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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 an negative effect on location.

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INTRODUCTION

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 sectors and slaughterhouses. Furthermore, we analyse the impacts of environmental regulation on location of pig productions.

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 1998, Herath et al. 2005a, Daucé and Léon 2003, Warren and Isserman 2006).

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 (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, Herriges 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 increased spatial concentration of pig production has typically been explained by positive spatial externalities (agglomeration economies) (e.g. Roe et al. 2002). Industry agglomeration is traditionally explained by the so-called Marshillian externalities arising from localised knowledge spillovers, labour market pooling, and availability of specialized input and services (Fujita and Thisse 2002). The underlying microeconomic mechanisms of agglomeration are sharing, matching,

and learning mechanisms (Duranton and Puga 2004). These mechanisms have in common that they cause increasing external economies of scale that produce agglomeration. Positive spatial externalities in pig production may arise from access to input services, e.g. feed processing plants and veterinary services, from diffusion of information and knowledge through producer organisations and farmer advisors, and from the pooling of skilled workers for the pig farms. 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.

Comparative advantages may also explain the spatial concentration of pig production. Access to cheap local feed production or availability of low-cost labour input may explain why we find a high concentration of pig productions in some areas.

Differences in environmental regulation and taxation may also cause that some areas are advantageous for pig production. The impact of the stringency of environmental regulation on the spatial location of pig production is analysed econometrically by Metcalfe (2001). He finds no link between changes in the concentration of pig production and environmental stringency. This result is confirmed by Weersink and Eveland (2006) who find that environmental stringency of livestock production in Ontario does dot have a negative impact on the number of building permits for barns. However, Roe et al. (2002) find that the stringency of environmental regulation has a negative impact on location of pig production in the main pig producing states in the U.S., and in the studies by Osei and Lakshminarayan (1996) and Isik (2004) it is found that the location and production in the U.S dairy sector is negatively affected by the stringency of environmental regulation. Herath et al. (2005b) find evidence of negative impacts of stringency of environmental regulation on the location of pigs and dairy operations but no impact on cattle-feeding. Park et al. (2002) find a positive correlation between livestock location in U.S. states and an indicator for environmental stringency. However, causality is not identified and their results may indicate that environmental stringency is a result of the concentration of livestock production.

Land prices may also be an important factor for the location of pig farms. Pig production has traditionally been closely linked to agricultural land, *i.e.* the feed was produced on the farmers' land

and the manure was used as fertilizer. After around 1950 the relative prices of commercial fertilizers decreased, and this, combined with technological changes, weakened the link between agricultural land and pig production. However, during the last two decades the link between agricultural land and pig production has been re-established due to environmental regulations. Today, a Danish pig farmer should have access to at least one hectare of agricultural land per 1.4 livestock for spreading of manure, and there are restrictions on how far from the farm eligible land can be located. This implies that pig producers will compete with other pig producers as well as other livestock producers about land for manure spreading. This is an example of a negative spatial externality which represents a dispersal force on the location of pig production.

Changes in agricultural policy and general business policy may also influence the location of pig production. Daniel and Kilkenny (2002) show in an analytical study that changes in the Common Agricultural Policy (CAP), including increased decoupling of agricultural subsidies and transfer of funding to rural development and diversification, the so-called second pillar, may influence the geographical location of agricultural production. Welsh et al. (2003) find in an empirical study that the existence and strictness of anticorporate farming laws at state level in the U.S. influences the location of pig production.

The location of livestock production has recently been analysed empirically in the U.S. (see Metcalfe 2001, Roe et 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 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. (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 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.

Isik (2004) estimates agglomeration effects and the impact of environmental restrictions on the U.S. dairy inventories at county level, based on a behavioural model of location and production of dairy farms, and applying a spatial autoregressive model. The results shows that counties in states with more stringent environmental regulations tend to lose dairy inventories to those with less stringent policies. They also find that agglomeration economics are present at the sector and the industry levels. In this study, the potential endogenous variables used for environmental regulation and for agglomeration economies are recognized, applying instrumental variable estimation procedures.

