

Modelling the Spatial Structure of Pig Production in Denmark

Solène Larue^{1,2}, *Jens Abildtrup*³, *Bertrand Schmitt*^{1,2},

¹ INRA, UMR1041 CESAER, F-21000 Dijon, France

² ENESAD, UMR1041 CESAER, F-21000 Dijon, France

³ FØI, Institute of Food and Resource Economics, Copenhagen, 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 as well as environmental regulation (unlike expected).

KEYWORDS: Agglomeration, Externalities, Spatial Econometrics, Environmental regulation.

JEL CODES: C13, R30, R15, Q11.

Corresponding author

Address: Solène Larue, CESAER, 26 Bd Dr Petitjean, BP 87999, F-21079 Dijon Cedex

Email: Solene.Larue@enesad.inra.fr

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1. INTRODUCTION

In this paper we analyse the determinants of the location of pig production in Denmark. We focus on traditional determinants of agglomeration, i.e. positive spillover between pig farms and the interaction between pig farms and upstream and downstream sectors, as well as the impact of environmental regulation on the location of pig farms. Production of pork meat is important for Danish agriculture and economy, i.e. around one third of the production value in Danish agriculture is from production of pork meat. The pig production in Denmark is unevenly distributed and in the preceding decades the production has increased significantly in some localities.

Changes in the spatial organisation of pig production may have consequences for the local rural economies. Besides the direct effects of agriculture on local economies, agricultural production influences the location of upstream and downstream sectors (Drabenstott et al. 1999, Welsh et al. 2003) 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 1996, Gómez and Zhang 2000, Herrerías et al. 2005). 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. 1995, Wossink and Wefering 2003).

The location of livestock production has recently been analysed empirically in the U.S. (see Metcalfe 2001, Roe et al. 2002, Welsh et al. 2003, Herath et al. 2005a, 2005b) and in Ontario (Weersink and Eveland 2006). Herath et al. (2005a) use an entropy index (Theil 1967) 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. (2003) 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 hog-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. This study applies a linear regression model without considering potential endogeneity of the explanatory variables and spatial interaction.

Roe et al. (2002) 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 localization economics, 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.

In Denmark, 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 (2008) for estimation of spatial models with endogenous variables.

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

2. THEORY AND PROCEDURE

2.1. Location and pig production

The increased spatial concentration of pig production has been explained by agglomeration economies (e.g. Roe et al. 2002). 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 2002) and the underlying microeconomic mechanisms of agglomeration are learning, sharing, and, matching mechanisms (Duranton and Puga 2004). 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.

2.2. A microeconomic model.

We develop a general model of location of pig production in Denmark. The model is inspired by Isik's (2004) 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. Cooperative-owned slaughterhouses slaughter about 95% of all pigs slaughtered in Denmark. All farmers in a co-operative pay the same levy per pig for the transportation to the slaughterhouses. The levy is an average of the cost of transporting pigs to the slaughterhouse. This implies there is only a weak incentive for farmers to locate close to the slaughterhouse, since the location decision of a single farmer has only limited impact on the average transport costs. On the other hand, cooperatives have still an interest in locating the slaughterhouses close to where pigs are produced. 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. In Isik's (2004) version of the model farmers pay farm specific transport costs of delivering farm output (milk) at the food processing plants (dairies). Therefore, we have modified Isik's model to account for the Danish approach to the allocation of transport costs between cooperative members, i.e. farmers pay a levy for transport corresponding to the average transport costs.

We use that the aggregate profit can be derived from maximizing an aggregate profit 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 ψ' as the transport rate per unit distance on the output q and α_j as the transport rate per unit distance on the j^{th} input.

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

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

where h_{ij} is the input used by farm i and delivered by input firm j , γ_i the farm technical coefficient affecting production, *i.e.* increasing productivity by increasing γ_i , and $\rho_i \equiv \rho_i(q_i)$ is the agglomeration externalities with $\forall l \neq i$, we consider ρ_i as exogenous for each farm. 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 do not introduce a risk factor, like 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.² Thereafter, the production function will be noted $q_i(\rho_i)$.

The profit of each farm i is:

¹ 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.

² This assumption involves that we do not regard potential risk aversion of farmers.

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

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

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

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). τ_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 cost³. 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, κ_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_i). The stringency of the environmental regulations may vary over space due to variations in environmental vulnerability.

