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# Modelling the Spatial Structure of Pig Production in Denmark

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**Abstract**—In Denmark, the concentration of pig production is highest in the western part of the country. However, there may be even larger local differences in the number of pigs produced. In this study we analyze the determinants of the location of pig production in Denmark with particular focus on spatial externalities and the interaction between the location of pig production and upstream sector and slaughterhouses. It is the assumption that the location of slaughterhouses is influenced by the location of the primary producers, implying that this variable is endogenous, whereas the location of primary producers is independent of the location of slaughterhouses. This is due to the fact that transportation costs of pigs are paid by the cooperatives owning the slaughterhouses. This assumption is tested applying a spatial econometric model. The model is estimated for 1999 and 2004. Furthermore, the impact of negative environmental externalities of pig production on location is analyzed. The results show that spatial externalities have a positive effect on the location of pig production whereas environmental regulation has a negative effect on location.

**Keywords**— Agglomeration, Externalities, Spatial Econometrics, Polluted Production.

## I. INTRODUCTION

From 1989 to 2004, the total number of pigs in Denmark has increased from 9 to 13 million pigs. This growth in production has been unevenly distributed, implying that in some rural areas the pig production was significantly intensified. Increased spatial concentration of the pig production over time has also been seen in the US and in France (Hubbell and Welsh [1], Herath *et al.* [2], Daucé and Léon [3], Warren and Isserman [4]).

Changes in the spatial organisation of pig production may have consequences for local supply and demand balances for key inputs and outputs, the

local rural economy, and it alters the utilization of industry-specific infrastructure and services. Even though the agricultural contribution to the local income and employment is, in general, decreasing over time, the location of agricultural production is still important for rural development. Besides the direct effects of agriculture on locale economies, agricultural production influences the location of upstream and downstream sectors (Welsh *et al.* [5]) as well as local land use and, consequently, the supply of natural amenities. Natural amenities have an impact on the quality of life of the local population and may also provide input to other sectors (Taff [6], , HERRIGES *et al.* [7]). In areas with increased spatial concentration of pig production there has been concern about the environmental impact of industrial pig production because several local areas dominated by such productions have witnessed environmental problems (Abdalla *et al.* [8], Wossink and Wefering [9]).

In this paper we analyse the location of pig production in Denmark in the period 1989 to 2004. We focus on spatial externalities in pig production and the interaction between location of pig production and upstream sector and slaughterhouses. Furthermore, we analyse the impacts of environmental regulation on location of pig productions.

The location of livestock production has recently been analysed empirically in the U.S. (see Roe *et al.* [10], Welsh *et al.* [5], Herath *et al.* [2]) and in Ontario (Weersink and Eveland [11]). Herath *et al.* [2] use an entropy index (Theil) in characterising changes in the geographic concentration of U.S. livestock production, *i.e.* pig, dairy, and fed-cattle sectors, from 1975 to 2000. The changes in spatial concentration are related to changes in the state level of slaughtering capacities, population density and environmental stringency. However, there is no formal econometric testing of these hypotheses of

causal interactions. Welsh *et al.* [5] also use an entropy index as measure for the spatial concentration of pig production at county level in the US. This measure is regressed on the economic concentration in the pig-slaughtering sector, the existence and strictness of anticorporate farming laws – both variables are measured on state-level. These variables represent the impact of global restructuring of the agrofood systems and the impact of national institutions on pig production, respectively. Furthermore, they included a number of other control variables to account for other potentially important determinants of geographic concentration. They find a positive correlation between an increasing concentration in the hop-processing industry and the geographical concentration of pig production within states. They find also that the local government policy can mitigate or worsen the geographic concentration of pig production. These two studies apply a linear regression model without considering potential endogeneity of the explanatory variables and spatial interaction.

Roe *et al.* [10] estimate a spatially explicit county-level model of the pig production sector within 15 key pig production states. They estimate three different models. As dependent variable they use natural logarithm of a county's total pig inventory, the change in the natural logarithm of pig inventories from 1992 to 1997, and the natural logarithm of the average number of pigs per farm, respectively. As a proxy for localization economics, a spatial lag of the dependent variable is included. They find that spatial agglomeration, urban encroachment, input availability, firm productivity, local economy, slaughter access, and regulatory stringency variables affect the sample regions' spatial organisation. However, they do not take into account that some of the explanatory variables may be endogenous. For example, they include the location of slaughtering capacity as an independent variable. However, one will expect that the location of slaughterhouses may be determined by the supply of pigs. Ignoring this may lead to estimation bias.

In Denmark there has been no explicit analysis of the location of livestock production. However, in a survey of 39 food-processing firms in Denmark,

firms were asked to estimate the importance of different factors for location decisions of processing and storage facilities (Christensen *et al.* [12]). Generally, access to qualified employees was found important, whereas access to transport infrastructure was of less importance. Local business environment, access to markets and suppliers had intermediate importance. However, large variations in how firms value different location factors and the limited sample size reduce the strength of the conclusions. Moreover, farmers who are member of a slaughterhouse cooperative pay all the same levy for transportation of pigs to the slaughterhouse. The levy is the average cost of transporting pigs to the slaughterhouse. This implies there is only a weak incentive for the farmers to locate close to the slaughterhouse, since the location decision of a single farmer has only limited impact on the average transport costs. Furthermore, this implies that slaughterhouses may have an interest in being close to pig producers to reduce the average transport costs of pigs for slaughtering. Co-operative members also receive the same price for pigs delivered to the slaughterhouses, implying that there is no price competition between farmers within the same cooperative.