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. 2002). 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 a fixed levy for transportation of pigs to the slaughterhouse which is independent of distance. This implies there is no direct incentive for the farmers to locate close to the slaughterhouse. Furthermore, this implies that slaughterhouses may have an interest in being close to pig producers to reduce the 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 with in 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 behavioural econometric model 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 (2007) 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.

Stylised facts about Danish pig production

The concentration of pig production on fewer and larger farms has increased during the last decades in the U.S. (Abdalla et al. 1995, Schrader and Boehlje 1996, Welsh et al. 2003, Azzam and Skinner 2007) as well as in Europe (Kristensen 2001, Trégaro and Lossouarn 2002). 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. This is linked to farm specialisation. In 1970, 81% of all Danish farms had pigs whereas the share was only 17% in 2006 (Hansen 2002 and Statistic Denmark 2007). There has been a long tradition for specialisation in breeding and finishing. From 1982 to 2006 the share of pigs farms with both breeding and finishing was rather constant around 40%, whereas the number of farms with only finishing increased from about 30% to 50%. The number of farms with only sows decreasing correspondingly in the period.

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. The number of pigs per hectare in the municipality with the highest concentration of pigs had increased from 6.4 in 1982 (the municipality of Nordborg) to 11.8 in 2004 (the municipality of Sydals).

Figure 1. Pigs per hectare land at municipality level in 1982 and 2004. Source: Statistics Denmark. (Table BDF5 and ARE2)

Generally, the highest increases in spatial concentration of pigs per ha 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 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. No membership fees or capital investments are required to become a member of a co-operative. The only commitment is the membership and marketing all produced pigs through the cooperative for one year. In 1980 there were 18 cooperatives slaughtering pigs (Danske Slagterier 2007). 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.

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). After the merger of the two largest co-operatives in 1999, members of 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 after the merger of Steff-Houlberg and Danish Crown in 2002.

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. Besides pigs there was an export of around 100.000 sows for slaughtering in 2006. 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. Also in Canada the export of piglets is significant. In 1998, approximately 15 percent of Canada's pigs were slaughtered in the U.S (Hayenga 2000). This export of living pigs is caused by a cost advantage of U.S. pork processing plants. 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).

The increased internationalisation of Danish pig production is also seen by Danish farmers' ownerships of production facilities in foreign countries. In 2004 Danish farmers owned production

facilities for around 6,000 sows, primarily in Germany, Poland, Slovakia, and the Baltic countries (Udesen et al. 2005).

Also Slaughterhouse co-operatives have invested in processing facilities abroad, *i.e.* Germany, Poland, and the United Kingdom (Hamann 2006). The strategy has been to obtain a closer relationship with local retailers and consumers.

MODEL AND PROCEDURE

Location and pig production: a microeconomic model.

We develop a general model of location of farm production for the purpose of analysing the spatial structure of the pig production sector (inspired by Isik, 2004). Our study takes into account production possibilities on the municipality level. It is assumed that an aggregate production function maximizes aggregate profit, if and only if each farm's production function maximizes its individual profit.

We consider a two-dimensional spatial world with input supply, production, transformation, and consumption.

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). To simplify the model, the location of the consumption market is assimilated to the location of the slaughterhouses (*i.e.*, no transport costs between slaughterhouses and consumers).

So let u_{ij} be the Euclidian distance[1] between the input firm j and the producer i, and s_{ik}[2] be the distance from the farm i to the slaughterhouse k. We suppose τ_i 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 of each farm i is given by a quasi-concave production function:

(1) $$q_i = f\left(h_{i1},...,h_{ij},...,h_{iJ},\gamma_i,\sigma_i,F\right)$$

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[1] The Euclidian distance between the input firm j and the farm i is: $u_{ij}\left[(x_i,y_i),(x_j,y_j)\right] = \left[(x_i - x_j)^2 + (y_i - y_j)^2\right]^{1/2}$