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 conditions⁴:

³ 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.

⁴ The second-order conditions are satisfied under quasi-concave production function.

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

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

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

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

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

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

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 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 production 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 pig's farms⁵. 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

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

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^*) could be defined as:

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

Thereby, there exists a simultaneous determination of optimal output for all farms due to agglomeration externalities ρ_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

⁵ In Isik (2004) changes in agglomeration externalities due to changes in location are ignored in the first order conditions even though these spatial interactions are addressed in the empirical analysis.

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 in technical externalities affect the change in production level over time.

2.3. 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.

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

$$Y = \beta_1 + \rho WY + \beta_2 (W + I)S + \beta_3 (W + I)X + \beta_5 E + \beta_6 WE + \beta_7 P + \beta_8 WP + \beta_9 G + u \quad (8)$$

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

The technical externalities of agglomeration, $\rho_i = \rho_i(q_i)$, are measured by ρ , representing the parameter of a distance weighted inventory level in the neighbourhood of a municipality. As in Roe et al. (2002), the inclusion of spatial interaction among county-level pig production will take into account the hypothesis of location externalities. Pig production is determined simultaneously across areas, implying that neighbouring productions are endogenous and that we will have biased parameter estimates if we include a spatial lag. We will also investigate the error term u for spatial correlation: this process implies a shock at one location j is transmitted to all other locations of the sample (Anselin, 2003).

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 decay function, $w_{ij} = 1/d_{ij}^\theta$, where d_{ij} equals the road distance in kilometres between administrative towns in 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 τ_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 are 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 κ_i in system (7), are represented by the competition for land for spreading of manure (E) and its spatial lag (WE): as Roe *et al.* [10], we expect that environmental regulations have a dispersal effect on location. The population density of municipality (P) can be envisaged as a negative externality (*i.e.* olfactory nuisance) and its spatial lag (WP) like an outlet (consumption area). Finally, the distance to the German border (G) is included as an explanatory variable and represents the transport costs associated with export of pigs to Germany. In the case of export of pigs, it is the individual farmer who organizes and pays for transport of pigs, implying an advantage for being close to the German border.

To estimate (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):

$$Y = \beta_0 + \rho WY + \beta_1 F + \beta_2 H + u \quad (9)$$

where Y is the $(n \times 1)$ vector of observations on the dependent variable; β_0 is the intercept, ρ is a scalar spatial autoregressive parameter, W is an $(n \times n)$ spatial weights matrix, F is an $(n \times k)$ matrix of observations on k exogenous variables with β_1 as the corresponding $(k \times 1)$ vector of parameters; H is a $(n \times c)$ matrix of observations on c endogenous variables (*i.e.* the slaughterhouses accessibility, the environmental ratio and its spatial lag) with β_2 as the corresponding $(c \times 1)$ vector of parameters, and u is the $(n \times 1)$ vector of error terms (specific spatial process). The endogenous and exogenous variables are summarizing in Table 1.

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 (1998) 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.

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. (2002) 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. The case of endogenous variables additional to the usual (single equation) dependent variable and its spatial lag is very common: these variables are the result of some kind of system feedback. Our interest is focused on a single equation, so that we do not know the precise structural equations leading to simultaneity. In this case, the conclusion of Fingleton and Le Gallo's paper (2008) is that "it is in fact preferable to not attempt to model a complete system without fairly precise knowledge of the structural equations, because assuming the wrong structure may compromise parameter estimates of interest". But, Fingleton and Le Gallo (2008) have extended Kelejian and Prucha's (1998) method by allowing additional endogenous variables in single equation model. In our analysis we will use the Fingleton and Le Gallo's (2008) approach (FGS2SLS).

With the Fingleton and Le Gallo's (2008) 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 λ and σ^2 using a GM procedure. In the final stage, the estimated λ is used to perform a Cochrane-Orcutt transformation to account for the spatial dependence in the residuals.

3. DATA

3.1. Danish hog production.

In Denmark the total number of pigs has increased from 11.6 million in 1999 to 13.2 million in 2004. However, the number of farms producing pigs has decreased from 15,500 to 10,000 in the same period, implying that the average number of pigs per farms has increased from 748 to 1320. The pig production has been geographically concentrated in Jutland and on the island Funen (see

Figure 1). 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. 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 1996, Laursen et al. 1999). 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 2007). This number was reduced to 3 in 1999 and 2 in 2004. However, the two cooperatives slaughtered in 2004 95% of all pigs slaughtered in Denmark. The majority of the remaining 5% was slaughtered by 10 private slaughterhouses.

