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**DOES MANURE MANAGEMENT REGULATION WORK AGAINST AGGLOMERATION ECONOMIES?
EVIDENCE FROM FRENCH HOG PRODUCTION***

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Abstract.

The well-known increase in the geographical concentration of hog production suggests the presence of agglomeration economies related to spatial spillovers and inter-dependencies among industries. In this paper, we examine whether regulation of manure management that limits manure application per acre may weaken productivity gains arising from the agglomeration process. We develop a model of production showing the ambiguous spatial effect of environmental regulation. Indeed, while environmental regulation triggers dispersion when manure is applied to land as a crop nutrient, it also prompts farmer to adopt manure treatment that favors agglomeration of hog production. Estimations of a reduced form of the spatial model with a spatial HAC procedure applied to data for French hog production for 1988 and 2000 confirm the ambiguous effect of regulation of manure management. It does not prevent spatial concentration of hog production, and even boosts the role played by spatial spillovers in the agglomeration process.

JEL Classification: Q10, Q53, R12

Key words: Hog production; Manure management regulation; Agglomeration economies; Spatial Econometrics.

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1. Introduction

Empirical evidence suggests that the spatial concentration of hog production has accompanied the rise in hog farm productivity. In the United States, Key and McBride (2007) report that hog production shifted from the Heartland to the Southeast between 1992 and 1998 and that mean farm output increased much more in the Southeast (see also Abdalla *et al.*, 1995). In Europe, similar changes are observed. For example, in France, Brittany hosts an increasing share of hog production and the productivity of hog producers located in this region has improved (Daucé and Léon, 2003). It appears that in hog production, agglomeration can be a source of productivity gains (Roe *et al.*, 2002).

However, the spatial concentration of pig producers is a serious source of pollutants in rivers and streams. This is why the European Union (EU) introduced the Nitrates Directive and the United States (US) the Clean Water Act, whose aim is to protect water bodies against pollution by nitrates from agricultural sources. In the EU, the application of manure is limited to a maximum level of nitrogen per hectare and per year. This restriction on spreading manure on the land creates difficulties for regions with a high livestock density: there is simply not enough land available on which manure could be applied. Because of the stringency of the EU Nitrate Directive and non-negligible costs of compliance for hog producers, the latter may respond to existing or impending costs of regulation by exiting the sector or by changing their scale of production.

The purpose of this paper is to study the effects of regulation of manure management on the location of hog production and agglomeration economies. Because the application of animal manure on land is restricted, regulation of manure management is expected to reduce the spatial concentration of production and, in turn, to affect productivity gains related to agglomeration economies. However, the story is more complex and deserves closer attention. Indeed, farmers may adopt two types of manure management: (i) manure spreading where animal manure is applied to land as a crop nutrient or/and (ii) manure treatment where the goals are nitrogen reduction, as well as a reduction in odor and in volume. In the first case, increasing hog production implies that farmers have to spread a larger volume of manure on more and more distant cropland. Because hauling nutrients to cropland in the form of manure is relatively expensive, the cost of this type of manure management not only increases with an increase in hog production but also with the distance to the cropland. This creates incentives

for producers to reduce their production. In this case, manure spreading triggers the dispersion of hog production. In the second case, manure treatment technology aims at reducing the volume (so that manure and nutrient transport costs become negligible) and improving market prospects by changing the nutrient composition. However, such a practice is characterized by substantial fixed costs (IFIP, 2002). Therefore, this manure management technology may favor the agglomeration of hog production. Indeed, because manure treatment technology exhibits economies of scale, this management system is more profitable with high levels of hog production. In other words, the use of treatment technology either at the individual or the collective level promotes agglomeration. As a result, environmental regulation may trigger either dispersion or agglomeration of hog production depending on the type of manure management system chosen by the farmers.

In this paper, we determine whether manure management regulation leads to relocation of hog production in areas with low livestock density or whether on the contrary, it strengthens the spatial concentration of hog production. To reach our goal, we first develop a model of location and production in which farmers can choose different technologies to manage manure and then we test its main predictions using French data. We obviously control for the other factors that usually shape the spatial structure of hog production. More precisely, we identify agglomeration economies by distinguishing market and non-market forces.

Cronon (1991) in his famous book *Nature's Metropolis* provides a detailed description of the market factors explaining the agglomeration process of hog production in Chicago and its hinterland that occurred in the second half of the 19th century (see chapter entitled *Porkopolis*). First, the proximity between farmers and slaughtering facilities may be one of the key determinants. As mentioned by Cronon (1991), incentives to slaughter and pack pigs near where farmers raised pigs were strong. Driving hogs was expensive because of relatively high transport costs and hogs lost weight as they traveled. It was thus unprofitable to haul them very far. A second factor explaining the local growth of hog production is the geographical proximity between crop or feed production and hog producers. As pointed out by Cronon (1991, p. 226): "*Their prodigious meat-packing powers meant that once farmers had harvested their corn crop, pigs (along with whisky) were generally the most compact and valuable way of bringing it to market*". As a result, the proximity to both crop production

(or feed suppliers) and slaughtering facilities tended to result in large productivity gains. Both these factors combined with innovations in meat transportation to serve final consumers and with increasing productivity of pork packers (due to higher division of labor) enabled Chicago and its surrounding area to produce and pack a very large quantity of hogs (more than a million hogs were slaughtered annually in Chicago in the 1870s). Although Cronon's explanations are related to the relative transport costs and scale economies observed around Chicago in the second half of 19th century, these arguments should hold today to explain the agglomeration of hog producers in a few locations. Indeed, the ratio of transport costs to output or input prices in the pork sector is far from negligible. New economic geography now provides rigorous frameworks to explain the role of increasing returns and trade costs in agglomeration processes (Fujita and Thisse, 2002).

The literature teaches us that producers can also benefit from the geographical proximity of other producers in the same sector: the non-market interactions or the so-called "Marshallian externalities" act as a shift factor that modifies the relationship between cost and output. Geographical proximity induces more contacts and, in turn, facilitates the transmission of information regarding changes in output and input markets as well as the development of technical or organizational innovations or new inputs (Duranton and Puga, 2004), the so-called *information spillovers*. Frequent contacts also allow purchasers or suppliers to build the trust required to write incomplete contracts as shown by Leamer and Storper (2001). In other words, the productive efficiency of farmers should increase with the number of farms that set up in the same area and decrease with an increase in the distance between them.

