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Positive and negative agglomeration externalities: Arbitration in the pig sector

ABSTRACT.

In this study we analyse the determinants of pig production location in Denmark with a particular focus on positive and negative agglomeration externalities. Based on the theory of agglomeration and a discussion of the organisation of the Danish pig production sector a model of pig production is developed and tested empirically, applying the FG2SLS approach. Our results show that technical and pecuniary externalities have a positive effect on location, while the impact of environmental regulations is ambiguous. Indeed, and that urbanization economies are more important than the negative impact of land competition at local level, but that neighbouring land competition implied by environmental regulations seems to have a negative effect on location.

KEYWORDS: Agglomeration externalities, Spatial econometrics, Environmental regulation.

JEL CODES: C13, R30, R15, Q11.

1. INTRODUCTION

In this paper we analyse the determinants of the pig production location in Denmark. We focus on the traditional determinants of agglomeration, i.e. positive spillovers among pig farms and interaction with the 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 the Danish economy, with around one-third of the production value in Danish agriculture coming from production of pork meat. Pig production in Denmark is unevenly distributed and increased significantly in certain localities in recent decades.

Changes in the spatial organization of pig production may have consequences for Denmark's 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 also may 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 rearing, with several local areas where pig production is dominant experiencing environmental problems (Abdalla et al., 1995; Wossink and Wefering, 2003).

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 localized knowledge spillovers, labour market pooling, and availability of specialized inputs and services (Fujita and Thisse, 2002). Duranton and Puga (2004) delimit the underlying microeconomic mechanisms of agglomeration, such as learning, sharing and

matching mechanisms. These mechanisms all cause increasing external economies of scale which produce agglomeration. Spatial externalities can be divided into technical and pecuniary externalities. Technical externalities can arise from the diffusion of information and knowledge through producer organizations and farmer advisors and from a higher quality available labour force. Pecuniary externalities are transmitted to individual farms, by the market, through price effects, which may affect location and production decisions. For example, location decisions will be influenced by accessibility to input services, such as feed processing plants and veterinary services, and accessibility to output markets. 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 may arise from general economic activity (urban economics), i.e. the performance of a pig farm improves when other firms are located nearby. On the other hand, competition in input and output markets may have a dispersal effect on location. This applies especially to access to agricultural land which is required to dispose of the manure according to environmental regulations. Overall, we would expect the location of pig farms to be affected positively by the presence of other pig farms and accessibility to input and output markets, but negatively by environmental stringency. In our study, we distinguish the impacts of technical and pecuniary externalities by including variables respectively for pig production in the neighbourhood, and the access to input and output markets.

The location of livestock production has been analysed empirically for the US (see Metcalfe, 2001; Roe et al., 2002; Welsh et al., 2003; Herath et al., 2005a and 2005b) and Ontario in Canada (Weersink and Eveland, 2006). In Denmark there has been no explicit analysis of the location of livestock production. Roe et al. (2002) estimate a spatially explicit county-level model of the pig production sector within 15 key US pig production states. They estimate three models in which

their dependent variables are natural logarithm of a county's total pig inventory, change in the natural logarithm of pig inventories from 1992 to 1997, and the natural logarithm of the average number of pigs per farm. As a proxy for localization economics, they include a spatial lag of the dependent variable. They find that location economics, urban encroachment, input availability, firm productivity, local economy, slaughter facilities access and regulatory stringency variables affect the sample regions' spatial organization. However, they do not take account of the fact that some of the explanatory variables may be endogenous. For example, they include slaughtering capacity location as an independent variable. However, one would expect the location of slaughterhouses might be determined by the supply of pigs; ignoring this could lead to estimation bias.

This study contributes to the literature by offering insights into the spatial organization of pig production in Denmark, the world's largest exporter of pork meat, by providing a location model for pig farmers. We also test the impact of recent environmental regulations on pig production in Denmark. We apply the approach proposed by Fingleton and Le Gallo (2008) for the estimation of spatial models with endogenous variables.

The paper is organized as follows. Section 2 presents our theoretical model and discusses some empirical issues. Section 3 provides an overview of the Danish pig production sector and the data used in the analysis. Section 4 discusses the results and Section 5 concludes the paper.

