect to hog expansion in the western subsample. That is, in western counties lower initial inventories of hogs are associated with higher rates of hog inventory growth, suggesting that counties with less recent experience in hog production were targeted for expansion. For all counties and both subsamples, having larger farms in 1992 is a positive predictor of future growth, particularly in the western subsample. Together, this paints a picture of the eastern states as a region where counties with large farms get larger, while in the western states counties with fewer hogs initially concentrated on fewer farms attract more hogs during the next period.

Production Intensity Model

The previous models elucidate the factors affecting the total number of hogs in a given county and the clustering patterns across counties but fail to directly address the spatial distribution of hogs within a county. A model of production intensity provides some understanding of clustering within a county as larger farms imply geographic concentration within a county, though no inference can be made as to whether farms are near to one another within a given county. While any size operation can produce environmental externalities, large-scale operations have been targeted for regulation and are often the center of local debate and strife with regard to negative, local spillovers. Spatial lag models with the natural log of the average number of hogs per farm are estimated for both 1992 and 1997. Several key variables provide significant explanatory power.

In both periods the spatial lag element is positive and significant, suggesting large hog operations are more likely to locate near other counties with large-scale hog operations. We do note, however, that, contrary to the time trend in total hog populations, the spatial lag in per farm hog intensity is significantly smaller in 1997 than in 1992 and may reflect the need to distribute these large-scale operations further apart across the landscape for reasons of nutrient sustainability. Similarly, agglomeration economies across other livestock industries are positive and significant in both periods, suggesting a general infrastructure created by the presence of other types of livestock is attractive to larger hog farms. As in the case of the spatial lag of hog farm size, however, this variable's importance has significantly diminished from 1992 to 1997, suggesting a possibly larger competition among different livestock species to claim both the harvest and absorptive capacity of local croplands.

With regards to input variables, both corn and soybean production affect hog farm size, though the effects are not uniform through time. Greater county corn yield facilitates larger hog farms in both 1992 and 1997 though only the 1997 estimates are significantly different from zero. Commercial feed production, while insignificant in both periods, does exhibit a significant time trend -- larger operations increasingly locate in counties with a high percent of commercially mixed feed inputs.

Within human capital proxies, counties with a higher percentage of operators in non-farm occupation house smaller operations. Within productivity proxies, counties with higher *Turnover* harbor larger operations, though this effect is only significant in 1997. Counties featuring more operations with both farrowing and finishing in the same farm tended to have larger hog farms, with a significant effect in 1997, while counties featuring a higher percent of hog inventory as sows have significantly smaller operations in both periods.

Market access variables have a significant impact upon average size of hog farm within a county: a one percent decrease in the minimum distance to the nearest county with large-scale processing is associated with a 0.46 and 0.31 percent increases in hog farm size in 1997 and 1992, respectively. The capacity of this nearby processing county has different effects in the two periods. In 1992 this capacity is not a significant predictor of farm size while in 1997 it has a positive, significant effect; a one percent expansion in this nearby processing capacity increases farm per size by 0.17 percent. The number of plants within a 500-mile radius of the county is a positive, significant influence on hog farm size in both periods, with a significantly larger elasticity in 1997. The capacity within this same radius is positively related to farm size in 1992, though it is insignificant. In 1997, however, larger capacity (holding constant the number of plants) becomes a negative influence on hog intensity.

Urban encroachment variables also impact hog intensity, though these effects change over the 1990's. Total population has no significant effect on size of hog farms in 1992 and, in fact, more rapid population growth is a positive, significant influence on hog farm size. By 1997 larger human populations repel larger hog operations and the pace of this population growth is no longer a significant factor in determining hog farm size. In both periods the per capita building permit variable has a similar, significant, negative impact on the size of hog farms within the county.

The story of ethnic homogeneity, which has been associated with larger total populations of hogs in counties with a concentration of Dutch and German ancestry, is also associated with larger hog farms in 1992. However, by 1997 this association is negative though insignificant, perhaps indicating that while this family structure begets more hog farms, that these farms are not of the same scale as the largest of new hog farms.