Our study differs sharply from recent empirical studies examining the role of traditional location factors as well as environmental regulation involved in the location of animal production. First, while much attention has been devoted to the impact of the stringency of environmental regulation on the location of animal production, little attention has been paid to the impact of manure management *systems* on the process of agglomeration. For example, Isik (2004) and Roe *et al.* (2002) studied how differences in the stringency of environmental regulations among US States affect the location of animal production. However, these authors did not test the impact of manure management on the agglomeration of hog production. Second, we build a theoretical model to enable us to identify

the relationship between location and hog production when farmers can choose different technologies to manage manure. The combined effects of spatial spillovers, access to suppliers or purchasers, environmental regulation and negative externalities on local production are not *a priori* obvious and can lead to serious problems in identifying and evaluating the respective roles of these different factors. Last, we implement recent developments in spatial econometrics to take into account some crucial biases that have been ignored. The approach used by Roe *et al.* (2002) does not control for the endogeneity of the location of slaughtering facilities and of input suppliers, whereas hog production and the production of other livestock by hog producers are determined simultaneously in different areas. In addition, unlike Isik (2004), who uses two-stage least squares, we perform a generalized spatial two-stage least squares estimation (GS2SLS), as suggested by Kelejian and Prucha (1998), combined with a heteroskedastic and autocorrelation consistent non-parametric estimation of the variance-covariance matrix (Kelejian and Prucha, 2007) to control for unmodeled factors in the residual terms.

Our theoretical model shows that regulation of manure management has an ambiguous effect on the spatial distribution of hog production. By favoring the use of a manure treatment system, stricter regulation of the manure application rate or a decrease in available land for manure application may trigger the spatial concentration of hog manure. Furthermore, we show from our framework that a larger share of manure managed by treatment technology strengthens the role of agglomeration economies in productivity gains. Our empirical tests of these predictions confirm the ambiguous effect of the ratio of manure production to available land on hog production. In accordance with our theoretical model, an increasing ratio of local manure production to land availability increases the density of hog production while a rise in this ratio for the surrounding counties triggers dispersion. The total effect is more likely to be negative but not significant. In other words, regulation of manure management does not work against the spatial concentration of hog production. In addition, we show that the regulation of manure management has boosted the role played by non-market spatial externalities in the agglomeration process.

The rest of the paper is organized as follows. In the following section, we develop the theoretical model while the empirical model and econometrics issues are described in Section 3. Data

are presented in Section 4 and our results are reported and analyzed in Section 5. The last section concludes the paper.

2. Theory

In this section we develop a spatial model of hog production by taking into account spillovers, linkages with the feed suppliers and with the slaughtering facilities/processors, and manure management. The objective of the model is to clarify the impact of environmental regulation on the hog producer's choice according to her/his location.

General framework

Consider an economy with R regions, labeled $r = 1, \dots, R$ separated by a given physical distance and with three types of producers (hog producers, slaughtering facilities and feed producers). Each region is formally described by a one-dimensional space y . Each region hosts one slaughtering facility (in short SF) located at the origin $y = 0$, I farms located at y_i with $i = 1, \dots, I$ (or at distance y_i from the SF) and K feed producers located at y_k with $k = 1, \dots, K$. The distance between farmer i and feed producer k is given by $u_{ik} \equiv |y_k - y_i|$ when they are located in the same part of the region or by $u_{ik} \equiv |y_k| + |y_i|$ when they are not located in the same part of the region. We focus on the behavior of a farmer producing in location i and belonging to region r . Because in our framework there are no interactions between hog or input producers located in different regions, we can drop in our notations for the index (r) identifying the region where the farmer produces (we only consider the impact of the location of the final consumers on production). We assume that the profit function of a hog producer is given by:

$$\pi_i = (z_r - \tau |y_i|)h_i - C(\cdot) - g(\cdot) \quad (1)$$

where z_r is the unit price of pork prevailing in region r (each farmer is a price taker), τ is the unit transport costs of pork between farms and the slaughtering facility, h_i is the production level of farm i , $C(\cdot)$ is the cost function in producing output and $g(\cdot)$ is the cost function in manure management.

Implementation of environmental regulations implies compliance costs for producers thereby reducing profits. We assume that the cost function is additively separable into output and manure management.

The technology of production is given by $h_i = A_i f(x_k, l)$ where x_k is the quantity of inputs used by farms with $f_x > 0$ and $f_{xx} < 0$ ¹ and l is the labor force dedicated to hog production with $f_l > 0$ and $f_{ll} < 0$ so that the marginal productivity of each production factor decreases. Note that $A_i = \sum_j a_{ij}$ where a_{ij} represents information spillovers received by a farmer located at y_i from a farmer located at y_j . Hence, A_i represents the information field, which is a spatial externality. The amount of information received by a farm depends on the size of the other farms and on its location relative to the others. We consider:

$$a_{ij} = \rho |y_j - y_i|^{-\delta} h_j \quad (2)$$

where $\rho > 0$ and $\delta > 0$ are two positive constants, δ measuring the intensity of the distance-decay effect and ρ is a scale parameter. This type of expression is extensively used in spatial models of interaction.

Given the technology of production, the cost function $C(\cdot)$ depends positively on h_i and negatively on A_i with $C_h \equiv \partial C / \partial h_i > 0$, $C_{hh} \equiv \partial^2 C / \partial h_i^2 > 0$ and $C_{hA} \equiv \partial^2 C / (\partial h_i \partial A_i) < 0$ as well as on the wage rate (denoted w_l) and the cost of feed (or crop when the feed is produced by the hog farmer) incurred by the farmer (denoted w_{ik}). We assume that $w_{ik} = \bar{w}_k + \xi_k u_{ik}$ where ξ_k is the unit transport cost of feed between farms and feed producers (u_{ik} is the distance between the two) and \bar{w}_k is the feed producer's price. Thus, we consider that the farmer incurs transport costs for each type of feed (or crop) input.

Next, we take into account the fact that manure management is regulated. Environmental regulation not only implies compliance costs for producers but also that the manure application rate

¹ f_x denotes the first derivative of $f(\cdot)$ with respect to each component. The second derivative is subsequently denoted by f_{xx} .

cannot exceed a threshold value. Hence, we consider that one unit of available cropland cannot exceed \bar{m} units of manure and that s units of cropland are available at each location i .

Let θ be the quantity of manure for each unit of output so that θh_i is the quantity of manure that farmer i has to manage. Farmer i may use two types of manure management technology: spreading or/and treatment. Farmer i allocates a fraction μ_i of manure to spreading.² Each farmer can also use a manure treatment facility with a capacity $v_i = (1 - \mu_i)\theta h_i$ and a cost function $c_1(v_i)$ characterized by $c_1' \equiv \partial c_1 / \partial v_i > 0$ and $c_1'' \equiv \partial^2 c_1 / \partial v_i^2 < 0$. What matters for our study is the fact that treatment technology is characterized by scale economies (IFIP, 2002) and that the cost of transporting treated manure is not significant. When the farmers choose to spread manure, this incurs costs of application that are given by $c_2(\mu_i \theta h_i)$ with $c_2' \equiv \partial c_2 / \partial h_i > 0$ and $\partial^2 c_2 / \partial h_i^2 = 0$. Without loss of generality, we assume the technology for applying manure yields constant economies of scale. Hence, the costs associated with manure management including the costs of treatment, manure application and manure transport are given by $g(.) \equiv c_1(v_i) + c_2(\mu_i \theta h_i) + \int_{-y_j^m}^{y_j^m} \tau_m |y_i - y_j^m| m_{ij} s$ where τ_m is the unit transport cost (including travel time) between where the manure is stored and the field³, and m_{ij} is the mass of manure applied in location j by farmer i . Given our assumptions, each farmer applies the same quantity of manure at each location ($m_{ij} = \bar{m}$).⁴ Each farmer has n_i locations where the manure can be applied with $n_i = \theta h_i / \bar{m} s$. In addition, we assume that $|c_1''|$ is not too high so that there are no increasing returns to scale in overall production ($C_{hh} + g_{hh} < 0$).