This study contributes to the literature by offering insight in the spatial organisation of the Danish pig production, the world's largest exporter of pork meat, by providing a location model for pig farmers which is consistent with a downstream sector organised in farmer cooperatives. Furthermore, the study allows testing of the impact of recent environmental regulations of pig production in Denmark. We apply the approach recently proposed by Fingleton and Le Gallo's [13] for estimation of spatial models with endogenous variables.

The outline of the paper is as follows. In the second section, we introduce a theoretical model and empirical issues. In the third section, we provide an overview of Danish pig production sector and of the data used in the analysis. The results are then described before the conclusion.

## II. THEORY AND PROCEDURE

### A. Location and pig production

The increased spatial concentration of pig production has been explained by agglomeration economies (e.g. Roe *et al.* [10]). Industry agglomeration is traditionally explained by the so-called Marshallian externalities arising from localised knowledge spillovers, labour market pooling, and availability of specialized input and services (Fujita and Thisse [14]). The underlying microeconomic mechanisms of agglomeration are learning, sharing, and, matching mechanisms (Duranton and Puga [15]). These mechanisms have in common that they cause increasing external economies of scale that produce agglomeration. The spatial externalities can be divided into technical and pecuniary externalities. The technical externalities may arise from diffusion of information and knowledge through producer organisations and farmer advisors and from improved quality of the available labour force. The pecuniary externalities are transmitted by the market through price effects for the individual farm which may alter its location and production decision. For example, location will be influenced by the accessibility to the input services like feed processing plants and veterinary services, and the accessibility to output markets. The spatial externalities may be sector specific (location economics), *i.e.* the performance of one pig farm improves when other pig farms are located nearby, or they arise from general economic activity (urban economics), *i.e.* the performance of a pig farm improves when other firms are located nearby. However, competition on input and output markets may on the other hand have a dispersal effect on location. This is especially the case with respect to agricultural land which is demanded for spreading of manure according to environmental regulations. In all we expect that location of pig farms is affected positively by other pig farms, accessibility to input and output markets but negatively by environmental stringency. In our study, we will separate the impact of technical and pecuniary externalities by including variables for pig production in the neighbourhood and the access to input and output markets, respectively.

### B. A microeconomic model.

We develop a general model of location of pig production in Denmark. The model is inspired by Isik's [16] model on location in the U.S. dairy sector, *i.e.* it is assumed that farmers' location decision can be derived from their profit-maximising behaviour. Farmers, input suppliers, and processing firms are located in a two-dimensional spatial world and the model accounts for local production possibilities. However, in our model slaughterhouses are organised as farmer-owned co-operatives. All farmers in a co-operative pay the same average transport costs of delivering pigs to the slaughterhouse.

We use that the aggregate profit can be derived from maximizing an aggregate production function, assuming that each single farmer maximizes its individual profit. The farm produces output  $q$  using inputs  $h$  and supplies the output to the slaughterhouses. Each input supplying firm  $j$ , pig farm  $i$ , and slaughterhouse  $k$  has a location given by Cartesian coordinates  $(x,y)$ . We assimilate the location of the final consumption at the location of slaughterhouses. So let  $u_{ij}$  be the Euclidian distance between the input firm  $j$  and the producer  $i$ , and  $s_{ik}$  be the distance from the farm  $i$  to the slaughterhouse  $k$ . We suppose  $\psi^l$  as the transport rate per unit distance on the output  $q$  and  $\alpha_j$  as the transport rate per unit distance on the  $j^{\text{th}}$  input.

The pig production at each farm  $i$  is given by a quasi-concave production function:

$$(1) \quad q_i = f(h_{i1}, \dots, h_{ij}, \dots, h_{il}, \gamma_i, \rho_i)$$

where  $h_{ij}$  is the input use by farm  $i$  delivered by input firm  $j$ ,  $\gamma_i$  the farm technical coefficient affecting production, *i.e.* increasing productivity by increasing  $\gamma_i$ , and  $\rho_i = \rho_i(q_i)$  is the agglomeration externalities with  $\forall l \neq i$ . We assume that  $\partial q_i / \partial h_{ij} > 0$  and  $\partial q_i / \partial^2 h_{ij} > 0$ . Finally, the sign of  $\partial q_i / \partial \rho_i$  gives us the impact of agglomeration externalities on pig production. We did not introduce a risk factor, like

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<sup>1</sup> We assume the same transport cost rate per unit of pig for all farms independent of location contrarily to transport cost rate per unit of input.

weather, because we assume that there is no spatial variation in potential risk factors due to the limited size of Denmark and the homogeneous weather conditions and landscapes<sup>2</sup>. Thereafter, the production function will be noted  $q_i(\rho_i)$ .

The profit of each farm  $i$  is:

$$(2) \quad \pi_i = [p - \tau_k(q_i)]q_i(\rho_i) - \sum_{j=1}^J [w_j + \alpha_j u_{ij}] h_{ij} - \lambda_i - F$$

with 
$$\tau_k(q_i) = \left[ \sum_{i=1}^n \psi s_{ik} q_i(\rho_i) \right] / \left[ \sum_{i=1}^n q_i(\rho_i) \right]$$

and 
$$\lambda_i = \lambda_i(x_i, y_i, q_i, Q_j)$$

where  $p$  is the exogenous output price on the final market,  $w_j$  is the exogenous input price and  $F$  is the fixed costs (same for each firm).  $\tau_k$  is the average transport cost per pig supplied to the slaughterhouse  $k$  where  $n$  is the number of farmers supplying pig farms to the slaughterhouse  $k$ . This implies all farmers delivering pigs to the same slaughterhouse pay the same transport cost<sup>3</sup>. However, the transport cost may differ between different slaughterhouses, e.g. a farm supplying pigs to a slaughterhouse where all farmers are located close to the slaughterhouse pays relatively low transport costs compared to farmers supplying to a slaughterhouse where suppliers are dispersed. Moreover,  $\lambda_i$  are the costs associated with complying to environmental regulations. An important factor in this regulation is the constraints on the amount of manure to be applied per ha of agricultural land. This imposes competition between livestock producers for land, implying that the costs of complying to the environmental regulations increase with the production of hogs at farm  $i$  ( $q_i(\rho_i)$ ) and hogs and other types of livestock produced on neighbouring farms with livestock production ( $Q_j$ ). The stringency of the environmental regulations may vary over space according to local environmental vulnerability and population density.