[2] The Euclidian distance from the farm i to the slaughterhouse k is: $s_{ik}\left[(x_i,y_i),(x_k,y_k)\right] = \left[(x_i - x_k)^2 + (y_i - y_k)^2\right]^{1/2}$

where h_{ij} is the input use by farm i delivered by input firm j, γ_i the farm technical coefficient affecting production (we suppose a positive one, *i.e.* it increases productivity), σ_i the agglomeration externalities such as $\sigma_i = \sigma_i(q_l)$, $\forall l \neq i$, and F the fixed costs (same for each firm). We assume that $\frac{\delta q_i}{\delta h_{ij}} > 0$ and $\frac{\delta q_i}{\delta^2 h_{ij}} < 0$. Finally, the sign of $\frac{\delta q_i}{\delta \sigma_i}$ gives us the impact of agglomeration externalities on pig production. We did 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.

The profit of each farm i is:

$$\pi_i = \left(p - \frac{\sum_{i=1}^{n} \tau_i s_{ik}}{n} \right) q_i - \sum_{j=1}^{J} \left(w_j + \alpha_j u_{ij} \right) h_{ij} - \lambda_i \quad (2)$$

where p is the output price on the final market, w_j is the input price, and $\lambda_i = \lambda_i(x_i, y_i)$ is the constraint associated with environmental regulations. This negative externality could vary across space, but if it is the same (or null) in each space unit then it would not affect the location decision.
The transport cost between the producer and the slaughterhouse depends on the neighboured network. In fact, all farmers supplying pigs to the same slaughterhouse pay the same for transport per pig, *i.e.* all farmers pay the average transport cost of pigs supplied to the slaughterhouse[3]. This implies farmers supplying pigs to a slaughterhouse where all farmers are located close to the slaughterhouse pay relatively low transport costs compared to farmers supplying to slaughterhouses where suppliers are dispersed.

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[4]:

[3] In equation (2), we assume that the size of a single farm's production has negligible impact on the average transport costs.
[4] The second-order conditions are satisfied under quasi-concave production function.

(3) $$\frac{\delta \pi_i}{\delta h_{ij}} = \left(p - \frac{\sum_{i=1}^{n} \tau_i s_{ik}}{n} \right) \frac{\delta q_i}{\delta h_{ij}} - \left(w_j + \alpha_j u_{ij} \right) = 0$$

(4) $$\frac{\delta \pi_i}{\delta x_i} = -\frac{\tau_i}{n} \frac{\delta s_{ik}}{\delta x_i} q_i - \alpha_j \frac{\delta u_{ij}}{\delta x_i} h_{ij} - \frac{\delta \lambda_i}{\delta x_i} = 0$$

(5) $$\frac{\delta \pi_i}{\delta y_i} = -\frac{\tau_i}{n} \frac{\delta s_{ik}}{\delta y_i} q_i - \alpha_j \frac{\delta u_{ij}}{\delta y_i} h_{ij} - \frac{\delta \lambda_i}{\delta y_i} = 0$$

With our model, the optimal input is given by $h_{ij}^* = h_{ij}^* \left(p, \tau_i, s_{ik}, w_j, \alpha_j, u_{ij}, \gamma_i, \sigma_i \,|\, (x_i, y_i) \right)$.

The dilemma is not relevant to the choice of whether or not to start a new production farm but where to place it. That is why we suppose that it is advantageous to locate the farm somewhere within the area (interior solution). The optimal farm location is determined by (4) and (5) depending on h_{ij}^*: $x_i^* = x_i^* \left(h_{ij}^*, p, \tau_i, s_{ik}, w_j, \alpha_j, u_{ij}, \gamma_i, \sigma_i, \lambda_i \right)$ and $y_i^* = y_i^* \left(h_{ij}^*, p, \tau_i, s_{ik}, w_j, \alpha_j, u_{ij}, \gamma_i, \sigma_i, \lambda_i \right)$. Farm *i* locates its operation where it obtains the highest profit. The optimal output depending on h_{ij}^* and $\left(x_i^*, y_i^* \right)$ is defined as $q_i^* = f \left(h_{i1}^*, ..., h_{iJ}^*, \gamma_i, \sigma_i \left(q_l^* \right), F \,|\, \left(x_i^*, y_i^* \right) \right)$. Thereby, there exists a simultaneous determination of optimal output for all farms due to agglomeration externalities σ_i.