Hence, the function cost of manure management can be rewritten as follows:

$$g(.) = c_1(v_i) + c_2(\mu_i \theta h_i) + \tau_m \frac{\mu_i^2 \theta^2 h_i^2}{2 \bar{m} s} \quad (3)$$

² Innes (2000) provides a detailed analysis of the impact of environmental regulation on livestock production with respect to the location of producers. However, this author does not analyze restrictions on manure application per unit of land and considers hog production as given.

³ Transporting manure is time consuming (and increases with the distance travelled).

⁴ Except for the more distant location where $0 \leq m_{ij} \leq \bar{m}$. For the sake of simplicity, we assume farmers spread the same quantity of manure at each location.

Hence, manure spreading yields decreasing economies of scale because of manure transport costs. In addition, trivial calculations reveal that the marginal cost of manure management ($g_h \equiv \partial g / \partial h_i$) is given by:

$$g_h = c_1' + c_2' + \tau_m \mu_i^2 \theta^2 h_i / \bar{m} s > 0 \quad (4)$$

The marginal cost increases with the quantity of manure per unit of output θ , more restricted application rates (lower \bar{m}), cost of transport between the farm and the manured field τ_m and the share of manure which is spread since we have:

$$\frac{\partial g_h}{\partial \mu_i} = -c_1' \theta h_i + 2\tau_m \frac{\mu_i \theta^2 h_i}{\bar{m} s} > 0$$

while the marginal cost varies with hog production as follows:

$$g_{hh} = c_1'' + \tau_m \mu_i^2 \theta^2 / \bar{m} s \quad (5)$$

which can be positive or negative.

Environmental regulation, location and production

The equilibrium output (h_i^*) for each farm is implicitly defined in the following equality:

$$\frac{\partial \pi}{\partial h_i} = (z_r - \tau |y_i|) - C_h(w_{ik}, w_l, A_i, h_i^*) - g_h(\theta, \mu_i, \bar{m}, s, \tau_m, h_i^*) = 0 \quad (6)$$

We first analyze the direct effects of the environmental regulation on production. Some trivial calculations reveal that:

$$\frac{\partial h_i^*}{\partial (\bar{m} s)} = \frac{\partial g_h / \partial (\bar{m} s)}{C_{hh} + g_{hh}} = \frac{-\tau_m \mu_i^2 \theta^2 h_i / (\bar{m} s)^2}{C_{hh} + g_{hh}} > 0 \quad (7)$$

Remember that $C_{hh} + g_{hh} < 0$ and $C_{hh} < 0$. It appears that stricter regulation of manure application rates (low \bar{m}) or lower availability of surrounding cropland (low s) works against agglomeration of hog production because of the increasing cost of spreading manure. This effect is weakened when the share of manure that is managed by treatment reaches high values (lower μ_i).

However, in (7), we assume that μ_i is exogenous and does not react to a change in the application rate (\bar{m}) or in land availability (s). When μ_i is endogenous, the effect is ambiguous.

Indeed, when in order to minimize the cost of manure management (3) each farmer sets μ_i at a given rate of hog production, the equilibrium share of manure managed by spreading μ_i^* is implicitly given by $\partial g(.) / \partial \mu_i = 0$ or, equivalently, by:

$$-c_1' + c_2' + \tau_m \frac{\mu_i \theta h_i}{\bar{m}s} = 0 \quad (8)$$

In addition, some standard calculations show that:

$$\frac{\partial^2 g(.)}{\partial \mu_i^2} = \left(c_1'' + \frac{\tau_m}{\bar{m}s} \right) \theta h_i, \quad \frac{\partial^2 g(.)}{\partial \mu_i \partial h_i} = -c_1'' + \frac{2\mu_i \tau_m \theta^2 h_i}{\bar{m}s} > 0 \quad \text{and} \quad \frac{\partial^2 g(.)}{\partial \mu_i \partial (\bar{m}s)} = -\frac{\mu_i \tau_m \theta h_i}{(\bar{m}s)^2} < 0$$

Hence, μ_i^* is an interior solution when $c_1'' + \tau_m / \bar{m}s > 0$ and it is easy to check that $d\mu_i^* / dh < 0$ and $d\mu_i^* / d(\bar{m}s) > 0$. In other words, manure treatment technology is more likely to be used when hog production is relatively high and when the manure application rate is strictly limited. Hence, when μ_i is endogenous, equation (7) becomes:

$$\frac{\partial h_i^*}{\partial (\bar{m}s)} = \frac{-1}{C_{hh} + g_{hh}} \left(\frac{\partial g_h}{\partial (\bar{m}s)} + \frac{\partial g_h}{\partial \mu_i} \times \frac{d\mu_i^*}{d(\bar{m}s)} \right) \quad (9)$$

where we have now:

$$g_{hh} = \frac{\partial g_h}{\partial h_i} + \frac{\partial g_h}{\partial \mu_i} \times \frac{d\mu_i^*}{dh} \quad (10)$$

As a result, stricter manure management regulation or decreasing land availability has an ambiguous effect on hog production. Even though the direct effect works against agglomeration of hog production (because of the costs associated with manure spreading), the indirect effect favors hog production because the use of treatment technology increases. Hence increasing the capacity to treat manure may enable economies of scale in manure management that off-set additional costs of compliance.

We now study the impact of location on hog production for a farmer located at i . By using (5), we can also study how a shock at location j is transmitted to location i . First, it is easy to check that

$$\frac{\partial h_i^*}{\partial h_j} = \frac{-C_{hA}}{C_{hh} + g_{hh}} \rho |y_i - y_j|^{-\delta} \quad (11)$$

which is positive and related to positive spatial information spillovers. Hence, increasing hog production in the farms located around farm i increases hog production on this farm. We expect that

the magnitude of the effect increases when the availability of the surrounding cropland (s) is very low (remember that g_{hh} decreases with s). More interesting, agglomeration is favored ($\partial h_i^* / \partial h_j$ is high) when the farmers manage more and more manure using the treatment system (lower μ_i). Indeed, g_{hh} increases with μ_i .

In addition, at a given distance to the slaughtering facility, the impact of the distance to a feed producer on hog production is as follows:

$$\frac{\partial h_i^*}{\partial u_{ik}} = \frac{\partial C_h / \partial w_{ik}}{C_{hh} + g_{hh}} \xi_k < 0 \quad (12)$$

As expected, the impact of the distance to an input supplier reduces hog production. It also appears that the magnitude of this effect increases when the farmers favor the manure treatment system (low μ_i) and decreases when manure application is strictly limited (high \bar{m}). Hence, environmental regulation favoring the adoption of manure treatment technology induces more hog production around input producers, while stricter limits on manure spreading discourage co-agglomeration of farmers and input producers.