<sup>2</sup> This assumption involves that we do not regard potential risk aversion of farmers.

<sup>3</sup> Because of some old solidarity principle in the co-operative, all members of a co-operative get the same net price of pigs, independent of where they are located.

The objective of each farm is to maximize its profit. Farms choose input quantity  $h_{ij}$  and its location  $(x_{ij}, y_{ij})$  to maximize profit. These variables are characterized by the first order conditions<sup>4</sup>:

$$(3) \quad \frac{\partial \pi_i}{\partial h_{ij}} = (p - \tau_k(q_i)) \frac{\partial q_i(\rho_i)}{\partial h_{ij}} - \frac{\partial \tau_k}{\partial q_{ij}} \frac{\partial q_i(\rho_i)}{\partial h_{ij}} q_i(\rho_i) - [w_j + \alpha_j u_{ij}] - \frac{\partial \lambda_i}{\partial q_i} \frac{\partial q_i}{\partial h_{ij}} = 0$$

where 
$$\frac{\partial \tau_k}{\partial q_{ij}} = \left[ \psi s_{ik} - \sum_{i=1}^n \psi s_{ik} q_i / \sum_{i=1}^n q_i \right] / \sum_{i=1}^n q_i$$

$$(4) \quad \frac{\partial \pi_i}{\partial x_i} = -\frac{\partial \tau_k}{\partial x_i} q_i(\rho_i) - [p - \tau_k] \frac{\partial q_i(\rho_i)}{\partial \rho_{ii}} \frac{\partial \rho_i}{\partial x_i} - \sum_{j=1}^J \alpha_j \frac{\partial u_{ij}}{\partial x_i} h_{ij} - \frac{\partial \lambda_i}{\partial x_i} = 0$$

where

$$\frac{\partial \tau_k}{\partial x_i} = \frac{\left[ \psi \frac{\partial s_{ij}}{\partial x_i} + \left( \psi s_{ik} - \sum_{i=1}^n \psi s_{ik} q_i / \sum_{i=1}^n q_i \right) \frac{\partial q_i(\rho_i)}{\partial \rho_{ii}} \frac{\partial \rho_i}{\partial x_i} \right]}{\sum_{i=1}^n q_i}$$

$$(5) \quad \frac{\partial \pi_i}{\partial y_i} = -\frac{\partial \tau_k}{\partial y_i} q_i(\rho_i) - [p - \tau_k] \frac{\partial q_i(\rho_i)}{\partial \rho_{ii}} \frac{\partial \rho_i}{\partial y_i} - \sum_{j=1}^J \alpha_j \frac{\partial u_{ij}}{\partial y_i} h_{ij} - \frac{\partial \lambda_i}{\partial y_i} = 0$$

where

$$\frac{\partial \tau_k}{\partial y_i} = \frac{\left[ \psi \frac{\partial s_{ij}}{\partial y_i} + \left( \psi s_{ik} - \sum_{i=1}^n \psi s_{ik} q_i / \sum_{i=1}^n q_i \right) \frac{\partial q_i(\rho_i)}{\partial \rho_{ii}} \frac{\partial \rho_i}{\partial y_i} \right]}{\sum_{i=1}^n q_i}$$

The first and third right hand side elements in (3) represent the standard condition for profit maximisation, *i.e.* price of an input should equal the value of the marginal product of this input. However, the second element take into account that the price of pigs net of transport costs may change as a result of changes in production. This element will be different from null when the transport

<sup>4</sup> The second-order conditions are satisfied under quasi-concave production function.

distance between farm  $i$  and the slaughterhouse  $k$  differs from the production-weighted average distance between slaughterhouse  $k$  and all other farms delivering pigs to this slaughterhouse. The last element corrects for the marginal environmental compliance cost, *i.e.* the farm  $i$ 's own impact on the local livestock concentration. The first right hand side element in (4) and (5) represents the marginal transport cost of pigs by changing the location of the farm in the two dimensional space. This includes the changes in average price due to changed distance and due to changed production if the effect of agglomeration changes. The second elements represent marginal changes in productivity due to changes in productivity. These elements are zero if the concentration of pigs is constant over space or if there are no spillovers between pigs farms<sup>5</sup>. The next  $J$  elements are the marginal changes in transport costs of inputs, and the last elements are the marginal changes in environmental compliance costs by moving the location of the farm in the two dimensional space.

With our model, the optimal input is given by

$$(6) \quad h_{ij}^* = h_{ij}^*(p, \tau_i, s_{ik}, w_j, \alpha_j, u_{ij}, \gamma_i, \rho_i | (x_i, y_i))$$

Our focus is on where to locate a farm and not on the choice of whether or not to start a new production. The optimal farm location is determined by (4) and (5) depending on (6). Farm  $i$  locates its operation where it obtains the highest profit. The optimal output depending on (6) and  $(x_i^*, y_i^*)$  is defined as:

$$(7) \quad \begin{cases} x_i^* = x_i^*(h_{ij}^*, p, \tau_i, s_{ik}, w_j, \alpha_j, u_{ij}, \gamma_i, \rho_i, \lambda_i) \\ y_i^* = y_i^*(h_{ij}^*, p, \tau_i, s_{ik}, w_j, \alpha_j, u_{ij}, \gamma_i, \rho_i, \lambda_i) \\ q_i^* = f(h_{i1}^*, \dots, h_{iJ}^*, \gamma_i, \rho_i(q_i^*), F | (x_i^*, y_i^*)) \end{cases}$$

Thereby, there exists a simultaneous determination of optimal output for all farms due to agglomeration externalities  $\rho_i$  and the environmental

costs which are influenced by the local competition for land.