2. THEORY AND PROCEDURE

2.1. The determinants of livestock location: Application in the Danish pig case.

The empirical model applied in this study is derived from a general model of the location of pig production in Denmark, inspired by Isik's (2004) model of location for the US dairy sector, i.e. we assume that farmers' location and production decisions can be derived from their profit-maximising behaviour. Consequently, farmers will take into account the access to inputs and outputs markets, potential positive spillovers from being located close to other pig producing farms, as well as environmental restrictions when they make their location decision. They will have an advantage of being located close to input suppliers and slaughterhouses because this will reduce transport costs. .

However, in Denmark cooperative-owned slaughterhouses account for some 95% of all pigs slaughtered and all farmers in the co-operative pay the same price per pig for transportation to the slaughterhouse. The levy is an average of the cost of transporting pigs from the members of the cooperative to the slaughterhouse. Also, co-operative members receive the same price for their pigs from the slaughterhouse, implying that there is no price competition among farmers within the same cooperative. This implies there is only a weak incentive for farmers to locate close to the slaughterhouse, since the location decision of a single farmer will have a limited impact on average transport costs and thereby the sales price net of transport costs. Nevertheless, transport costs may differ between co-operatives, e.g. a farm supplying pigs to a co-operative where all farmers are located close to the slaughterhouses will have relatively low transport costs compared to farmers supplying to slaughterhouses where suppliers are more widely dispersed. On the other hand, cooperatives still have an interest in locating their slaughterhouses close to where the pigs are produced to save transport costs. Due to positive technical externalities, farmers will locate in areas

where other similar or related activities are located. A high local concentration of similar activities may, for example, increase the information spillovers between farmers, influencing positively their productivity.

Environmental regulation has impacts on location in two ways. First, an important factor in the regulations is the limit on the amount of manure that can be applied per ha of agricultural land. This introduces competition among livestock producers over land, implying that the costs of conforming to the environmental regulations increase with the production of pigs at a farm and with pigs and other types of livestock produced on neighbouring farms with livestock. Secondly, the stringency of environmental regulation may vary between different areas, due to variations in environmental vulnerability. We do not introduce risk factors, such as weather, because we assume that there is no spatial variation in potential risk factors due to the small size and homogeneous weather conditions and landscape of Denmark¹.

2.2. Empirical model and econometric issues

The empirical model we estimate uses municipality-level agricultural and economic data from 1999 and 2004 for Denmark. It examines the factors affecting the pig inventory using the pig density in municipality i (Y_i) as a proxy for location of pig production. More specifically, the following model (1) is used for the estimations:

$$Y = \mathbf{b}_1 i_n + \mathbf{r}WY + \mathbf{b}_2 (W + I)S + \mathbf{b}_3 (W + I)X + \mathbf{b}_4 E + \mathbf{b}_5 WE + \mathbf{b}_6 P + \mathbf{b}_7 WP + \mathbf{b}_8 G + u \quad (1)$$

with $u = IW^*u + \mathbf{e}$

where $\mathbf{b}_1, \mathbf{b}_2, \dots, \mathbf{b}_8$, and, \mathbf{r} are parameters to be estimated and i_n is a vector of ones. WY , $(W+I)S$, $(W+I)X$, E , WE , P , WP and G are explanatory variables described below and u is term of errors.

α : The technical externalities of agglomeration are measured by α , 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 interactions among county-level pig production units accounts for the hypothesis of location externalities. Pig production is determined simultaneously across areas, implying that neighbouring productions are endogenous and that our parameter estimates will be biased if we include a spatial lag. We also investigate the error term u for spatial correlation: this process implies that a shock at one location j is transmitted to all other locations in the sample (Anselin, 2003). The neighbourhood relationships between observations are expressed by a spatial weight matrix W in which the rows and columns correspond to the cross-sectional observations. An element w_{ij} in the matrix can be interpreted as the presence of a link between observation in county i and observation in location j . In this analysis, the elements of the weight matrix are derived using a distance decay function, $w_{ij} = 1/d_{ij}^\alpha$, where d_{ij} equals the distance by road in kilometres between administrative towns in counties i and j . In this paper, we use the distance decay function where $\alpha=1$ for all variables except for E where $\alpha=2$. In this case, the distance squared decay function gives a low weighting to observations that are far apart. The elements along the main diagonal are $w_{ii} = 0$. To interpret the spatial variables, the weights are standardized so that the elements in each row sum to 1. These standardized elements are $w_{ij}^s = w_{ij} / \sum_j w_{ij}$. We expect to find positive technical agglomeration externalities.