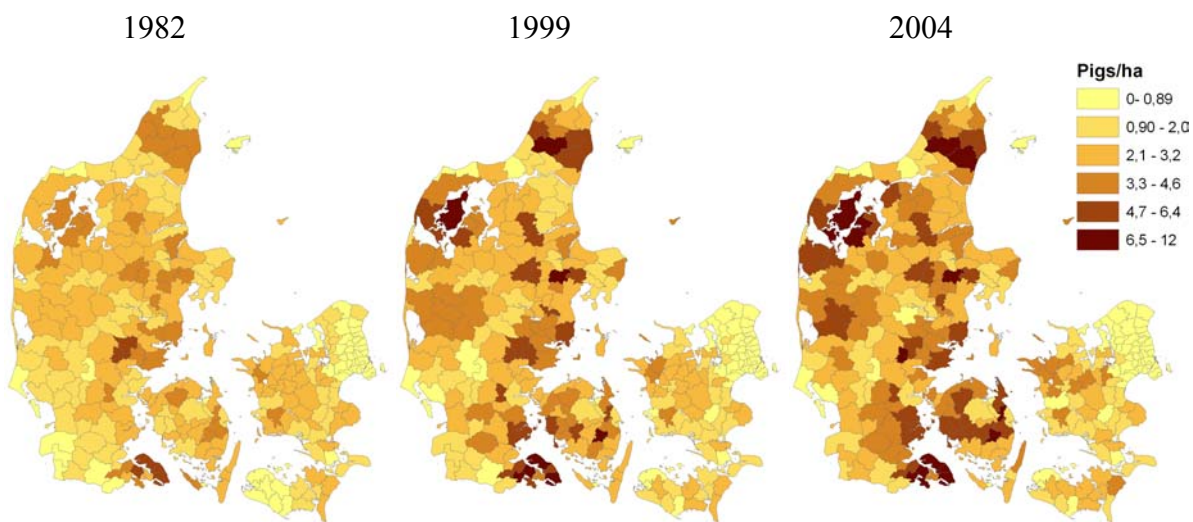


FIGURE 1. Development in spatial concentration of pig per hectare from 1982 to 2004 at municipality level in Denmark.

Source: Statistics Denmark.

The number of plants operated by the co-operatives was reduced from 36 in 1980 to 14 in 2004 (Dansk Landbrug 2005). Even though the number of plants has been reduced there is rather short distance between pig producers and a larger slaughter facility, *i.e.* in average approximately 50 km (Lemoine et al. 2002). In 1999, after the merger of the two largest co-operatives, members of the new large co-operative were allowed to sell 15% of their production outside their co-operative (Konkurrencestyrelsen 2002). This change was demanded by the EU commission to facilitate competition after the merger of the two cooperatives. These requirements were strengthened by the Danish Competition Authority in 2002.

There has recently been a significant increase in the amount of pigs exported for slaughtering, primarily to Germany. From 1999 to 2004 this export has increased from 285,000 to about 343,000 pigs per year (Statistics Denmark 2008). 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 1.9 million piglets in 2004. 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. 2005).

3.2. Data description.

In our analysis the geographical units are the local municipalities: We take into account all Danish municipalities except Bornholm. This island 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 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 1999). The main data source is the public database *StatBank Denmark*.

Variables and instruments used to estimate equation (8) are defined in Table 1.

Variables.

The dependant variable is the municipal density of pigs, i.e. the number of pig inventory per hectare pig inventory (Y). We use the density instead of the inventory at municipality level because the size of municipalities is not homogenous. We follow Roe et al. (2002) by including a spatial lag of the depended variable (WY). This represents the potential existence of location economics, i.e. industry-specific positive technical externalities. The spatial lag is constructed by multiplying the spatial weight matrix W with the vector with the dependent variable, and thus it is endogenous.

The local pig demand is represented by the local capacity of slaughterhouses (S). Data on the total number of pigs slaughtered is obtained from *The Danish Veterinary and Food Administration*. Pigs slaughtered abroad are not included. The slaughterhouse capacity (which takes into account only capacity more than 50,000 heads)⁶ is weighted with the spatial accessibility weight matrix to

⁶ 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.

include demand from slaughterhouses in neighbouring municipalities $((W + I)S)$. We suppose this variable as endogeneous.