Local property taxes are negatively associated with large hog farms, both in 1992 and 1997, though the statistical significance of this result fades in 1997. In both periods, holding all else equal, the smallest farms would occur at about three times the average per capita property tax.

Conclusions

Firm-internal scale economies, firm-external/industry-internal scale economies (localization economies), firm-external/industry external scale economies (urbanization economies), and transportation costs are often cited as the basic factors affecting firm location (Eberts and McMillen, Krugman, and Kilkenny and Thisse). This research attempts to shed light on the role of three of these factors – localization economies (both within the hog sector and general livestock sector), urbanization economies, and market access – in the spatial evolution of hog production.

Hog sector specific infrastructure and livestock industry infrastructure emerge as an important component of hog production location, as evidenced by positive and significant spatial lags in the data. However, the data suggest that this infrastructure in the eastern sample of this data is location specific and depends on historical hog production patterns. Western states, on the other hand, whose production capacity has been boosted via capital infusion from horizontal and vertical production contracts, may have replaced the need for location specific infrastructure with firm or supply chain specific infrastructure, perhaps signaling a weakening of location-specific inertia in hog production.

It is clear that, at least in the eastern portion of this study region, hog production does not benefit from a robust local economy that houses a substantial workforce and varied pool of other industrial specialties. The massive reliance on land-intensive feed stuffs, particularly in the eastern portion of our data, and the direct conflict with increasing eastern populations revealed by the analysis suggest that hog production in these states is undergoing an atomistic devolution in which only counties with large, highly productive farms and lower population and building activity retain or increase production. In the west, larger counties with favorable property taxes and depressed local economies attract hog production -- even in the presence of larger human populations and building activity. These differences may be driven by the west's lesser reliance on local feedstuffs, greater dependence on commercially mixed feed grown in other regions, and more sites to choose from when locating large-scale operations.

Finally, market access variables suggest that the presence of large local processing plants has become increasingly important in determining the location and intensity of hog production, particularly in the western counties considered in this paper. The number of slaughter plants within a day's drive of a county is also of increasing importance, perhaps due to the simultaneous consolidation within the hog processing sector.

These results do show that counties may be able to shape the future level of hog production. In western counties, localities may wield local policy instruments, such as the property tax rate, to alter the siting of hog facilities within the county, suggesting that standard policy tools used in industrial recruitment models transfer to industrial agriculture. In the eastern counties policies that affect human population levels and building activity seem to have stronger correlation to hog production activity, suggesting a different, non-traditional set of policy variables may be relevant to successful recruitment or repellant of large-scale hog production.

Future directions of research must consider the location of hog production at a more refined resolution, so that issues of nutrient absorptive capacity that are often crucial for local environmental health and, hence, local community acceptance, can be studied directly. Though the data requirements for such an undertaking are immense, we feel it would be fruitful. Another interesting direction is to consider the question of vertical coordination more directly by estimating models that endogenize the movement of processing capacity through time to the movements of production.

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Table 1. Akaike's Information Criterion for Selecting Spatial Weights Matrix.

Model	50 Miles	100 Miles	200 Miles	300 Miles
1997 Ln(Hogs)	4031.49	4027.60*[A]	4030.35	4039.55
1992 Ln(Hogs)	3464.78	3458.18	3456.03*	3464.66
1997 Ln(Hogs per Farm)	3518.06*	3519.02	3518.99	3521.93
1992 Ln(Hogs per Farm)	2688.85	2683.21	2678.93*	2692.61
Ln(97 Hogs) – Ln(92 Hogs)	1985.28	1985.26	1984.99	1751.44*

A - * denotes the distance matrix that provided the best fit with the data as measured by Akaike's Information Criterion.