$(W+I)S$: We also include a variable for accessibility to slaughterhouse capacity $((W + I)S)$, which is assumed to affect the net price of pigs positively. However, this variable is expected to have only a weak impact on location since the farmers supplying to co-operative-owned slaughterhouses pay an average transport price. The accessibility to slaughterhouse capacity is computed by multiplying

the slaughterhouse capacity variable with an accessibility weight matrix, $(W+I)$ where W is an inverse distance matrix and I the identity matrix.

$(W+I)X$: The effect of gross input prices (including transport costs) is measured by the accessibility to feedstuffs $((W+I)X)$, assuming that the price will be lower the shorter the distance from the port where imported protein-rich feed is unloaded. The same matrix as in the case of slaughterhouses is used to compute accessibility to feedstuffs.

Access to slaughterhouse capacity and feed give us a proxy for the pecuniary externalities of agglomeration which are supposed positive.

E and WE: Several measures for regulation are implemented to reduce the negative environmental impact of livestock production. In Denmark, the environmental regulation on pig production includes area limitations for spreading manure, standards for the design of production facilities, restrictions on the proximity of production facilities to cities and vulnerable ecosystems (Hansen, 2002; Miljøministeriet, 2002), among others. To what degree these environmental regulations have reduced agglomeration is not, a priori, clear. Minimum land requirements for the spreading of manure have imposed a new condition on the “landless” pig sector: land competition. This reduces the agglomeration forces. At the same time, restrictions related to the location of new production facilities in environmentally vulnerable areas may increase intensity in less vulnerable areas.

Environmental compliance costs are represented by the competition for land for spreading manure (E) and its spatial lag (WE): similar to Roe et al. (2002), we expect that environmental regulation will have a dispersal effect on location.

P and WP : The population density of municipality (P) can be envisaged as a negative externality (i.e. an olfactory nuisance) and its spatial lag (WP) as an outlet (consumption area).

The spatial weight matrix related to P is the same inverse distance matrix also used for S and X , $\rho=1$. Using the same spatial weight matrix for all these variables means that we consider the transportation costs are quite similar for all corresponding ‘goods’: alive pigs, pork meat, and feedstuffs. We use a more restricting form of the spatial weight matrix for the spatial lag of the environmental regulation (WE): the square of the inverse distance ($\rho=2$). By this, we consider the transportation costs of manure are higher than for other goods.

G : 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, it is the individual pig farmer who organizes and pays for transport, implying an advantage in being close to the German border.

To estimate (1), 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):

$$Y = \mathbf{b}_0 + \rho WY + \mathbf{b}_1 F + \mathbf{b}_2 H + u \quad (2)$$

where Y is the $(n \times 1)$ vector of observations on the dependent variable; \mathbf{b}_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 \mathbf{b}_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. access to a slaughterhouse, the environmental ratio and its spatial lag) with \mathbf{b}_2 as the corresponding $(c \times 1)$

vector of parameters, and u is the $(n \times 1)$ vector of the error terms (specific spatial process). The endogenous and exogenous variables are presented in Table 1.

The maximum likelihood (ML) estimation method is the methodological framework most commonly applied in spatial econometrics. However, estimation of a model with a spatial error process and endogenous variables is not possible with the usual ML approach and there are other approaches that can be used to avoid the problems inherent in ML estimations. One such methodology is the feasible generalized spatial two-stage least squares (FGS2SLS) estimation. As Kelejian and Prucha (1998) noted, 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 dependent variable can be corrected.