Farmers choose location *i* against *l* if the profit is highest in *i*, *i.e.* $\pi_i > \pi_l \;\; \forall i, l$. Thus, farms are more concentrated in areas with higher profit. The profit goes up with an increase in output prices and with a decrease in input prices but decreases with increasing transport costs. The transport costs increase with the distance to input supplying firms, whereas the transport costs of pigs to slaughterhouses is independent of the distance between the slaughterhouse and the farm. This implies that a farm has an advantage of being located close to input supplying firms. A falling-off in the environmental regulations induces a reinforcement of the profit. That is why farmers want to locate the activities in a county where environmental costs are lower and profit thereby can be maximized. The technical coefficient of the farm also affects its profit and location *via* the production function. Agglomeration externalities may be important for the technical efficiency of pig production and consequently also influence profit and location. Due to positive technical

externalities, farmers will locate in areas where other similar or related activities are located, *i.e.* $\frac{\delta q_i}{\delta \sigma_i} > 0$. Agglomeration leads to improved *sharing* of indivisible inputs, e.g. sharing of infrastructure, and thereby increased profits. Furthermore, improved *matching* by labour pooling may reduce fixed labour cost. Finally, *learning* may increase when pig farms are agglomerated and increase the knowledge and technology diffusion.

Changes over time of these externalities could also have an effect on changes in the farm's output and indirectly on location. Yet, their impact on the changes could be different from their impact on the production level. The sign of $\left(\frac{\delta q_{i,t}}{\delta \sigma_{i,t}} - \frac{\delta q_{i,t-1}}{\delta \sigma_{i,t-1}} \right)$ ascertains how agglomeration factors affect the change in production level over time.

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 inventory 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. 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):

(6) $$Y = \rho WY + \alpha X + \beta H + u$$

where Y is the $(n \times 1)$ vector of observations on the dependent variable; ρ 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 α as the corresponding $(k \times 1)$ vector of parameters; H is a $(n \times c)$ matrix of observations on c endogenous variables with β as the corresponding $(c \times 1)$ vector of parameters, and u is the $(n \times 1)$ vector of error terms, which can be generated in two ways, by a specific spatial process or non-parametrically.

The agglomeration effect, $\sigma_i = \sigma_i(q_l)$, is measured by ρ, 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 paper, 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*[5]. 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 $w_{ij}^s = w_{ij} / \sum_j w_{ij}$. *X* and *H* represent the other explanatory variables included in the theoretical model.

The affect of gross input prices (including transport costs) is measured by the accessibility of cereal and industrial food, assuming that prices are lower with a large local production of cereals and short distance to harbours where imported protein-rich feed is unloaded. The environmental compliance costs are represented by the competition for land for spreading of manure. We have also included a variable representing the local slaughterhouse capacity 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.

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, 1988a). The most used models are variants of the model suggested in Cliff and Ord (1981), 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 modeling this type of dependence among the errors.

[5] A Distance matrix and a contiguity matrix were supplied by Jørgen Lauridsen, University of Southern Denmark

The maximum likelihood (ML) model is by far the most common methodological framework applied in spatial econometrics. Yet, other approaches exist to avoid the problems due to ML estimation: the estimation of a model with a spatial error process and endogenous variables is not possible with the usual maximum likelihood approach. 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. 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 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. (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. But, Fingleton and Le Gallo (2007) have extended Kelejian and Prucha's (1998) method by allowing additional endogenous variables. In our analysis we will use the Fingleton and Le Gallo's (2007) approach.

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

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

where λ 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 ε is a $(n \times 1)$ vector of normally distributed error terms, with $\varepsilon \sim iid(0, \sigma^2 I_n)$. We assume that the AR process implies that a shock at one location j is transmitted to all other locations of the sample (Anselin, 2003).