Further, it appears that the magnitude of the distance effect to a feed producer on hog production increases with the weight of this input in the production process (because $\partial C_h / \partial w_{ik}$ increases) and transport costs of feed unit (ξ_k). Hence, we expect that the location of hog production is strongly affected by access to feed suppliers because the intermediate consumption of feed represents more than 50 percent of production costs for hog producers.

Concerning the impact of the distance to the slaughtering facility on farm i 's production, the relationship is more complex. Indeed, at a given distance to the input suppliers, we have:

$$\frac{\partial h_i^*}{\partial |y_i|} = -\frac{\tau}{C_{hh} + g_{hh}} + \frac{-C_{hA}}{C_{hh} + g_{hh}} \frac{\partial A_i}{\partial |y_i|} < 0 \quad (13)$$

The first term of the RHS in (13) concerns unit transport costs of the hogs between the farm and the SF while the second term of the RHS captures the influence of a change in location on the intensity of spillovers. Without information spillovers, hog production decreases with respect to the distance to the

SF. The slope increases with the cost of transporting hog units (τ) and with the share of manure managed by a treatment system (g_{hh} decreases). When information spillovers occur, we have $\partial A_i / \partial |y_i| < 0$ so that the decrease in hog production with the distance to the SF is higher when technological externalities occur. As mentioned above, an increasing share of manure managed by a treatment system makes the slope stronger.

We now turn to the impact of a consumption shock on hog production. More precisely, we study the impact of a shock in the demand prevailing in region r' . We know that the regional price of pork depends positively on the demand for pork and thus on the spatial distribution of consumers because transport costs increase consumer prices. We denote the demand for pork by consumers located in region r' to producers located in region r by $D_{r',r}(t_{r',r}, I_{r'})$ where $t_{r',r}$ is the transport cost, increasing the distance between the region where the pork is produced and the region where the pork is consumed whereas $I_{r'}$ is the income in region r' . Because $z_r(I_{r'})$ and $D_r = \sum_{r'} D_{r',r}$ (the total demand addressed to producers in region r), some standard calculations reveal that:

$$\frac{\partial h_i^*}{\partial I_{r'}} = \frac{d(t_{r',r})}{C_{hh} + g_{hh}} \frac{\partial z_r}{\partial D_r} > 0 \quad (14)$$

with $d(t_{r',r}) = \partial D_{r',r} / \partial R_{r'}$. Hence, the impact of a change in the wealth prevailing in a region depends both on the transport costs of the processed product and on the relationship between the regional pork price and regional demand.

To sum up, our model shows that regulation of manure management has an ambiguous effect on the spatial distribution of hog production. On the one side, manure management regulation triggers dispersion when manure is applied to land as a crop nutrient. On the other side, by favoring the use of treatment systems, stricter regulation of the manure application rate or a decrease in available land for manure spreading triggers spatial concentration of hog manure. Furthermore, the characteristics of manure management technology affect the magnitude of agglomeration economies related to information spillovers and access to slaughtering facilities and to input suppliers. More precisely, a higher share of manure managed by treatment technology strengthens agglomeration economies.

3. The empirical model and econometric issues

Given the discussion in the foregoing section, our aim is to evaluate the impact of land availability for manure spreading on the spatial re-allocation of hog production and, in turn, what extent manure management regulation affect agglomeration economies. To test our theoretical predictions, we consider the following empirical model:

$$H = \rho W_h H + \gamma_X X + \gamma_E E + \gamma_Z Z + \varepsilon \quad (15)$$

where H is a $n \times 1$ vector of the dependent variable in each of the n counties for a given period, ρ is the scalar spatial autoregressive parameter, W_h is an $(n \times n)$ spatial weights matrix, X , E and Z are $n \times k_1$, $n \times k_2$ and $n \times k_3$ matrices of $k = k_1 + k_2 + k_3$ explanatory variables related to access to purchasers and suppliers (X), environmental constraints (E) and farm structures (Z), whereas ε is a $n \times 1$ vector of error terms, the properties of which are detailed below. Finally, γ_X , γ_E and γ_Z are the $k_1 \times 1$, $k_2 \times 1$ and $k_3 \times 1$ parameter vectors to be estimated.

The spatial lag of the dependent variable is introduced in order to capture the role of spatial information spillovers in hog production. The spatial weight matrix W_h contains elements φ_{ij} that can be interpreted as the decreasing role of distance in the intensity of positive interactions between farmers located in county i and those located in j (respectively, in the row, column, of the matrix). We use a distance squared decay function as, $\varphi_{ij} = d_{ij}^{-1}$ (where d_{ij} is the physical distance in kilometers between the capital of county i and j) if the distance is less than 200 km, otherwise φ_{ij} is set to 0. The cut-off value of 200 km was chosen because it appears that cooperatives (producer organizations via which information spreads) have a regional field of action. The elements along the main diagonal are $\varphi_{ij} = 0$. The weights have been standardized so that the elements in each row sum to 1: $\varphi_{ij}^s = \varphi_{ij} / \sum_j \varphi_{ij}$.

Concerning access to slaughtering facilities, local consumers and input suppliers (vector X), we consider the three following variables:

(i) Access to the slaughtering facility from location i : $S^* = (W_s + I)S$ where S is a vector containing the size of the slaughtering facilities, W_s is a spatial weight matrix related to S and I the identity matrix. Therefore, line i of S^* contains the size of the slaughtering facility located in county i plus a distance-weighted average of i 's neighboring facilities. The introduction of the $(W_s + I)$ matrix aims to capture the role of transportation costs of live pigs between farms and nearby slaughterhouses. We use an inverse distance matrix. For the cut-off, we consider the minimum distance ensuring that each observation has at least one neighbor. Thus, for W_s , the cut-off is around 34 kilometers.

(ii) Access to final consumers from location i : $Pop^* = W_R \times Pop$ where Pop is a vector containing the population of the county and W_R is the spatial weight matrix related to Pop , in order to capture the transport cost of hog meat to end markets. W_R is an inverse distance matrix with a cut-off set to the same distance as that to the slaughterhouses.