Table 2. Summary Statistics

VARIABLE	Mean	Std. Dev.	Min	Max
Cornbelt State	0.67	0.47	0	1
Ln(Hogs) – 97	8.86	2.54	0	13.72
– 92	9.18	2.25	0	13.31
Change: Ln(Hogs)	-0.022	0.62	-4.65	6.21
Ln(Hogs/Farm) – 97	5.30	1.65	0	10.62
– 92	5.03	1.24	0	8.76
Corn – 97	6,512,468	7,639,331	0	47,087,380
– 92	6,676,361	8,106,327	0	51,671,510
Soybean – 97	1,783,436	2,138,321	0	14,573,950
– 92	1,440,684	1,883,073	0	13,995,760
CommFeed – 97	0.48	0.21	0	0.97
– 92	0.39	0.19	0	0.99
Land Area	785.31	705.47	86.67	7820.7
Unemployment – 96	4.62	2.28	1	16
– 90	5.69	2.76	0.5	20.9
Education – 90	74.63	7.15	46.9	95.5
Nonfarm Occ – 97	0.46	0.12	0.12	0.82
– 92	0.41	0.13	0	1
Turnover – 97	1.99	0.67	0	3.75
– 92	1.91	0.56	0	3.6
FF – 97	1.13	0.10	1	2
– 92	1.20	0.10	1	2
% Sows – 97	0.14	0.090	0	1
– 92	0.14	0.076	0	1

VARIABLE		Mean	Std. Dev.	Min	Max
MinDistance	– 97	105.43	78.84	7.98	415.23
	– 92	101.47	6,907.73	7.98	428.60
CapNear – 97		7561.37	5,566.06	250	17,000
– 92		6,447.14	5,085.54	250	17,000
Cap500 – 97		225,908	84,778.16	650	321,350
– 92		213,780	81,634	1,500	305,050
Plant500 – 97		26.86	9.61	1	39
– 92		28.08	10.25	1	43
Population	– 97	63,451.75	209,458	382	5,187,717
	– 92	60,937.78	205,784	452	5,128,681
Popgrowth: 92-97		0.033	0.063	-0.40	0.44
87-92		0.010	0.057	-0.17	0.47
BuildPermit	– 97	0.0044	0.0057	0	0.079
	– 92	0.0034	0.0042	0	0.04
EthnicHomog – 90		0.42	0.15	0.035	0.83
PropTax – 92		1039.20	1,529.41	50	6442
Poverty – 93		13.87	5.51	2.20	48.7
Agglom – 97		30,348.45	54,821.24	5	1,043,662
– 92		29,944.99	50,847.86	0.04	968,289

N = 1103.

Table 3. 1997 and 1992 Spatial Location Models: Ln(Hogs).

Variable	1997 Model Estimate	Z-Value	Elasticity	1992 Model Estimate	Z-Value	Elasticity	χ^2 Test of Time Stability[A]
Input Availability Variables							
Corn	6.97E-08	*[B]5.20	0.454	3.85E-08	*3.86	0.257	*51.22
Soybean	6.59E-08	1.40	0.118	7.93E-08	**2.01	0.114	0.79
CommFeed	0.79	*3.21	0.378	0.68	*3.12	0.265	1.71
Land Area	0.00068	*3.34	0.450	0.00091	*5.82	0.592	*12.61
Land Area^2	-6.78E-08	**-2.08		-9.98E-08	*-3.95		
Unemployment	-0.10	-1.27	-0.538	0.12	**2.34	0.035	*466.46
Unemploymnt^2	-0.0018	-0.31		-0.01	**-2.20		
Education	0.37	*4.09	-0.234	0.16	**2.23	0.802	*29,486.10
Education^2	-0.0025	*-4.03		-0.0010	**-2.08		
Nonfarm Occ	-1.58	**-2.53	-0.729	-1.83	*-4.14	-0.750	**6.36
Productivity and Specialization Variables							
Turnover	0.15	**2.13	0.298	0.07	1.04	0.134	*13.72
FF	1.65	*3.64	1.864	1.17	*3.20	1.400	*148.54
%Sows	-2.13	*-3.83	-0.303	-3.52	*-6.87	-0.502	*27.48
Market Access Variables							
MinDistance	-0.008	*-3.58	-0.802	-0.01	*-7.56	-0.803	*95.40
MinDistance^2	1.85E-06	0.31		1.03E-05	**2.22		
CapNear	3.57E-05	*3.94	0.270	-7.74E-06	-0.88	-0.050	*84.17
Cap500	-2.92E-05	*-8.14	-6.597	2.59E-07	0.10	0.055	*26,129.70
Plant500	0.29	*8.75	7.789	0.05	**2.52	1.404	*23,875.55