Farmers choose location  $i$  against  $l$  if the profit is highest in  $i$ , *i.e.*  $\pi_i > \pi_l \quad \forall i, l$ . Thus, farms are more concentrated in areas with favourable production conditions. The profit and production go down with an increase in transport costs. The transport costs increase with the distance to input supplying firms, whereas the transport costs of pigs to slaughterhouses is only weakly dependent on the distance between the slaughterhouse and the farm. This implies that a farm has an advantage of being located close to input supplying firms whereas the advantage of being close to the slaughterhouses is less important. A reduction in the stringency of environmental regulations induces a reinforcement of the profit. That is why farmers want to locate the activities in a county where environmental stringency is lower. The technical coefficient of the farm may also affect its profit and location *via* the production function. Due to positive technical externalities, farmers will locate in areas where other similar or related activities are located, *i.e.*  $\partial q_i / \partial \rho_j > 0$ . Changes over time of the agglomeration externalities could also explain changes in the farm's output and indirectly the location over time. The impact on the changes in production level could be different from their impact on the production level. The sign of  $(\partial q_{i,t} / \partial \rho_{j,t} - \partial q_{i,t-1} / \partial \rho_{j,t-1})$  shows how changes technical externalities affect the change in production level over time.

### C. Reduced form and Econometric issues.

The empirical application of the theoretical model uses municipality-level agricultural and economic data from 1999 and 2004 in Denmark. We examine the factors affecting the pig inventory using the reduced form of the optimal output defined by the theoretical model, *i.e.* pig density in municipality  $i$  ( $Y_i$ ) is used as a proxy for the optimal output in estimation of the determinants of pig production in that municipality.

<sup>5</sup> Isik [16] ignores potential spillovers in the theoretical model even though he estimates impact of spillover on location in his empirical model.

More specifically, the following model (8) is used for the estimations:

$$(8) \quad Y = \beta_0 + \beta_1 \rho W Y + \beta_2 (W + I) S \\ + \beta_3 (W + I) X + \beta_5 E + u$$

with  $u = \kappa W^* u + \varepsilon$

The technical externalities of agglomeration,  $\rho_i = \rho_i(q_i)$ , are measured by  $\rho$ , representing the parameter of a distance weighted inventory level in the neighbourhood of a municipality. The neighbour relation  $W$  is expressed by a spatial weight matrix in which the rows and columns correspond to the cross-sectional observations. An element  $w_{ij}$  of the matrix can be interpreted as the presence of a link between observation in county  $i$  and observation in location  $j$  (respectively, in the row, column, of the matrix). In this analysis, the elements of the weights matrix are derived using a distance squared decay function,  $w_{ij} = 1/d_{ij}^2$ , where  $d_{ij}$  equals the centroid-to-centroid road distance in kilometres between counties  $i$  and  $j$ . The distance squared decay function gives a low weighting to observations that are far apart. Thus, beyond a certain distance, pig production does not influence local activity anymore. The elements along the main diagonal are  $w_{ii} = 0$ . For the interpretation of the spatial variables, the weights have been standardised so that the elements in each row sum to 1. Thus, the standardized elements are  $w_{ij}^s = w_{ij} / \sum_j w_{ij}$ . We expect to find positive technical agglomeration externalities.

We have also included a variable representing the accessibility of slaughterhouse capacity  $((W + I)S)$ , called  $\tau_i$  in system (7), which is assumed to affect the net price of pigs positively. However, this variable is only expected to have a weak impact on location since farmers supplying to co-operative-owned slaughterhouses pay an average transport price. The affect of gross input prices (including transport costs, called  $h_{ij}$  in system (7)) is measured by the accessibility to industrial food  $((W + I)X)$ , assuming that prices are lower with short distance to harbours where imported protein-rich feed is unloaded. The accessibilities to slaughterhouse

capacity and to industrial food give us a proxy of pecuniary externalities of agglomeration which supposed positive.

Several measures of regulation have been implemented to reduce the negative environmental impact of livestock production. In Denmark, the environmental regulations on pig production include, among others, area requirements for spreading of manure, standards for design of production facilities, restrictions on location of production facilities close to cities and vulnerable ecosystems (Hansen [21], Miljøministeriet [22]). To what degree the environmental regulations have reduced the agglomeration is not, a priori, clear. Minimum requirements of land for the spreading of manure have introduced a new condition for the “landless” pig sector: land competition. This reduces the agglomeration forces. At the same time, restrictions in the positioning of new production facilities in environmentally vulnerable areas may increase intensity in less vulnerable areas. The environmental compliance costs, called  $\lambda_i$  in system (7), are represented by the competition for land for spreading of manure ( $E$ ): as Roe *et al.* [10], we expect that environmental regulations have a dispersal effect on location.

To estimate the last model (8), we consider a general regression model, including both the spatial lagged term as well as a spatially correlated error structure, given in the equation (using customary notation):

$$(9) \quad Y = \beta_0 + \rho W Y + \beta_1 X + \beta_2 H + u$$

where  $Y$  is the  $(n \times 1)$  vector of observations on the dependent variable;  $\beta_0$  is the intercept,  $\rho$  is a scalar spatial autoregressive parameter,  $W$  is an  $(n \times n)$  spatial weights matrix,  $X$  is an  $(n \times k)$  matrix of observations on  $k$  exogenous variables with  $\beta_1$  as the corresponding  $(k \times 1)$  vector of parameters;  $H$  is a  $(n \times c)$  matrix of observations on  $c$  endogenous variables with  $\beta_2$  as the corresponding  $(c \times 1)$  vector of parameters, and  $u$  is the  $(n \times 1)$  vector of error terms (specific spatial process).