(iii) Two measures of access to the input suppliers at location i : first, $X_1^* = (W_x + I)X_1$ with X_1 , a vector containing the available quantity of crops and W_x , the spatial weight matrix related to X_1 . We expect a positive impact of the access to purchasers or suppliers on pork production. W_x is an inverse distance matrix with a cut-off set to 100 kilometers, in order to take into account the transport cost of cereals. Second, we introduce the regional mixed feed production (specific for hogs) as vector X_2 .⁵

To capture environmental constraints (vector E), we first build a variable related to the EU regulation concerning manure spreading. We use the ratio of the potential quantity of nitrogen produced by all livestock located in region i (N) to the supply of land available for manure spreading (L) in order to capture the impact of \bar{ms} . We also introduce a spatial dimension of this variable by using the ratio (N/L) in county i and in neighboring places, i.e. the ratio of neighboring places weighted by distance. $(W_N \times (N/L))$. In this way, we consider that land availability for spreading hog

⁵ As can be seen below, we were unable to collect precise data on the location and production quantities of each firm producing industrial mixed feed. The only available data concern regional production of feed. This is why the form of this variable differs from the others.

manure decreases with livestock production and with the distance between the location of farms and the location of the cropland.

Second, we consider the impact of population location on the location or the growth of the production facilities. Indeed, hog production causes local external costs related to odors and other ambient effects that the hog producer must reduce because of local environmental regulations. This constraint (for the producer) creates some additional costs by shrinking the expansion of hog production. We assume that these emission abatement costs increase with an increase in the size of the local population (Pop). The effort to reduce emissions increases with an increase in the number of residents).

To estimate model (15), called a spatial lag or spatial autoregressive model, we use spatial econometric techniques (Anselin, 2006; LeSage and Pace, 2008). The maximum likelihood (ML) estimation method is by far the most common methodological framework applied in spatial econometrics in this case since it allows the endogeneity of the spatially lagged variable $W_h H$ to be controlled for (Anselin, 2006). Such an approach was used by Roe *et al.* (2002) to reveal agglomeration economies in hog production. However, as we argue below, other variables are determined at the same time as the dependent variable, such as the location of slaughtering facilities or input suppliers. The location of processors or suppliers is also determined by the spatial distribution of hog producers due to market mechanisms or vertical coordination prevailing in the hog sector. Furthermore, our environmental constraints (N/L and $W_N N/L$) include hogs among the local livestock and might be also endogenous. Although the endogeneity issue could be source of econometric biases, this problem has been disregarded so far. It causes additional econometric complexities, since, as pointed out by Fingleton and Le Gallo (2008), the estimation of such a model with a spatial autoregressive process and endogenous variables is not possible with the usual maximum likelihood (ML) approach. Other approaches have to be used. The strategy that we follow consists in performing a generalized spatial two-stage least squares estimation, suggested by Kelejian and Prucha (1998). This approach uses the lower orders of the spatial lags of the exogenous variables as instruments for the endogenous spatial lag $W_h H$, together with other instruments for the other endogenous variables.

These are detailed below. Moreover, in order to control for unmodeled factors in equation (15), two strategies may be adopted, one of which is used in this paper.

The first is to specify a parametric error process, such as a first spatial autoregressive error process or spatial correlation process in the errors:

$$\varepsilon = \eta W_\varepsilon \varepsilon + v \quad (16)$$

where η is a scalar spatial autoregressive parameter; W_ε is a first-order contiguity matrix and v is a $n \times 1$ vector such as $v \sim \text{iid}(0, \sigma^2 I_n)$. The method of estimation of a general model with an endogenous spatial lag, additional endogenous variables and a spatial autoregressive error term was suggested by Fingleton and Le Gallo (2008).

However, while specifying the error process could result in gains in efficiency if properly specified, there is also a risk of misspecification if the error terms are also heteroskedastic or if they are not distributed according to a first-order spatial autoregressive model. Therefore, in this paper we use Kelejian and Prucha's (2007) non-parametric heteroskedasticity and autocorrelation consistent (HAC) estimator of the variance-covariance matrix in a spatial context, i.e. a SHAC procedure. In particular, these authors assume that the $(N \times 1)$ disturbance vectors ε of model (15) is generated as follows: $\varepsilon = R\xi$, where R is an $(N \times N)$ non-stochastic matrix whose elements are not known. This disturbance process allows for general patterns of correlation and heteroscedasticity. The asymptotic distribution of the corresponding OLS or IV estimators implies the variance-covariance matrix $\Psi = n^{-1}Z' \Sigma Z$, where $\Sigma = (\sigma_{ij})$ denotes the variance-covariance matrix of ε . Kelejian and Prucha (2007) show that the SHAC estimator for its $(r, s)^{\text{th}}$ element is:

$$\hat{\Psi}_{rs} = n^{-1} \sum_{i=1}^n \sum_{j=1}^n x_{ir} x_{js} \hat{\varepsilon}_i \hat{\varepsilon}_j K(d_{ij} / d_n) \quad (17)$$

where x_{ir} is the i^{th} element of the r^{th} explanatory variable; $\hat{\varepsilon}_i$ is the i^{th} element of the OLS or IV residual vector; d_{ij} is the distance between unit i and unit j ; d_n is the bandwidth and $K(\cdot)$ is the Kernel function with the usual properties. Here, we use the Parzen kernel with bandwidth set to the first

decile, the first quantile and the median of the distance distribution. The results obtained are quite robust with respect to the choice of bandwidth and we report those obtained with the median.

4. Data.

The majority of data used in this paper come from agricultural censuses (1988 and 2000). Variables relative to slaughterhouses and to the mixed feed sector as well as data on the structures of farms were supplied by the French Pork Sector Institute (IFIP). Data concerning populations (and the labor market among the instruments) come from population censuses (1990 and 1999). Finally, to build instrument variables, we used climate variables provided by *Météo France*, whereas data on land quality come from the *INDIQUASOL* database (from Service Unit *INFOSOL*, INRA, Orléans).

The spatial unit used in this paper is the French “*canton*” (an administrative delineation similar to a county). This is a quite fine spatial disaggregation for analysis. However, some of these units changed during our study period because of administrative changes (merged or split) so we performed the analysis on 3,589 units for 1988 and 3,572 units for 2000.

Dependent variable

Considering the heterogeneity in the size of the county and working on the impact of environmental regulations on the agglomeration of hog production, we use the density of pigs in the county as dependent variable, i.e. the number of hogs inventory per hectare at the county level expressed in large stock units. Figure 1 shows the spatial distribution of the dependent variable for 2000. Hog production is quite unevenly distributed across French counties, with a strong geographical concentration in some areas of France, notably in Brittany in the West.

[Figure 1 about here]

Explanatory variables

Variables used to estimate equation (15) are described in Table 1. As explanatory variables, we include access to agricultural land used for corn $((W_x + I) \times \text{Corn})$ and other cereals $((W_x + I) \times \text{Cereal})$ as a proxy for access to local production of hog feed $(X_1^* = (W_x + I) \times X_1)$. Moreover, given that the protein-rich feed used to feed hogs is imported, we

use the regional quantity of industrial hog feed ($X_2 = \text{Mixed Feed}$). As data on supplies of hog feed at the county level were not available we use data available at the regional level. In contrast to access to corn and other cereals, access to industrial feed is assumed to be exogenous.

[Table 1 about here]

The potential demand for pork is represented by access to slaughterhouses ($S^* = (W_s + I) \times S$) and by the spatial lag of the population ($Pop^* = W_R \times Pop$). We assume the first variable is endogenous, because of the location of slaughterhouses and the location of pig farms are endogenously determined, while the second is considered to be exogenous.