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 2002). 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. To obtain the accessibility to protein-rich feed $((W + I)X)$ we weight the import with the spatial accessibility matrix. That is, the supply increases with proximity to a harbour or the German border. In contrast to the accessibility of cereal which is assumed to be endogenous the accessibility to protein feed is supposed exogeneous as we use the quantity of industrial feed unloaded in harbours as a proxy.

We use the competition for land for spreading of manure as a proxy for impact of environmental regulation on pig production. The degree of competition is measured as the ratio between the demand for land for spreading of manure and the available land for spreading of manure, both measured 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-aside area. It is not allowed to spread manure on land which is set-aside. To take into account that manure may be spread in neighbouring municipalities we also include the spatial lag of available land (WE), i.e. we multiply E with a distance matrix. We distance matrix differs from the W , used above, since we take into account the high transport costs of manure.. The competition for land and its spatial lag are obviously endogenous since they depend on the size of the total livestock production, including pig production.

The population variable (P) represents the population density in a municipality. The population density represents the restrictions on the expansion of production close to cities as well as the local resistance to the sitting of large-scale pig production facilities, e.g. caused by the so-called “not in my backyard” attitude. Moreover, its spatial lag is taken into account like a conceivable consumption basin. This density and its spatial lag (WP) are assumed as exogenous. Finally, it is assumed that all exported pigs (to Germany, Poland and The Netherlands) 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 and joins the German town of Ladelund. Thus, the distance to German border (G) is approximated by the distance from the municipalities to Ladelund, which is assumed to be exogenous.

[Table 1 about here]

Instrumental variables.

In the first step of the estimation the endogenous variables are regressed on all exogenous variables including exogenous model variables and instrumental variables.

Firstly, the exogenous variables and their spatial lags are used as instruments for spatial lag of the depended variable (WY). In addition, we use the area with cereals ($CERE$) and its spatial lag ($WCERE$), the distance to the nearest harbour with import of feed (IMP) and the distance to the nearest harbour with export of pig meat (EXP) to instrument the spatial lag of the pig density.

We use the share of working force unemployed ($UNEMP$) and the ratio of non-skilled workers to all workers ($SKILL$) as instruments for slaughterhouses. Since the labour used in slaughtering is relative non-specialized, unemployed and unskilled workers can relative easy take a job in this

sector. Moreover, we use the distance to the nearest slaughterhouse (*NEARS*) to take into account the proximity effect in the upstream sector.

The pig production has an impact on the use of land as the total amount of manure to be spread,, implying that our environmental ratio is endogenous. As instrumental variable we use soil quality (*SOILQ*) which is assumed exogenous. Furthermore, the environmental vulnerability is used as an instrumental variable for environmental regulation. As a proxy for the environmental vulnerability we use the share of land appointed as Natura2000 (*NATURA*)⁷ 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 2004).

4. EMPIRICAL RESULTS

Table 4 and 5 presents the results of estimating the production equation for the FGS2SLS estimation, described above and moreover results for the OLS and the 2SLS estimations⁸. The Table 6 summarizes the elasticities evaluated at the mean point, with coefficient from FG2SLS estimation and for each year.

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.

⁷ 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. The legal basis for the Natura 2000 network comes from the EU Birds Directive and the EU Habitats Directive. There is emphasis on ensuring a sustainable development in areas included in the Natura 2000 network.

⁸ The instruments (detailed in section Data) are independent of the residuals, as shown by the Sargan test statistics *p*-values (Tables 4 and 5).

Thus, auto-agglomeration is evident, and the spatial lag is the best variable to explain location of pig production. Moreover, the determinant becomes higher with time.

Accessibility to slaughterhouses becomes significant both years when we control the endogeneity, at the same significant level. 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 only weakly dependent of distance and all co-operative members receive the same price for pigs. But when we look after elasticities evaluated at the mean point (Table 6), it appears influence of accessibility of slaughterhouses doubles during the studying period.

Accessibility variable to industrial feed is significant for the 2SLS and FGS2SLS models. They seem significant when the spatial lag is controlled, whatever year is observed. Input access has a positive impact on location of pig production as expected. Thus our theoretical expectation about the positive effect of upstream sector is verified: the coefficient of industrial feed accessibility is positive, significant and increasingly in time.