	1997 Model			1992 Model			χ^2 Test of Time
Variable	Estimate	Z-Value	Elasticity	Estimate	Z-Value	Elasticity	Stability[A]
Urban Encroachment and Population Characteristic Variables							
Population	-1.84E-06	*-4.12	-0.115	-8.45E-07	**-2.37	-0.052	*9.61
$Population^2$	2.57E-13	**2.39		-1.56E-14	-0.18		
Popgrowth	2.69	**2.46	0.088	4.91	*4.96	0.050	*13.45
BuildPermit	-73.39	*-3.89	-0.310	-132.03	*-6.37	-0.399	*46.17
$BuildPermit^2$	415.95	1.23		2140.69	*3.05		
EthnicHomog	2.62	*5.48	1.103	3.16	*8.37	1.330	*29.97
Local Economic Condition Variables							
PropTax	-0.0008	*-4.09	-0.594	-0.0008	*-5.19	-0.585	1.11
$PropTax^2$	1.10E-07	*3.78		1.14E-07	*5.00		
Poverty	0.06	***1.80	0.139	0.026	0.95	-0.063	*57.31
$Poverty^2$	-0.0018	**-1.99		-0.0011	-1.45		
Agglomeration Variables							
Spacelag	0.25	*3.74	2.229	0.22	*3.87	2.031	*45.40
Agglom	3.66E-06	*3.65	0.111	3.88E-06	*4.63	0.116	0.08
Constant	-10.75	-3.10		-2.03	-0.73		*39,319.98
Diagnostics							
Psuedo – $R^{2,\ C}$	0.67			0.75			
Likelihood	-1984.17			-1697.01			
Spatial Error Test[D]	0.10			1.57			
Heteroscedas-ticity Test[E]	0.80			2.33			

N = 1103.

A - Likelihood ratio test, distributed as a chi-square with the number of degrees of freedom equal to the number of parameters involved in the test, that imposing the 1992 parameter(s) on the 1997 model is not restrictive.

B - *, **, *** denotes statistical significance at the one, five, and 10 percent levels, respectively.

C – Psuedo-R^2 is defined as the correlation between the sample's actual and predicted endogenous variable.

D – LaGrange multiplier test, distributed as a chi-square with one degree of freedom, that the model's residuals are not spatially correlated.

E - Modified Breusch-Pagan test, distributed as a chi-square statistic with one degree of freedom, that the models errors conform to linear heteroscedasticity in the variable *Land Area*.

Table 4. 1997 Model of Ln(Hogs) by Spatial Regimes: Eastern and Western States.

	Eastern States			Western States			F-Test of Spatial Stability[A]
Variable	Estimate	Z-Value	Elasticity	Estimate	Z-Value	Elasticity	
Input Availability Variables							
Corn	7.38E-08	*[B]3.28	0.57	4.97E-08	*2.93	0.18	0.73
Soybean	4.89E-08	0.68	0.12	1.45E-07	1.11	0.06	0.41
CommFeed	0.30	0.99	0.16	0.90	***1.95	0.24	1.16
Land Area	-3.40E-04	-0.94	-0.15	1.31E-03	*5.05	1.04	*13.76
Land Area^2	7.26E-08	1.13		-1.71E-07	*-4.35		*10.40
Unemployment	-0.10	-1.04	-0.61	-0.11	-0.69	-0.29	0.00
Unemployment^2	-1.81E-03	-0.26		3.96E-03	0.32		0.16
Education	0.13	1.14	1.06	0.34	1.62	-2.79	0.77
Education^2	-7.88E-04	-0.99		-2.46E-03	***-1.80		1.12
Nonfarm Occ	-0.81	-0.99	-0.39	-3.53	*-3.22	-1.34	**3.97
Productivity and Specialization Variables							
Turnover	0.15	***1.74	0.31	0.10	0.89	0.19	0.12
FF	0.91	1.47	1.03	1.80	*2.90	2.14	1.03
%Sows	-3.18	*-4.36	-0.43	-1.62	***-1.92	-0.23	1.95
Market Access Variables							
MinDistance	-0.01	*-2.64	-0.41	-0.01	*-3.87	-1.41	1.03
MinDistance^2	2.28E-05	1.62		1.45E-05	*1.67		0.25
CapNear	4.74E-05	*4.87	0.37	-5.43E-05	**-2.38	-0.29	*16.75
Cap500	-3.02E-05	*-6.24	-6.86	-1.88E-05	*-2.69	-2.99	0.04
Plant500	0.31	*6.85	8.45	0.24	*3.80	4.54	0.75