Many traditional econometric models, such as linear regression, assume that the learning samples

are *independently and identically distributed (i.i.d.)*. This assumption is violated in the case of spatial data due to spatial autocorrelation (Anselin [17]). The most used models are variants of the model suggested in Cliff and Ord [18], where spatial autocorrelation is included in the regression model as an endogenous spatial lag variable and/or a spatial error process. If there is evidence of spatial dependence in the error structure in a spatial autoregressive (SAR) model, the autoregressive disturbances (SAC) model is an appropriate approach to modelling this type of dependence among the errors.

The maximum likelihood (ML) model is by far the most common methodological framework applied in spatial econometrics. However, the estimation of a model with a spatial error process and endogenous variables is not possible with the usual maximum likelihood approach. Other approaches exist to avoid the problems due to ML estimation. One of these alternative methodologies is the feasible generalized spatial two-stage least squares (FGS2SLS) estimation. As Kelejian and Prucha [19] noticed in their work, instrumental variables estimation can be helpfully implemented in models with spatial lag (*i.e.* with simultaneous spatial interaction): thereby, the endogeneity of the spatially lagged dependant variable can be corrected. As in Roe et al. [10], the inclusion of spatial interaction among county-level pig production will take into account the hypothesis of location externalities. Pig production is determined to be simultaneous across areas. Since neighbouring productions are endogenous, we will have biased parameter estimates if we include a spatial lag.

Moreover, when non-spatial endogenous variables are included in the model, they will also require the use of instruments. In fact, in the empirical applications of spatial econometrics, the effects of other endogenous variables have often been disregarded in comparison with the well-known spatial lag endogeneity. Indeed, Roe et al. [10] have not considered the endogeneity of slaughterhouse location. However, endogeneity of the location of slaughterhouses may be a result of the existence of an unknown set of simultaneous structural equations representing the vertical

coordination between pig producers and slaughterhouses. But, Fingleton and Le Gallo [13] have extended Kelejian and Prucha's [19] method by allowing additional endogenous variables. In our analysis we will use the Fingleton and Le Gallo's [13] approach (FGS2SLS).

We will also investigate the error term  $u$  for spatial correlation, *i.e.* the autoregressive (AR) process where  $u$  takes the following form:

$$(7) \quad u = \kappa W^* u + \varepsilon$$

where  $\kappa$  is the scalar spatial error autoregressive parameter;  $W^*$  is an  $(n \times n)$  first-order spatial contiguity matrix (*i.e.* neighbouring municipalities have the value one) and  $\varepsilon$  is a  $(n \times 1)$  vector of normally distributed error terms, with  $\varepsilon \sim iid(0, \sigma^2 I_n)$ . We note that in the AR process implies that a shock at one location  $j$  is transmitted to all other locations of the sample (Anselin [20]).

With the Fingleton and Le Gallo's [13] model, we analyze both endogeneity and simultaneous spatial interaction. The estimation procedure has three stages. In the first one, the model is estimated by 2SLS. The second stage uses the resulting 2SLS residuals to estimate  $\lambda$  and  $\sigma^2$  using a GM procedure. In the final stage, the estimated  $\lambda$  is used to perform a Cochrane-Orcutt transformation to account for the spatial dependence in the residuals.

### III. DATA

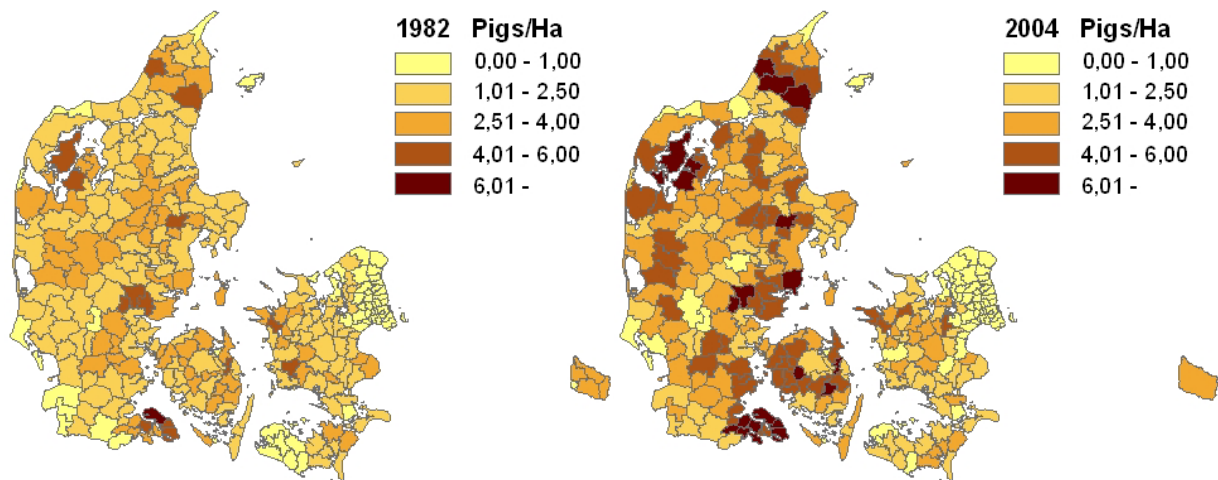
#### A. Danish hog production.