In fact, in empirical applications of spatial econometrics, the effects of other endogenous variables are often disregarded, unlike the well-known spatial lag endogeneity. Indeed, Roe et al. (2002) do not consider the endogeneity of slaughterhouse location. However, endogeneity of slaughterhouse location may be the result of an unknown set of simultaneous structural equations representing vertical coordination between pig producer and slaughterhouse. 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 on a single equation; thus, we do not know precisely the structural equations leading to simultaneity. It is sometimes 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. However, Fingleton and Le Gallo (2008) extend Kelejian and Prucha's (1998) method by allowing additional endogenous variables in a single equation model. We adopt this approach in our analysis.

Using Fingleton and Le Gallo's (2008) procedure, we analyse both endogeneity and simultaneous spatial interaction. The estimation procedure has three stages. In the first, the model is estimated by 2SLS. The second stage uses the resulting 2SLS residuals to estimate ρ and σ^2 using a GM procedure. In the final stage, the estimated ρ is used to perform a Cochrane-Orcutt transformation to account for spatial dependence in the residuals.

With the GM procedure, we are able to reduce identification problems related to a model with a spatial lag and spatial dependence in the residuals. The spatial lag is derived from our model of location, i.e. the presence of technical externalities (e.g. information spillovers). Some other agglomeration externalities, i.e. pecuniary externalities, are captured by the r.h.s. variables of the regression model, implying that the spatial lag mainly represents the technical externalities. Moreover, the spatial modelling of the residuals contributes also to the identification of the model: they capture the influence of all other non-modelled spatial correlated factors, and thereby ensure that the parameters of interest are estimated in the most reliable manner, and the spatial lag can therefore be taken as the impact of technical externalities on location

3. DATA

3.1. Danish pig production.

In Denmark the total number of pigs increased from 11.6 million in 1999 to 13.2 million in 2004. However, in the same period, the number of farms producing pigs decreased from 15,500 to 10,000, implying an increase in the average number of pigs per farm from 748 to 1,320. Pig production in Denmark is geographically concentrated in Jutland and on the island of Funen (see Figure 1). It would appear, from comparing maps of pig density for 1982 and 2004, that the places where pig production was agglomerated in 2004 are mostly the same as in 1982. In some municipalities,

especially Sealand, geographical concentration of pigs has decreased although the total numbers of pigs has increased in the period.

The Danish pig production sector in international comparisons is characterized by strong vertical integration in which 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 most Danish pig producers have been members of co-operatives with their own slaughterhouses. In 1980 there were 18 cooperatives with slaughterhouses (Danske Slagterier, 2007). In 1999 this number was only 3 and in 2004 it was 2. However, these two cooperatives in 2004 accounted for 95% of all pigs slaughtered in Denmark. The majority of the remaining 5% were treated in 10 private slaughterhouses.

[**Figure 1 about here**]

The number of plants operated by co-operatives has reduced from 36 in 1980 to 14 in 2004 (Dansk Landbrug, 2005), nevertheless, the average distance between pig producers and a large slaughterhouse facility, is quite small, on average 50 km (Lemoine et al., 2002). In 1999, after the two largest co-operatives merged, the members of the new large co-operative were allowed to sell 15% of their production outside their co-operative (Konkurrencestyrelsen, 2002). This was a change required by the European Commission to facilitate competition following the merger and strengthened in 2002 by the actions of the Danish Competition Authority.

There has been a significant increase in the numbers of pigs exported for slaughter, primarily to Germany. From 1999 to 2004 the annual export trade increased from 285,000 to about 343,000 pigs

(Statistics Denmark, 2008). Growth in the export of piglets for fattening in Germany has been even higher. From an almost non-existent trade in 1988, Denmark exported 1.9 million piglets in 2004. It has been suggested that this export in piglets is being driven by is the higher prices of pigs and the higher costs of piglet production in Germany, and the 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 consider all Danish municipalities except Bornholm. This island is excluded because it is located far from the rest of country in the Baltic Sea, and in 2002 the island's municipalities were reduced from five to one, implying data discontinuity. We also exclude eight municipalities for which there are no soil quality observations. These include Copenhagen and its nearest suburbs. Our final sample for analysis is 262 municipalities. The model is estimated for 2 years; 1999 and 2004. The choice of years was determined by the availability of data on pig production and land use at municipality level. In 1999 Statistics Denmark carried out surveys within a total census, and for 2004 data were available from the *General Agricultural Register* and the *Central Husbandry Register*. The main data source is the public database *StatBank Denmark*, provided by Statistics Denmark. Variables and instruments used to estimate equation (8) are defined in Table 1 and the descriptive statistics are summarized in Table 2 (for 1999) and Table 3 (for 2004).