	Eastern States			Western States			F-Test of Spatial Stability[A]
Variable	Estimate	Z-Value	Elasticity	Estimate	Z-Value	Elasticity	
Urban Encroachment and Population Characteristic Variables							
Population	-2.49E-06	*-5.09	-0.19	6.04E-06	**2.34	0.18	*10.52
Population^2	4.11E-13	*3.63		-7.84E-12	***-1.91		**4.06
Popgrowth	2.60	***1.69	0.09	3.57	**2.15	0.02	0.18
BuildPermit	-157.34	*-3.79	-0.50	-26.69	-0.94	-0.08	*6.74
BuildPermit^2	4625.89	***1.85		18.50	0.04		***3.31
EthnicHomog	2.59	*4.50	1.15	1.11	1.18	0.42	1.80
Local Economic Condition Variables							
PropTax	2.28E-03	***1.90	0.02	-7.03E-04	*-3.08	-0.66	**5.94
PropTax^2	-2.11E-06	**-2.34		9.33E-08	*2.84		**5.96
Poverty	0.11	*2.80	0.10	0.01	0.13	0.30	1.66
Poverty^2	-4.01E-03	*-3.71		4.32E-04	0.23		**4.14
Agglomeration Variables							
Spacelag	0.21	*2.60	1.85	0.21	*2.60	1.85	NA
Agglom	9.03E-06	*3.68	0.20	3.34E-06	*3.05	0.16	**4.47
Constant	-1.86	-0.44		-7.32	-0.91		0.36
Diagnostics							
Psuedo – R^2 [C]	0.70						
Likelihood	-1929.83						
Spatial Error Test[D]	0.18						
Heteroscedasticity Test[E]	*51.98						
N	737			366			

A – F-test of the null hypothesis that the parameter is identical in both the eastern and western spatial regime.

B - *, **, *** denotes statistical significance at the one, five, and 10 percent levels, respectively.

C – Psuedo-R^2 is defined as the correlation between the sample's actual and predicted endogenous variable.

D – LaGrange multiplier test, distributed as a chi-square with one degree of freedom, that the model's residuals are not spatially correlated.

E - Modified Breusch-Pagan test, distributed as a chi-square statistic with one degree of freedom, that the models errors conform to linear heteroscedasticity in the variable *Land Area*.

Table 5 Spatial Model of Change in Ln(Hogs) 1997 – 1992.

	13 States		Eastern States		Western States		F-Test of
Variable	Estimate	Z-Value	Estimate	Z-Value	Estimate	Z-Value	Spatial Stability[A]
Input Availability Variables							
Corn	-2.72E-09	-0.59	3.39E-09	0.53	-4.76E-09	-0.70	0.77
Soybean	-8.83E-09	-0.49	-2.31E-08	-0.95	7.47E-08	1.28	2.40
CommFeed	0.03	0.34	-0.17	-1.38	0.48	*[B]2.64	*8.77
Land Area	8.29E-05	1.11	8.10E-05	0.60	5.47E-05	0.55	0.02
Land Area^2	-1.08E-08	-0.91	-3.45E-08	-1.47	-8.61E-10	-0.06	1.48
Unemploy	-0.05	**-2.08	-0.07	**-2.07	7.80E-03	0.14	1.43
Unemploy^2	1.72E-03	1.12	2.26E-03	1.14	-1.48E-03	-0.34	0.60
Education	-5.63E-02	***-1.70	0.11	*2.69	-0.36	*-4.69	*29.15
Education^2	3.70E-04	***1.64	-8.49E-04	*-2.97	2.42E-03	*4.79	*31.67
Nonfarm Occ	1.12	*5.37	1.10	*4.28	1.33	*3.37	0.24
Productivity and Specialization Variables							
Turnover	-0.19	*-5.89	-0.21	*-5.02	-0.21	*-4.21	0.01
FF	0.37	**2.17	0.61	*2.71	0.44	***1.74	0.24
%Sows	-9.01E-01	*-3.73	-1.02	*-3.43	-0.89	**-2.07	0.07
Market Access Variables							
MinDistance	1.51E-03	***1.89	1.39E-03	1.24	1.19E-03	0.87	0.01
MinDistance^2	-2.68E-06	-1.24	-2.61E-06	-0.64	-2.14E-06	-0.61	0.01
CapNear	1.15E-05	*2.84	1.13E-05	*2.68	-1.50E-05	-1.14	***3.65
Cap500	-1.01E-06	-0.85	9.28E-07	0.55	-1.61E-06	-0.64	0.71
Plant500	-5.49E-03	-0.59	-0.02	-1.23	-1.33E-03	-0.06	0.32