In Denmark the total number of pigs has increased from 9.3 million in 1982 to 13.4 million in 2006. However, the number of farms producing pigs has decreased from 55,000 to 7,800 in the same period, implying that the average number of pigs per farms has increased from 169 to 704. The pig production has been geographically concentrated in Jutland and on the island Funen (see Figure 1)<sup>6</sup>.

<sup>6</sup> We applied Moran's  $I$  statistic (details are given in Cliff and Ord [18], p.42-46) to the density of pig per municipality, using a standardized distance matrix, for 1999 and 2004. Each statistic is significant at 1 percent, yielding standardized z-scores of 73.55 and 28.43, respectively (with  $N$  expectation).



Figure 1. Pigs per hectare land at municipality level in 1982 and 2004.



Source: Statistics Denmark [26].

It appears also from comparing the maps of pig density from 1982 and 2004 that most of the places where pig production was agglomerated in 2004 were the same as in 1982. Generally, the highest increases in spatial concentration of pigs per hectare are found in the areas with high concentration already in 1982. In some municipalities, especially at Sealand, the geographical concentration of pigs has been decreasing even though the total number of pigs has been increasing in the period.

The Danish pig production sector is in international comparison characterized by strong vertical integration where farmer-owned co-operatives operate breeding facilities, slaughterhouses, processing, and wholesale facilities (Schrader and Boehlje [23], Laursen et al. [24]). For more than a century the major part of Danish pig producers have been members of co-operatives owning slaughterhouses. In 1980 there were 18 cooperatives slaughtering pigs (Danske Slagterier [25]). This number was reduced to 2 in 2006. However, these two cooperatives slaughtered 95% of all pigs slaughtered in Denmark. The majority of the remaining 5% was slaughtered by 10 private slaughterhouses.

There has recently been a significant increase in the amount of pigs exported for slaughtering, primarily to Germany. From 1990 to 2006 this export has increased from zero to about 455,000

pigs per year. The growth in export of piglets for fattening in Germany is even more significant than the growth in export of pigs for slaughtering. From almost non-existing in 1988, the export has increased to 3.8 million piglets in 2006. It has been suggested that the driving factors behind the increased Danish export of piglets are higher prices on pigs in Germany, higher costs in German piglet production, and high environmental compliance costs in Denmark (Udesen et al. [27]).

In our analysis the geographical units are the local municipalities. We take into account all Danish municipalities except Bornholm<sup>7</sup>. Bornholm is not included because it is located far from the rest of county in the Baltic Sea, and in 2002 the island's municipalities were reduced from five to one, implying discontinuity in data. Furthermore, we exclude eight municipalities where soil quality observations are lacking. These municipalities include Copenhagen and nearest suburbs. Therefore, we end up basing our analysis on 262 municipalities. The model is estimated for 2 years; 1999 and 2004. The choice of years has been determined by the availability of data on pig production and land use at the municipality level. In 1999 Statistics Denmark carried out surveys conducted as total census, and in 2004 data was available from the *General*

<sup>7</sup> Bornholm is an island located in the Baltic Sea,

*Agricultural Register* and the *Central Husbandry Register*.

Below the variables used in the empirical estimation is described, and descriptive statistics are summarized in Table 1 (for 1999) and Table 2 (for 2004). The main data source is the public database *StatBank Denmark*.

### B. Variable description.

The dependant variable considered is the natural logarithm of the total pig inventory ( $Y$ ). We follow Roe *et al.* [10] by including a spatial lag of the depended variable ( $WY$ ). This represents the potential existence of location economics, *i.e.* industry-specific positive spatial externalities. Therefore, we expect that the coefficient of the spatial lag is positive. The spatial lag is constructed by multiplying the spatial weight matrix  $W$  with the vector with the dependent variable. To account for

the endogeneity of the spatial lag of the depended variable, we construct a non-theoretical instrumental variable (Kennedy [28], p163). When spatial lag is placed in rank order, this quasi-instrument is equal to -1 for the upper third, 0 for the middle third, and 1 for the lower third. The local pig demand is represented by the local capacity of slaughterhouses. Data on the total number of pigs slaughtered is obtained from The Danish Veterinary and Food Administration. Pigs slaughtered abroad are also included, *i.e.* the number of pigs exported to Germany, The Netherlands, and Poland is representing the export demand. It is assumed that all pigs are transported by truck through the municipality of Bov which is located on the border to Germany. The only motorway crossing the border between Denmark and Germany is passing through the municipality of Bov.

Table 1. Summary statistics for 1999.

<i>Variable</i>	<i>Mean</i>	<i>Median</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
$Y$	9.389	10.385	3.059	0	12.401
$(W+I)S$	157,560.62	59,187.25	322,892.60	1,716.32	2,826,545.53
$(W+I)X$	35.428	11.950	119.914	0.383	1,255.51
$E$	0.533	0.565	0.282	0	1.205
$UNEARSH$	30.533	24	22.560	0	105
$INCBAS$	206.252	205.991	10.415	174.073	235.798
$SOILO$	0.411	0.360	0.333	0	1
$NATURA$	0.157	0.126	0.143	0	0.852

Table 2. Summary statistics for 2004.