With the Fingleton and Le Gallo's (2007) model, we analyze both endogeneity and simultaneous spatial interaction. We apply the same estimation procedure in 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.
Tests for the presence of spatial autocorrelation in the errors and omitted lag are performed on OLS estimation and confirm our intuition that the GMM estimation is the best one.

DATA

The geographical units are the local municipalities: We take into account all Danish municipalities except Bornholm[6] . Bornholm is not included because it is located far from the rest of county, 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*.

Dependant variable

Dependant variable considered is the natural logarithm of the total pig inventory (LNBPIG). We use the natural logarithm to obtain homoscedastic error terms.

[6] Bornholm is an island located in the Baltic Sea,

Agglomeration variable

We follow Roe et al. (2002) by including a spatial lag of the depended variable (WLNBPIG). 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. However, due to environmental restrictions and land competition there may also be negative externalities of being located close to other pig farms as well as other types of livestock producers (cf. *environmental effects*).

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 2003, p163). When spatial lag is placed in rank order, this quasi-instrument (NTINST) is equal to -1 for the upper third, 0 for the middle third, and 1 for the lower third.

Output market access

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 number of slaughtered pigs at Danish slaughterhouses. 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. The slaughterhouse capacity (which takes into account only capacity more than 50,000 heads)[7] is weighted with the spatial accessibility weight matrix $(W+I)$ to include demand from slaughterhouses in neighbouring municipalities (UACCSH). Since it is the cooperative-owned slaughterhouses that pay the transport cost of pigs from the farms to slaughterhouses there is no direct incentive for farmers to locate nearby a slaughterhouse. However, pig producers that are sending pigs to a cooperative slaughterhouse where the average transport distance is short, will experience a relatively high net

[7] 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.

price of pigs (gross price minus transport costs) compared to producers delivering to slaughterhouses where the average transport distance is long. This may impose a negative correlation between the distance to slaughterhouses and size of the pig production in a municipality. Furthermore, the slaughterhouses may be a centre for exchange and diffusion of information and technology relevant for pig producers. This imposes an advantage of being close to the slaughterhouses. Finally, a small share of pigs is sold to private slaughterhouses and an increasing share is exported for slaughtering in Germany. In these two cases it is the farmer who is paying the transport costs.

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. (2002) 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 (UNEARSH).

Input availability

We include the area of agricultural land used for cereals in a municipality as a proxy for the local availability of pig feed. We weight the area with cereal with the spatial accessibility weighting matrix $(W+I)$ to include the cereal production in nearby municipalities (ACCERE). However, it is expected that the pig production has an impact on the use of land, implying that the area with cereal is endogenous. Therefore, we include soil quality as a valid instrument for cereal production. We expect a positive correlation between the share of soil with a high content of clay and the production of cereals in a given municipality (SOILQ). This is because grass and maize for silage has relative higher yields on sandy soils.

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, *i.e.* the municipality of Bov. To obtain the local supply of

protein-rich feed we weight the import with the spatial accessibility matrix $(W+I)$ (ACCFEED). That is, the supply increases with proximity to a harbour or the German border.

Environmental effects

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 2002, Miljøministeriet 2002). 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.

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 (ENVRAT). 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 his variable is endogenous. Therefore, we use the population density (POPARE) and the environmental vulnerability (NATURA) 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 sitting 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[8] 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).

[8] 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.

EMPIRICAL RESULTS

Table 3 and 6 presents the results of estimating the production equation for the GMM estimation described above and moreover results for spatial autoregressive (SAR) model, spatial error autocorrelation (SAC) model and 2SLS estimation.

Accessibility[9] for industrial feed 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 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 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 Tables 5 and 8).
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 (ENVRAT)

[9] We estimate also our initial equation with other input accessibility variable ACCERE. But this variable disturbs results without explanation.

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 GMM 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, Tables 4 and 7 indicate 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 λ parameter implies a chock in a municipality is transmitted outwards as a chain reaction with diminishing force to all other areas.

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 week 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 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. 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. Summary statistics for 1999.