	13 States		Eastern States		Western States		F-Test of Spatial Stability[A]
Variable	Estimate	Z-Value	Estimate	Z-Value	Estimate	Z-Value	
Urban Encroachment and Population Characteristic Variables							
Population	-7.11E-07	*-4.31	-4.88E-07	*-2.58	-7.47E-07	-0.73	0.06
$Population^2$	1.16E-13	*2.91	7.29E-14	***1.72	4.65E-13	0.26	0.05
Popgrowth	0.30	0.65	-0.98	-1.56	1.34	**1.99	**6.34
BuildPermit	0.92	0.09	9.05	0.55	-28.48	***-1.70	2.56
$BuildPermit^2$	483.51	1.49	1566.61	1.50	438.79	0.99	0.99
EthnicHomog	-4.09E-02	-0.22	-0.16	-0.73	0.24	0.70	0.97
Local Economic Condition Variables							
PropTax	3.91E-05	0.54	-1.54E-05	-0.04	1.16E-04	1.41	0.09
$PropTax^2$	-7.66E-09	-0.72	-2.20E-08	-0.07	-2.20E-08	***-1.84	0.00
Poverty	1.54E-02	1.20	6.79E-03	0.45	0.02	0.64	0.10
$Poverty^2$	-2.59E-04	-0.75	1.18E-04	0.27	-8.42E-04	-1.25	1.45
Historic Production and Production Intensity Variables							
ln(Hogs)	-0.02	-0.96	0.02	0.49	-0.10	**-2.43	**4.63
ln(Hogs/farm)	0.35	*9.59	0.24	*4.24	0.53	*9.79	***3.73
Agglomeration Variables							
Spacelag	-0.29	-1.56	-0.28	-1.52	-0.28	-1.52	NA
Agglom	-2.93E-07	-0.75	2.28E-07	0.23	-6.81E-07	-1.60	0.69
Constant	0.39	0.31	-5.15	*-3.34	11.33	*3.87	*24.81
Diagnostics							
Psuedo – $R^{2, C}$	0.30		0.38				
Likelihood	-842.51		-776.74				
Spatial Error Test[D]	**4.63		0.99				

	13 States		Eastern States		Western States		F-Test of Spatial Stability[A]
Variable	Estimate	Z-Value	Estimate	Z-Value	Estimate	Z-Value	
Heteroscedasticity Test: Area[E]	*14.95		*157.25				
N	1103		737		366		

N = 1103.

A – F-test of the null hypothesis that the parameter is identical in both the eastern and western spatial regime.

B - *, **, *** denotes statistical significance at the one, five, and 10 percent levels, respectively.

C – Psuedo-R^2 is defined as the correlation between the sample's actual and predicted endogenous variable.

D – LaGrange multiplier test, distributed as a chi-square with one degree of freedom, that the model's residuals are not spatially correlated.

E - Modified Breusch-Pagan test, distributed as a chi-square statistic with one degree of freedom, that the models errors conform to linear heteroscedasticity in the variable *Land Area*.

Table 6. 1997 and 1992Spatial Model: Ln(Hogs per Farm).