[Table 4 about here]

[Table 5 about here]

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 (the competition for land) at municipality level (E) and its spatial lag (WE) are both significant at the same level in 1999 or in 2004. Indeed, the impact of environmental ratio in the own-municipality is positive in spite of our expectation whereas the effect of the competition for land in neighbouring municipalities is negative as expected Larue and Latruffe (2008) have shown that environmental regulations have a

positive influence on technical efficiency of pig producers in France. While the countries investigated, and thus the contexts, are different, this may reveal that farmers are able to adjust their input use in order to maintain their productivity despite a reduction in production caused by pollution legislation. Moreover, it can be due to urbanisation economies which are partially enclosed in our proxy (we take into account the non-porcine livestock too) Despite this fact, the spatial lag of environmental ratio has a negative impact on pig production: if the producers must go away to spread their manure they prefer reduce their production to decrease their spreading cost and thus don't lose their profit. Finally we observe that environmental regulation does not have the same impact in local or proximal area. The distance to the German border is only significant in 2004. This is consistent with an increasing export of pigs to Germany during the last decade. This increase in export is linked with the fact that farmers, due to new competition regulation, no longer is restricted to sell all pigs to the slaughterhouse cooperative of which they are member. Finally, the use of the AR error model is well-justified in so far as it appears significant at the 1 per cent level for 2004: the λ parameter implies that a shock in a municipality is transmitted outwards as a chain reaction with diminishing force to all other areas, only in 2004.

[Table 6 about here]

5. DISCUSSION.

In this study we analysed the impact of agglomeration externalities, input and output market access, and environmental regulation 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 spill over. 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 feed (cereal accessibility and industrial feed accessibility). Finally, we found that the environmental regulation, despite its spatial lag, imply a positive agglomeration externality due to probably some urbanisation economies. 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. 2002, Isik 2004). 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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TABLES

TABLE 1. Description of variables.

<i>Variable</i>	<i>Definition</i>	<i>Nature</i>
<i>Y</i>	Density of pigs in a municipality (head/ha)	Dependant
<i>WY</i>	Spatial lag of density of pigs	Endogenous
<i>(W+I)S</i>	Accessibility to capacity (head) of slaughterhouses	Endogenous
<i>E</i>	Supply / demand of land for spreading manure	Endogenous
<i>WE</i>	Spatial lag of environmental ratio	Endogenous
<i>(W+I)X</i>	Accessibility to quantity (1000 tons) of protein-rich feed	Exogenous
<i>P</i>	Density of population per municipality (number/ha)	Exogenous
<i>WP</i>	Spatial lag of population density	Exogenous
<i>G</i>	Distance to the German border (km)	Exogenous
<i>UNEMP</i>	Share of working force unemployed	Instrumental
<i>SKILL</i>	Ratio of non-skilled workers to all workers per municipality	Instrumental
<i>NEARS</i>	Distance to the nearest slaughterhouse (km)	Instrumental
<i>SOILQ</i>	Share of clay soils	Instrumental
<i>NATURA</i>	Share of land appointed as nitrate vulnerable or Natura2000 area	Instrumental
<i>CERE</i>	Area with cereals (ha)	Instrumental
<i>WCERE</i>	Spatial lag of cereal area	Instrumental
<i>IMP</i>	Distance to the nearest harbour with import of feed (km)	Instrumental
<i>EXP</i>	Distance to the nearest harbour with export of pork meat (km)	Instrumental

TABLE 2. Summary statistics for 1999 (270 municipalities).

<i>Variable</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
<i>Y</i>	2.41	1.82	0.00	10.71
<i>WY</i>	2.38	0.74	0.78	3.76
<i>(W+I) S</i>	149,590.42	303,503.64	23,407.77	2,833,666.55
<i>(W+I)X</i>	47.05	115.52	6.13	1,270.60
<i>E</i>	0.53	0.28	0.00	1.21
<i>WE</i>	0.53	0.24	0.05	0.97
<i>P</i>	2.62	8.03	0.19	102.88
<i>WP</i>	3.07	2.94	1.24	17.42
<i>G</i>	259.76	117.00	15.00	496.00

TABLE 3. Summary statistics for 2004 (270 municipalities).