Variable	*Mean*	*Median*	*Std. Dev.*	*Min*	*Max*
LNBPIG	9.389	10.385	3.059	0	12.401
UACCSH	157,560.62	59,187.25	322,892.60	1,716.32	2,826,545.53
ACCERE	10,304.35	10,462.53	5,077.25	351.289	25,642.62
ACCFEED	35.428	11.950	119.914	0.383	1,255.51
ENVRAT	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
SOILQ	0.411	0.360	0.333	0	1
NATURA	0.157	0.126	0.143	0	0.852

Table 2. Summary statistics for 2004.

Variable	*Mean*	*Median*	*Std. Dev.*	*Min*	*Max*
LNBPIG	9.555	10.553	2.963	0	12.576
UACCSH	175,073.16	63,020.05	383,576.24	1,831.80	2,612,116.06
ACCERE	12,661.74	12,028.73	6,461.24	754.221	30,481.03
ACCFEED	31.213	8.768	112.136	0.206	1,361.21
ENVRAT	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
SOILQ	0.411	0.360	0.333	0	1
NATURA	0.157	0.126	0.143	0	0.852

Table 3. Parameter estimates of the pig production in 1999. Dependant variable is LNBPIG, the natural logarithm of pig production per municipality.

	Spatial autoregressive (SAR)	***Spatial error autocorrelation (SAC)***	***2SLS with ρ***	***GMM with ρ , λ endogenous ex variabl***
Intercept	0.867 **	6.286 ***	- 2.028 **	- 1.898 **
ρ	0.788 ***		1.573 ***	1.517 **
UACCSH	2.8 E-07	4.3 E-07 *	- 4.6 E-07	- 4.8 E-07
ACCERE				
ACCFEED	4.9 E-04	0.001 **	- 6.1 E-04	- 5.7 E-04
ENVRAT	2.400 ***	4.966 ***	- 5.292 ***	- 4.760 **
λ		0.810 ***		- 0.196 **
R^2	0.492	0.229	0.503	0.555
Sargan Test			4.158	5.211

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

Table 4. Parameter estimates of the pig production in 1999. First stage R^2.

	2SLS with ρ	*GMM with ρ , λ and endogenous explicative variables*
ρ	0.823	0.840
UACCSH	0.236	0.241
ENVRAT	0.567	0.592

Table 5. Parameter estimates of the pig production in 1999. Elasticity.

	Elasticity evaluated at the mean point	*Elasticity evaluated at the median point*
ρ	1.4727	1.4930
UACCSH	- 0.0081	- 0.0028
ACCFEED	- 0.0022	- 0.0007
ENVRAT	- 0.2706	- 0.2589

Table 6. Parameter estimates of the pig production in 2004. Dependant variable is LNBPIG, the natural logarithm of pig production per municipality.

	Spatial autoregressive (SAR)	*Spatial error autocorrelation (SAC)*	*2SLS with ρ*	*GMM with ρ , λ endogenous ex variabl*
Intercept	0.998 **	6.792 ***	- 1.772 **	- 1.698 **
ρ	0.788 ***		1.569 ***	1.499 **
UACCSH	1.8 E-07	3.5 E-07	2.8 E-06 **	2.8 E-06 **
ACCFEED	5.8 E-04	0.001 *	- 0.001	- 9.1 E-04
ENVRAT	2.155 ***	4.042 ***	- 6.685 ***	- 5.929 **
λ		0.777 ***		- 0.260 **
R^2	0 .404	0.170	0.422	0.506
Sargan Test			0.930	1.269

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

Table 7. Parameter estimates of the pig production in 2004. First stage R^2.

	2SLS with ρ	*GMM with ρ , λ and endogenous explicative variables*
ρ	0.773	0.809
UACCSH	0.209	0.223
ENVRAT	0.514	0.571

Table 8. Parameter estimates of the pig production in 2004. Elasticity.

	Elasticity evaluated at the mean point	*Elasticity evaluated at the median point*
ρ	1.4583	1.4720
UACCSH	0.0505	0.0165
ACCFEED	- 0.0030	- 0.0008
ENVRAT	- 0.3423	- 0.3290