	1997			1992			χ^2 Test of Time
Variable	Estimate	Z-Value	Elasticity	Estimate	Z-Value	Elasticity	Stability[A]
Input Availability Variables							
Corn	3.35E-08	*[B]3.15	0.22	1.04E-08	1.49	0.07	*46.83
Soybean	-1.04E-09	-0.03	-0.002	6.19E-08	**2.24	0.09	*22.83
CommFeed	0.15	0.74	0.07	-0.03	-0.20	-0.01	*8.28
Land Area	0.00015	0.91	0.09	9.57E-05	0.87	0.07	1.47
Land Area^2	-1.92E-08	-0.75		-6.11E-09	-0.34		
Unemployment	-0.092	-1.45	-0.33	0.015	0.41	0.08	*170.70
Unemployment^2	0.0022	0.47		-0.00013	-0.06		
Education	0.14	***1.94	-0.58	0.05	0.94	0.07	*7,976.15
Education^2	-0.00099	**-2.01		-0.00031	-0.89		
Nonfarm Occ	-3.20	*-6.44	-1.48	-2.05	*-6.61	-0.84	*239.34
Productivity and Specialization Variables							
Turnover	0.15	*2.64	0.30	0.06	1.24	0.12	*30.65
FF	1.09	*3.02	1.23	0.26	1.02	0.31	*730.28
%Sows	-2.31	*-5.22	-0.33	-2.58	*-7.15	-0.37	2.16
Market Access Variables							
MinDistance	-0.0047	*-2.83	-0.46	-0.0030	**-2.56	-0.31	*23.42
MinDistance^2	1.50E-06	0.32		-3.90E-07	-0.12		
CapNear	2.30E-05	*3.20	0.17	-8.40E-06	-1.36	-0.05	*75.89
Cap500	-1.67E-05	*-5.81	-3.77	6.45E-07	0.36	0.14	*14320.43
Plant500	0.17	*6.36	4.51	0.03	***1.92	0.76	*13297.35

	1997			1992			χ^2 Test of Time Stability[A]
Variable	Estimate	Z-Value	Elasticity	Estimate	Z-Value	Elasticity	
Urban Encroachment and Population Characteristic Variables							
Population	-1.24E-06	*-3.52	-0.08	-8.44E-08	-0.34	-0.01	*15.04
Population^2	2.31E-13	*2.71		-5.70E-14	-0.94		
Popgrowth	1.10	1.27	0.04	1.79	**2.56	0.02	1.43
BuildPermit	-41.18	*-2.75	-0.18	-73.30	*-5.03	-0.21	*53.70
BuildPermit^2	157.85	0.58		1609.37	*3.27		
EthnicHomog	-0.23	-0.61	-0.10	0.52	**1.98	0.22	*87.85
Local Economic Condition Variables							
PropTax	-0.00015	-0.97	-0.10	-0.00022	**-1.98	-0.15	1.86
PropTax^2	2.54E-08	1.11		3.60E-08	**2.24		
Poverty	-0.00046	-0.02	-0.18	-0.0083	-0.43	-0.27	**7.70
Poverty^2	-0.00044	-0.60		-0.0004	-0.76		
Agglomeration Variables							
Spacelag	0.22	*2.57	2.01	0.29	*4.06	2.68	*94.44
Agglom	1.96E-06	**2.46	0.06	1.99E-06	*3.37	0.06	0.01
Constant	-0.56	-0.20		1.92	0.98		*5,032.48
Diagnostics							
Psuedo – $R^{2,C}$	0.51			0.59			
Spatial Error Test[D]	**6.34			*5.87			
Heteroscedasticity Test: Area[E]	0.58			*14.37			

N = 1103.

A - Likelihood ratio test, distributed as a chi-square with the number of degrees of freedom equal to the number of parameters involved in the test, that imposing the 1992 parameter(s) on the 1997 model is not restrictive.

B - *, **, *** denotes statistical significance at the one, five, and 10 percent levels, respectively.

C – Psuedo-R^2 is defined as the correlation between the sample's actual and predicted endogenous variable.

D – LaGrange multiplier test, distributed as a chi-square with one degree of freedom, that the model's residuals are not spatially correlated.

E - Modified Breusch-Pagan test, distributed as a chi-square statistic with one degree of freedom, that the models errors conform to linear heteroscedasticity in the variable *Land Area*.