<i>Variable</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
<i>Y</i>	2.82	2.23	0	11.79
<i>WY</i>	2.78	0.90	0.88	4.82
<i>(W+I)S</i>	162,593.81	349,310.38	24,794.45	2,619,425.84
<i>(W+I)X</i>	45.47	107.75	5.21	1,391.80
<i>E</i>	0.55	0.29	0.00	1.19
<i>WE</i>	0.55	0.24	0.09	1.00
<i>P</i>	2.66	8.16	0.19	104.58
<i>WP</i>	3.12	2.98	1.26	17.67
<i>G</i>	259.76	117.00	15.00	496.00

TABLE 4. Parameter estimates of the pig production density in 1999.

	<i>OLS</i>	<i>2SLS</i>	<i>FGS2SLS</i>
<i>Intercept</i>	- 3.2061 ***	- 7.5280 ***	- 8.3588 ***
<i>WY</i>	2.4625 ***	5.2843 ***	5.4328 ***
<i>(W+I)S</i>	2.06 e-07	8.57 e-07 *	9.09 e-07 **
<i>(W+I)X</i>	0.0002	0.0011 *	0.0011 *
<i>E</i>	7.6555 ***	11.1763 ***	11.5943 ***
<i>WE</i>	- 9.2120 ***	- 19.1988 ***	- 19.9282 ***
<i>P</i>	- 0.0038	- 0.1511 **	- 0.1351 *
<i>WP</i>	0.1051 **	- 0.5287 ***	0.5326 ***
<i>G</i>	0.0009	0.0008	0.0010
λ			- 0.1485
<i>Adjusted R²</i>	0.7411	0.5443	0.5519
<i>Sargan test</i> *		8.08	7.27
<i>Hausman test</i>		14.39 ***	15.90 ***

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

e-06: multiplied by 10 exponent -6.

* H₀: instrumental set is valid. We accept H₀ if probability is upper than 10 per cent.

Bold variables are endogenous.

TABLE 5. Parameter estimates of the pig production density in 2004.

	<i>OLS</i>	<i>2SLS</i>	<i>FGS2SLS</i>
<i>Intercept</i>	- 3.5945 ***	- 16.0024 ***	- 24.8029 ***
<i>WY</i>	2.1662 ***	8.0114 ***	9.3943 ***
<i>(W+I)S</i>	1.94 e-08	2.01 e-06 ***	1.79 e-06 **
<i>(W+I)X</i>	0.0002	0.0030 ***	0.0037 ***
<i>E</i>	7.3059 ***	13.1600 ***	16.5441 ***
<i>WE</i>	- 7.9403 ***	- 27.7607 ***	- 32.4480 ***
<i>P</i>	- 0.0116	- 0.5493 ***	- 0.5858 ***
<i>WP</i>	0.1504 **	1.4187 ***	1.7966 ***
<i>G</i>	0.0011	0.0035	0.0058 *
λ			- 0.3828 ***
<i>Adjusted R²</i>	0.6684	0.3700	0.3638
<i>Sargan test</i> *		6.17	3.20
<i>Hausman test</i>		17.40 ***	20.11 ***

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

e-06: multiplied by 10 exponent -6.

* H₀: instrumental set is valid. We accept H₀ if probability is upper than 10 per cent.

Bold variables are endogenous.

TABLE 6. Elasticities evaluated at the mean point for 1999 and 2004. FGS2SLS estimation.

	<i>Elasticity 1999</i>	<i>Elasticity 2004</i>
<i>WY</i>	5.3655	9.2407
<i>(W+I)S</i>	0.0565	0.1044
<i>(W+I)X</i>	0.0212	0.0589
<i>E</i>	2.5718	3.2328
<i>WE</i>	-4.4158	-6.3380
<i>P</i>	-0.1472	-0.5524
<i>WP</i>	0.6805	1.9871
<i>G</i>	0.1100	0.5377

TABLE 7. Parameter estimates of the pig production. First Stage R².

	<i>2SLS 1999</i>	<i>FG2SLS 1999</i>	<i>2SLS 2004</i>	<i>FGS2SLS 2004</i>
<i>WY</i>	0.9405	0.9432	0.9362	0.9437
<i>(W+I)S</i>	0.3224	0.3218	0.2583	0.2806
<i>E</i>	0.6858	0.7024	0.6502	0.7012
<i>WE</i>	0.9204	0.9238	0.9123	0.9230