The ratio of the quantity of nitrogen to land potentially available for manure spreading at the level of the county (N/L) and its spatial lag ($W_N \times (N/L)$) are built as follows. The quantity of nitrogen at county level (N_i) is calculated for all livestock located in the county using coefficients from the French agricultural census. The land potentially available for manure spreading (L_i) represents 70% of the total cultivated area. If the ratio at county level is higher than a maximum threshold, farmers could try to spread their manure in neighboring counties or/and treat hog manure. Thus, we also take into account the spatial lag of the ratio (with a distance matrix adjusted because of high transport costs of manure). This environmental ratio and its spatial lag are considered to be endogenous because they include manure produced by hog production at county level.

Hog producers can be separated into three main orientations, due to a difference in their production technologies: breeding only, breeding-and-fattening, and after-weaning-and-fattening. Farmers who only breed manage sows to produce small weanling hogs, farmers who wean and fatten raise weanlings to fatten them, and farmers who breed and fatten do both. The majority of French hog producers breed and fatten, so we use the density of the other two orientations as control variables in our model ("*B density*" for breeding only and "*F density*" for after-weaning-and-fattening). These variables control for the effect of production orientation on the agglomeration of production.

Finally, we include a variable describing the local density of non hog farms in the county i (NHF density) in order to test whether inter-sector externalities exist between the different types of animal production, as suggested by Roe *et al.* (2002).

Instrumental variables.

Following Kelejian and Prucha (1998), we should use a linearly independent subset of the exogenous variables and their low order spatial lags to account for $W_H H$ and other endogenous variables: $(W_x + I) \times \text{Corn}$; $(W_x + I) \times \text{Cereal}$; $(W_s + I) \times S$; (N/L) ; and, $W_N \times (N/L)$. Other instruments should also be included to account for the other endogenous variables. We use accessibility of crops (when this is not included as an explanatory variable) and the density of hog smallholders.⁶ We also use the share of unemployed workforce and the ratio of non-skilled workers to all workers as instruments for the slaughterhouse. Since slaughterhouse labor is mainly not specialized, unemployed and unskilled workers can relatively easily get a job in this sector.

Hog production has an impact on the land use as well as on the total amount of manure to be spread, implying that our environmental ratio is endogenous. As an instrumental variable, we use soil quality (as a proxy for the proportion of clay in soils) which is assumed to be exogenous. In addition, we use “climate” variables such as mean sunshine, mean rainfall and mean temperature.

We chose these instruments using a step by step procedure based on the Sargan test. If the Sargan test shows that the set of instruments is not valid⁷, the residuals are regressed on all instrumental variables. This regression helps identify which instruments are significantly correlated with the residuals and are thus not valid.

5. Results.

In this section, we present the results of our different estimations. We first estimate equation (15) for the year 2000 with several specifications to examine the robustness of the main results. Then, we estimate the same specification using data for 1988 and 2000 to compare the change in results over time.

From an econometric point of view, regardless of regressions, the Hausman test is always significant at 5%, meaning that, depending on the instruments we specified, the variables that we suspected to be simultaneously determined with the dependent variable are indeed endogenous. In

⁶ We used a French typology taking into account four kinds of farm’s orientations: hogs and cereals, hogs and milk, smallholders, and hog specialisation.

⁷ So that the set of instruments is valid, the probability associated with the test must be above 0.10.

addition, we can never reject the null hypothesis of exogenous instruments, according to Sargan's test. Finally, the quality of adjustment ranges from 40% to 50%.

Location of hog production: agglomeration economies vs. environmental regulations.

When we focus on the results of models 1, 2, 3 and 4 presented in Table 2, it first appears that the explanations for the increase in hog production around Chicago in the second half of 19th century given by Cronon (1991) is still valid in 2000 to explain the agglomeration of hog producers in a few locations in France. Indeed, proximity to slaughtering facilities $((W_s + I) \times S)$ and to industrial feed producers (*Mixed Feed*) plays a significant and positive role in the location of hog production, whatever the specification. However, proximity to final consumers $(W_R \times Pop)$ appears to have no effect on the spatial location of hog production and the relationship with the slaughterhouses is the only forward linkage at work. Similarly, while higher regional production of industrial feed tends to increase local hog production, access to cereals or to land under corn $(W_x + I) \times Corn$ and $(W_x + I) \times Cereal$ has no influence on the location of hog production, in contrast to the results of Roe *et al.* (2002). This point is important because, unlike Roe *et al.* (2002), we control for the endogeneity of access to corn and cereal production as well as of access to slaughtering facilities and to mixed feed. When we do not control for this endogeneity (see Table A.1 in the Appendix), we obtain the same results reported in Roe *et al.* (2002).

[Table 2 about here].

Like in Roe *et al.* (2002), our results show that the spatial lag of the dependant variable $(W_H.H)$ aiming at capturing information spillovers plays a positive and significant role in the density of hog production. Hence, agglomeration economies arising from spatial non-market interactions between farmers are at work in the French hog sector.

We now turn to the role of environmental regulation. The estimate of local population (*Pop*) exhibits the expected sign. Local population size has a negative and significant effect on the agglomeration of hog production, regardless of estimations. Analysis of the role of regulation of manure management is more complex. Indeed, in model 1, we build a global ratio of nitrogen

production by animals to available land at the county level and at the level of the surrounding counties: $(W_N + I) \times (N/L)$). This variable has no significant effect so that there is no global effect of the availability of land for manure spreading on the location of hog production. In the following models, we separate the ratios of nitrogen production to available land at the county level and at the level of the surrounding places. In this case, the estimations reveal a significant and positive effect of the ratio when it is calculated at the county level and an opposite sign (i.e. significantly negative) for its spatial lag. Thus, increasing the local production of manure relative to the land available raises the density of hog production while a rise in this ratio for the surrounding counties triggers spatial dispersion of hog production. The latter effect is expected when manure spreading is the manure management technology used by farmers, while the former effect suggests that farmers may also use manure treatment technology to reduce manure spreading. Hence, this suggests that both types of technology for managing manure are used at county levels. In other words, higher transport costs arising from manure spreading or lower land availability in surrounding places reduce hog production, *ceteris paribus*, as shown by the negative sign of the spatial lag, but favor the spatial concentration of hog production because the use of the manure treatment system leads to economies of scale. Note that this result is quite robust. It still holds when we introduce the variables measuring access to crops (models 3 and 4). Indeed, even if there may be some linkages between the activities of manure spreading and the presence of crops, the introduction of these variables does not disturb the sign or the magnitude of the coefficients associated with manure management variables.

Exploring the role of costs related to manure management.