<i>Variable</i>	<i>Mean</i>	<i>Median</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
$Y$	9.555	10.553	2.963	0	12.576
$(W+I)S$	175,073.16	63,020.05	383,576.24	1,831.80	2,612,116.06
$(W+I)X$	31.213	8.768	112.136	0.206	1,361.21
$E$	0.552	0.585	0.289	8.3 E-05	1.188
$UNEARSH$	28.348	23	20.767	0	106
$INCBAS$	237.220	236.392	13.726	200.643	312.069
$SOILO$	0.411	0.360	0.333	0	1
$NATURA$	0.157	0.126	0.143	0	0.852

The slaughterhouse capacity (which takes into account only capacity more than 50,000 heads)<sup>8</sup> is weighted with the spatial accessibility weight matrix  $(W+I)$  to include demand from slaughterhouses in neighbouring municipalities  $((W+I)S)$ . It is expected that the location of the pig production has an impact on the location of slaughterhouses, since it is the slaughterhouses that carry the cost of transporting the pigs. This is confirmed by Christensen et al. [12] who find in a survey of Danish slaughterhouses and meat processing firms that slaughterhouses see proximity to pig production as an important location factor. This implies that the location of slaughterhouse capacity is an endogenous variable. The distance to the nearest slaughterhouse municipality (always with more than 50,000 slaughtered heads) is used as an instrument of the local slaughterhouse capacity.

Most of the protein-rich feed, e.g. soybeans, used in pig production is imported and mostly this import passes through small coastal harbours in Denmark (Lemoine [29]). We assume that it is only the import from Germany which is not imported by ships but by road or rail. Therefore, we use the quantity of industrial feed unloaded in Danish harbours as a measure for the availability of protein-rich feed. This is supplemented by the import for industrial food from Germany which is assumed to be transported by road or rail, *i.e.* the municipality of Bov. To obtain the local supply of protein-rich feed we weight the import with the spatial accessibility matrix  $((W+I)X)$ . That is, the supply increases with proximity to a harbour or the German border. Several measures of regulation have been implemented to reduce the negative environmental impact of livestock production. In Denmark, the environmental regulations on pig production include, among others, area requirements for spreading of manure, standards for design of production facilities, restrictions on location of production facilities close to cities and vulnerable

<sup>8</sup> The data on slaughterhouses includes also butcher shops which slaughter only a small number of pigs per year. These were excluded by imposing a lower limit on the size of the slaughterhouses which were included in the analysis. This limit is necessary because we have used the distance to nearest slaughterhouse as an instrument for output demand. We assume that it is only slaughterhouses with more than 50,000 slaughtered heads per year which have an impact on the local demand for pigs.

ecosystems (Hansen [21], Miljøministeriet [22]). Minimum requirements of land for the spreading of manure have introduced a new condition for the “landless” pig sector: land competition. This reduces the agglomeration forces. At the same time, restrictions in the positioning of new production facilities in environmentally vulnerable areas may increase intensity in less vulnerable areas.

We measure the competition for land for spreading of manure as the ratio between the demand for land for spreading of manure at municipality level and the available land for spreading of manure at municipality level ( $E$ ). The demand for land for spreading of manure is calculated by using the norms from the Danish livestock regulation. The supply of land for spreading of manure is calculated as the total arable land minus the set a side area. It is not allowed to spread manure on land which is set aside. However, the competition for land will depend on the size of the pig production, implying that this variable is endogenous. Therefore, we use the population density and the environmental vulnerability as an instrumental variable for the impact of negative externalities of pig production. The population density represents the restrictions on the expansion of production close to cities as well as the local resistance to the siting of large-scale pig production facilities, *e.g.* caused by the so-called “not in my backyard” attitude. To account for the environmental vulnerability of a municipality we include a variable representing the share of land appointed as Natura2000<sup>9</sup> protected area or appointed as sensitive drinking water areas within a municipality. In appointed areas there are more constraints on the environmental impacts by expansion of livestock production than in others (Kørnøv and Christensen [30]).

#### IV. EMPIRICAL RESULTS

Table 3 and Table 4 present the results of estimating the production equation for the FGS2SLS estimation described above and moreover results for spatial

<sup>9</sup> Natura 2000 is a European network of protected sites which represent areas of the highest value for natural habitats and species of plants and animals which are rare, endangered or vulnerable in the European Community.

autoregressive (SAR) model, spatial error autocorrelation (SAC) model and 2SLS estimation.

Accessibility for industrial feed ( $X$ ) is significant only for SAC model. However, it does not seem significant when the spatial lag is controlled, whatever year is observed. Like this, it seems that input access has no impact on location of pig production in spite of our expectations. It may be that the distance to nearest harbour is rather low in all municipalities in Denmark and, and therefore we do not have a significant effect.

Accessibility to slaughterhouses ( $S$ ) becomes significant when we control the endogeneity for 2004 (but not for 1999). Thus, endogenous link between pig production and slaughterhouses is self-evident: simultaneous location appears in 2004. As explained in the introduction we will not expect a strong impact of the access to slaughterhouses since farmers payment for transport of pigs are independent of distance and all co-operative members receive the same price for pigs. However, in 2004 changes in competition laws have opened up for sales of pigs to other slaughterhouses for members of the largest co-operative, Danish Crown. Some farmers have used this right for exporting pigs for slaughtering in for example Germany.

But if this impact is significant in 2004, it is less than the agglomeration variable: elasticity for accessibility to slaughterhouses is 0.05.

The potential existence of location economics, *i.e.* the spatial lag, is positive and significant at 1%. Our expectations are confirmed. Moreover, the impact increases when endogeneity is controlled. Thus, an auto-agglomeration is evident, and it is the best variable to explain location of pig production. Furthermore, the coefficients are stable during years:

in 2004, the elasticity evaluated at the mean point is 1.46 and in 1999, it is 1.47 (see Table 5).

Several measures of regulation have been implemented to reduce the negative environmental impact of livestock production. The ratio between the demand for land for spreading of manure at municipality level and the available land for spreading of manure at municipality level ( $E$ ) does not have the same impact with or without endogeneity control in spite of its high significance (at 1%). Indeed, if we don't control for the endogenous aspect of this variable, its coefficient is positive. But, when we control for endogeneity it becomes negative as we were expecting. This important result shows that a direct correlation between the production and this ratio exists. Moreover, this dispersion effect increases with time: elasticity goes from -0.27 in 1999 to -0.34 in 2004. This is consistent with increasing stringency of environmental regulation.