The role played by regulation of manure management deserves more attention. We checked the robustness of the effects of regulation of manure management on local hog production density by adding two types of control variables. First, the specialization of farmers may influence our results. Indeed, whether the local farms are specialized either in piglet production or in pork production, may modify the parameter results. In model 5, we introduce the type of specialization prevailing in each county. While the density of breeding farms plays a role in the location of hog production, the density of feeding farms has a significant and positive effect. However, it does not change the estimates of all the other variables but only slightly reduces the significance of the positive N/L effect.

Second, the quantity of manure resulting from all animal production can capture agglomeration economies related to the sharing of the same indivisible infrastructure by the different types of animal producers (“inter-sector scale economies”). Hence, the local ratio of manure production by animals to land available for spreading may capture inter-sector scale economies, explaining the positive sign of this effect. In order to control for this, in our model, we also integrate the density of non-hog farms in the county (*NHF density* in model 6), i.e. the other livestock raisers. We expect a positive sign for the latter variable. The results show that the density of livestock farms with no hog production positively influences the agglomeration of hog producers revealing the positive role of spatial spillovers between different types of livestock farms. However, the introduction of this type of ‘urbanization economy’ does not change the parameter values associated with amount of land potentially available for manure spreading. These values keep the same sign and remain significant even if the magnitude of the coefficient decreases slightly.

Hence, the role of regulation of manure management has an ambiguous impact on agglomeration. The local level of land available for manure spreading favors agglomeration while the level reached in the surrounding location favors dispersion of hog production. However we can use the elasticities evaluated at the mean values from the parameter values of model 6 (see Table 3 obtained with the means listed in Table 1) to analyze the global impact of EU regulations concerning manure spreading. The same change in the ratio of manure production to available land in all counties leads to the following global impact of the regulation of manure management on hog production: $\partial h_i / \partial (N/L) \approx 1.0119 - 1.2103 \sum_j \varphi_{ij}^s = -0.1984$ where φ_{ij}^s are the standardized weights in the spatial matrix with $\sum_j \varphi_{ij}^s = 1$ (see section 3). The global effect is thus more likely to be negative. However, the total effect is not significant. Consequently, regulation of manure management does not work against the spatial concentration of hog production.

Another strategy to check the robustness of our results consists in estimating model 6 from data for 1988 (data concerning the last agricultural campaign before 2000). Because the EU nitrate directive was introduced in 1991, we would not expect the effects of the variables associated with regulation of manure management to be significant in 1988. In order to discuss the changes in the

magnitude of coefficients between 1988 and 2000, we report the elasticities evaluated at the mean values for 1988 and 2000 for each variable in model 6 (see Table 3). As expected, our results show that the potential for manure spreading at county level or at the level of the surrounding counties had no significant impact in 1988. This confirms that the regulation of manure management has a significant effect on the location of hog production.

[Table 3 about here].

The impact of manure management regulation on agglomeration economies

The results presented in Table 3 also show that the significance and the sign for the other variables do not change over time, except for the density of livestock farms without hogs, which was not significant in 1988. This result confirms the positive role of access to inputs/outputs and spatial spillovers and the negative role of urbanization in hog production. However, while the magnitudes of the elasticities associated with the spatial lag and with the proximity to slaughtering facilities and access to mixed feed reached comparable levels in 1988 (elasticities between 0.33 and 0.35), a hierarchy emerges among those three variables during the period 1988-2000. Indeed, in 2000, the elasticity to the spatial lag of hog production density becomes much higher the elasticities related to both access variables (0.61 for the former versus 0.24 and 0.27 for access variables). Thus, while all the three variables appear to act with the same strength, the role of spatial interaction between hog producers (i.e. spatial lag) is clearly strengthened in 2000. We can interpret these changes by the following phenomena. First, the limited decline in elasticity to access to slaughtering facilities and feed producers may be due to the fall in transport costs over this period. Second, the introduction of the EU nitrate directive also boosted agglomeration economies by strengthening spatial interactions between farmers. This may be due to the need to invest in shared inputs to change manure management (such as a collective treatment facility) and to the increasing role of producers organization in the French hog sector.

6. Summary and concluding remarks

In this paper, we have developed a theoretical analysis to explain how regulation of manure management affects the location of hog production within a spatial model that also takes into account traditional spatial spillovers and access to input suppliers and to demand. Our theoretical model

includes a choice between two technologies for manure management and results show that dispersion is favored when manure is spread on land as a crop nutrient, while agglomeration is strengthened when farmers choose manure treatment. We showed how the adoption of a manure treatment system is favored by increasingly strict regulation of manure spreading. Then, we conducted an econometric study taking into account different biases that are ignored in the literature. Our estimations using 1988 and 2000 French hog production data confirm the important role played by local interactions between hog producers (spatial spillovers) and by their backward and forwards relationships (input/output market accessibility). Empirical results also suggest that the regulation of manure management introduced by the European Union in 1991 does not prevent the agglomeration of hog production. It may even boost agglomeration in two ways. First, it may induce a shift in manure management technology from manure spreading to manure treatment which is more profitable with high levels of hog production. Second, it may boost agglomeration economies related to non-market spatial externalities via shared inputs or producer organizations. These results could be an interesting illustration of Porter's hypothesis.

Further investigations require a specific focus. In particular, it would be interesting to open the 'black box' of spatial externalities by studying the role played by agricultural cooperatives in the spatial diffusion of knowledge. It would also be interesting to examine in detail the manure management technologies used by farmers and how they change over time in order to confirm (or not) our different interpretations. Our theoretical model could also develop and calibrate our empirical results to examine other types of public regulations such as ambient taxes.

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Figure 1. Geographical distribution of hog density at the county level in 2000.