Finally, the use of FGS2SLS estimation increases R-squared: 0.555 in 1999 and 0.506 in 2004. This R-squared indicates a close association between instruments and endogenous variables. Moreover, the instruments (detailed in section Data) are evidently independent of the residuals, as shown by the Sargan test statistics  $p$ -values: for 1999, 0.16 and for 2004, 0.74. Nevertheless, Table 6 indicates us that accessibility to slaughterhouses does not explain very well the dependant variable. We must find a better instrument. Finally, the use of the AR error model is well-justified in so far as it appears significant at the 5 per cent level for each year: the  $\lambda$  parameter implies a chock in a municipality is transmitted outwards as a chain reaction with diminishing force to all other areas.

Table 3. Parameter estimates of the pig production in 1999.

	<i>Spatial autoregressive (SAR)</i>		<i>Spatial error autocorrelation (SAC)</i>		<i>2SLS</i>		<i>FGS2SLS</i>	
<i>Intercept</i>	0.867	**	6.286	***	- 2.028	**	- 1.898	**
<i>WY</i>	0.788	***			1.573	***	1.517	***
<i>(W + I) S</i>	2.8 E-07		4.3 E-07	*	- 4.6 E-07		- 4.8 E-07	
<i>(W + I) X</i>	4.9 E-04		0.001	**	- 6.1 E-04		- 5.7 E-04	
<i>E</i>	2.400	***	4.966	***	- 5.292	***	- 4.760	***
$\lambda$			0.810	***			- 0.196	**
$R^2$	0.492		0.229		0.503		0.555	
<i>Sargan p-value*</i>					0.245		0.157	

\*\*\*, \*\*, \*: significant at 1, 5, 10 percent

\*  $H_0$ : instrumental set is valid. We accept  $H_0$  if probability is upper than 10 per cent.

Table 4. Parameter estimates of the pig production in 2004.

	<i>Spatial autoregressive (SAR)</i>	<i>Spatial error autocorrelation (SAC)</i>	<i>2SLS</i>	<i>FGS2SLS</i>
<i>Intercept</i>	0.998 **	6.792 ***	- 1.772 **	- 1.698 **
<i>WY</i>	0.788 ***		1.569 ***	1.499 ***
<i>(W + I) S</i>	1.8 E-07	3.5 E-07	2.8 E-06 **	2.8 E-06 **
<i>(W + I) X</i>	5.8 E-04	0.001 *	- 0.001	- 9.1 E-04
<i>E</i>	2.155 ***	4.042 ***	- 6.685 ***	- 5.929 ***
$\lambda$		0.777 ***		- 0.260 **
$R^2$	0.404	0.170	0.422	0.506
<i>Sargan p-value*</i>			0.818	0.736

\*\*\*, \*\*, \*: significant at 1, 5, 10 percent

\*  $H_0$ : instrumental set is valid. We accept  $H_0$  if probability is upper than 10 per cent.

Table 5. Parameter estimates of the pig production. First stage  $R^2$ .

	<i>2SLS 1999</i>	<i>FGS2SLS 1999</i>	<i>2SLS 2004</i>	<i>FGS2SLS 2004</i>
<i>WY</i>	0.823	0.840	0.773	0.809
<i>(W + I) S</i>	0.236	0.241	0.209	0.223
<i>E</i>	0.567	0.592	0.514	0.571

Table 6. Parameter estimates of the pig production. Elasticity.

	<i>Elasticity evaluated at the mean point 1999</i>	<i>Elasticity evaluated at the median point 1999</i>	<i>Elasticity evaluated at the mean point 2004</i>	<i>Elasticity evaluated at the median point 2004</i>
<i>WY</i>	1.4727	1.4930	1.4583	1.4720
<i>(W + I) S</i>	- 0.0081	- 0.0028	0.0505	0.0165
<i>(W + I) X</i>	- 0.0022	- 0.0007	- 0.0030	- 0.0008
<i>E</i>	- 0.2706	- 0.2589	- 0.3423	- 0.3290

## V. SUMMARY

In this study we analysed the impact of agglomeration externalities, input and output market access, and environmental regulations on the location of pig production in 1999 and 2004 in Denmark. The results show that spatial externalities are important for location of pig production, *i.e.* pig farms have higher profit if there is a high concentration of pigs in the neighbourhood. This indicates that pig farms benefit from input sharing, labour pool matching and knowledge spillovers. On the other hand, we found no or only a weak effect of input and output accessibility. However, we did not expect to find a strong effect of accessibility of slaughterhouses due to the organisational structure of the Danish slaughterhouse sector, *i.e.* farmer-owned slaughterhouses and farmers' distance-independent payment of transport costs. The lacking impact on location of input accessibility may

be caused by weak instruments for the accessibility of industrial feed. Finally, we found that the environmental regulations imply a negative agglomeration externality. The econometrical analysis showed that it is important to consider that explanatory variables in a location model may be endogenous. The analysis showed also that it is also important to consider the potential spatial dependence in the error terms.

Future research should consider changes in production by modelling the differences in the pig inventory between 1999 and 2004 (see e.g. Roe et al. [10], Isik [16]). It may also be relevant to include other variables representing the accessibility of other input factors in production, e.g. the local costs of labour and taxation. Furthermore, it will also be worth while to include more direct measures of environmental regulations using indicators for the stringency in the regional implementation of the regulation. This could help us to identify the

underlying mechanisms which cause the impact of the environmental regulation on pig location.

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