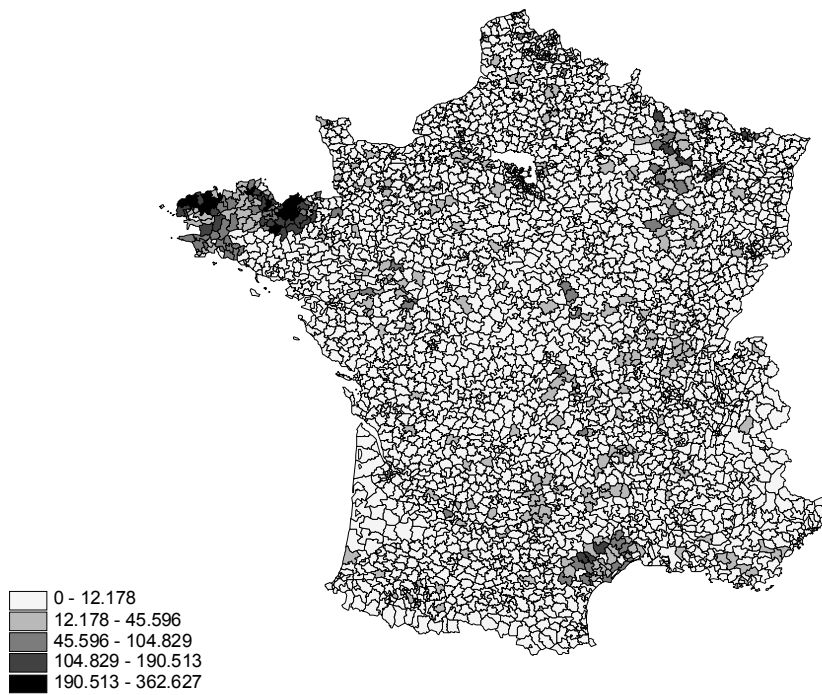


Table 1. Description of variables

<i>Variable</i>	<i>Definition</i>	<i>Source</i>	<i>Nature</i>	<i>Mean</i>		<i>Standard Deviation</i>	
				1988	2000	1988	2000
H_i	Density of hogs (head/km ²)	AC	Dependent	6.30	7.23	19.40	24.85
$W_h \times H_i$	Spatial lag of density of hogs	AC	Endogenous	6.07	7.66	10.75	19.80
$(W_x + I) \times \text{Corn}$	Access to corn production (km ²)	AC	Endogenous	10.88	15.08	15.08	93.44
$(W_x + I) \times \text{Cereal}$	Access to other cereals production (km ²)	AC	Endogenous	36.58	38.86	33.44	42.70
Mixed Feed	Quantity (million tons) of protein-rich feed	IFIP	Exogenous	265.79	367.65	0.633	1002
$(W_s + I) \times S$	Access to capacity (1000 tons) of slaughterhouses	IFIP	Endogenous	713.93	223.09	3841	3735
$W_R \times \text{Pop}_j$	Access to final consumers	PC	Exogenous	15.04	24.09	100.42	494.89
Pop_i	Population per municipality (1,000 inhabitants)	PC	Exogenous	14.65	14.89	24.50	24.76
N_i / L_i	Availability of land for spreading manure	AC	Endogenous	70.07	65.34	133.7	59.39
$W_N \times (N_j / L_j)$	Spatial lag of N_i / L_i	AC	Endogenous	69.08	72.04	51.77	247.54
B density	Density of hog breeding farms (number/km ²)	IFIP	Exogenous	0.25	0.17	0.31	0.28
F density	Density of hog raising farms (number/km ²)	IFIP	Exogenous	0.25	0.25	0.32	0.33
NHF density	Density of farms with no hogs (number/km ²)	AC	Exogenous	1.99	1.31	1.48	1.16

AC: Agricultural census; PC: Population census ; IFIP: French Institute of the Pork Sector.

Table 2. Results of estimations for the year 2000 for models 1 to 6 (SHAC estimator).

<i>Variables</i>	[1]		[2]		[3]		[4]		[5]		[6]	
Wh	0.5910	***	0.6450	***	0.6455	***	0.6306	***	0.6399	***	0.6332	***
(W+I)Corn					0.0043							
(W+I)Cereal							0.0119					
Mixed Feed	3.4014	**	5.5029	***	5.5198	***	5.9951	***	4.3619	***	5.2844	***
(W+I)S	2.2399	***	1.3480	***	1.3385	***	1.1419	**	1.7741	***	1.4446	***
WPop	0.0115		-0.0212		-0.0210		-0.0153		-0.0010		-0.0170	
Pop	-0.0510	***	-0.0365	***	-0.0362	***	-0.0330	**	-0.0411	***	-0.0356	***
N/L			0.1458	***	0.1475	***	0.1503	***	0.0849	*	0.1120	**
W(N/L)			-0.1713	***	-0.1731	***	-0.1686	***	-0.1075	**	-0.1375	**
(W+I)(N/L)	-0.0009											
B density									-0.6219		-0.8366	
F density									2.4816	**	2.2414	**
NHF density											0.6340	*
Intercept	-0.0734	n.s.	1.3776	n.s.	1.3363	n.s.	0.4934	n.s.	0.4934	n.s.	0.1869	n.s.
Adj.R ²	0.4		0.49		0.49		0.5		0.46		0.48	
Sargan test	17.78	n.s.	11.86	n.s.	11.87	n.s.	11.59	n.s.	9.53	n.s.	7.17	n.s.
Hausman test	245.38	***	172.42	***	148.13	***	137.42	***	170.67	***	171.93	***
Nb of obs	3,572		3,572		3,572		3,572		3,572		3,572	
<i>First stage Adj. R²</i>												
Wh	0.96		0.96		0.96		0.96		0.96		0.96	
(W+I)Corn					0.40							
(W+I)Cereal							0.70					
(W+I)S	0.12		0.12		0.12		0.12		0.12		0.12	
N/L			0.51		0.51		0.51		0.51		0.51	
W(N/L)			0.74		0.74		0.74		0.75		0.75	
(W+I)(N/L)	0.69											

***, **, *: significant at 1, 5, 10% .

Table 3. Mean elasticities for the entire sample (SHAC estimator).

<i>Variables</i>	[6]		[6]	
	1988		2000	
Wh	0.3259	*	0.6074	***
Mixed Feed	0.3335	***	0.2686	***
(W+I)S	0.3515	**	0.2371	***
WPop	0.0799	.	-0.0358	
Pop	-0.1155	***	-0.0740	***
N/L	-0.4031		1.0119	***
W(N/L)	0.6039		-1.2103	***
B density	0.0263		-0.0199	
F density	0.0783	***	0.0779	***
NHF density	0.0526		0.1113	**
<i>First stage Adj. R²</i>				
Wh	0.96		0.96	
(W+I)S	0.12		0.12	
N/L	0.08		0.51	
W(N/L)	0.48		0.75	

***, **, *: significant at 1, 5, 10%.

Appendix

Table A.1. IV estimations for the year 2000 for models 1 to 6 when only the spatial lag is endogenous

<i>Variables</i>	[1]		[2]		[3]		[4]		[5]		[6]	
Wh	0.5891	***	0.5491	***	0.5491	***	0.5237	***	0.5636	***	0.5501	***
(W+I)Corn					0.0062	**						
(W+I)Cereal							0.0400	***				
Mixed Feed	10.2532	**	8.6667	***	8.6776	***	8.8288	***	8.5928	***	8.7399	***
(W+I)S	2.2425	***	1.3245	***	1.3335	***	1.0219	**	1.4341	***	1.4345	***
WPop	0.0201	***	0.0021	***	0.0021	***	0.0038	***	0.0022	***	0.0021	***
Pop	-0.0515	***	-0.0297	**	-0.0300	**	-0.0223	**	-0.0278	**	-0.0271	**
N/L			0.5757	***	0.0574	***	0.0596	***	0.0513	***	0.0490	***
W(N/L)			-0.0254	***	-0.0255	***	-0.0232	***	-0.0266	***	-0.0259	***
(W+I)(N/L)	-0.0237											
B density									-0.7799		-0.8406	
F density									2.5735	***	2.4947	***
NHF density											0.7566	**
Intercept	3.2835	***	-1.1459	*	-1.3407	n.s.	0.4934	n.s.	-1.5450	**	-2.3440	***
Nb Obs	3,572		3,572		3,572		3,572		3,572		3,572	

***, **, *: significant at 1, 5, 10%