Variables.

The dependent variable is municipal pig density, i.e. number of pigs per hectare (Y). We use density rather than inventory at municipality level because the size of municipalities is not homogenous. As explained before, we follow Roe et al. (2002) in including a spatial lag for the dependent 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 by the vector of the dependent variable, thus it is endogenous.

Local pig demand is represented by the capacity of the local slaughterhouse (S). Data on the total number of pigs slaughtered is from *The Danish Veterinary and Food Administration*. Pigs slaughtered abroad are not included. Slaughterhouse capacity is based on slaughterhouses which slaughter more than 50,000 pigs per year² is weighted with the spatial accessibility weight matrix to include demand from slaughterhouses in neighbouring municipalities ($(W + I)S$). We assume this variable to be endogenous.

The majority of the protein-rich feed, e.g. soybeans, used for pig production is imported, mostly through small coastal harbours in Denmark (Lemoine, 2002). We assume that it is only feed imported from Germany that comes by road or rail. Therefore, we use the quantity of industrial feed unloaded at Danish harbours as a measure for the availability of protein-rich feed. This is supplemented by imports from Germany which it is assumed are transported by road or rail. To estimate accessibility to protein-rich feed ($(W + H)X$) we weight imports with the spatial accessibility matrix. That is, supply increases with proximity to a harbour or the German border and it is assumed to be exogenous as we use the quantity of industrial feed unloaded in harbours as a proxy.

We use competition for land for spreading of manure as a proxy for the impact of environmental regulation on pig production. The degree of competition is measured as the ratio of demand for land for spreading of manure and available land for spreading manure, both measured at municipality level (E). The demand for land for spreading of manure is calculated by using the norms from Danish livestock regulation. The supply of land for spreading manure is calculated as total available

arable land minus set-aside land, where manure spreading is not allowed. To take account of the fact that manure may be spread in neighbouring municipalities we also include a spatial lag for the available land (WE), i.e. we multiply E by a distance matrix. Our distance matrix differs from the W , used above, since we take into account the high transport costs for manure. The competition for land and its spatial lag are obviously endogenous since they depend on the size of total livestock production, including pig production.

The population variable (P) represents the population density in a municipality. Population density represents the restrictions on the expansion of production close to cities as well as local resistance to the sitting of large-scale pig production facilities, e.g. the NIMBY - “not in my backyard” effect. Moreover, the spatial lag acts as a kind of consumption basin. This density and its spatial lag (WP) are assumed to be 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 with Germany. The only motorway crossing the border between Denmark and Germany passes through the municipality of Bov and goes to 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. These instruments were chosen with a step by step procedure based on the Sargan test³.

The exogenous variables and their spatial lags are used as instruments for the spatial lag of the dependent variable (*WY*). Our approach is based on Kelejian and Prucha (1998), i.e. the lower orders of the spatial lags of the exogenous variables are used as instruments for the endogenous spatial lag, together with other instruments for the other endogenous variables. Firstly, we use as additional instruments for the spatial lag of pig density (the dependant variable of the model), the cereal producing area (*CERE*) and its spatial lag (*WCERE*), the distance to the nearest harbour importing feed (*IMP*) and the distance to the nearest harbour exporting pig meat (*EXP*). Access to cereal is determined by the agricultural land and the share of agricultural land used for cereal. In Denmark, agricultural land is assumed to be exogenously given (basically determined by land use regulation and urban development). Furthermore, the farmers' choice between crops is not influencing by the level of pig production, since pig farmers are typically purchasing cereal for feeding the pigs and cereal is abundantly available locally because it is the dominant crop in Denmark.

Secondly, we use the share of unemployed workforce (*UNEMP*) and the ratio of non-skilled workers to all workers (*SKILL*) as instruments for the slaughterhouse. Since slaughterhouse labour is relatively non-specialized, unemployed and unskilled workers can relatively easily take a job in this sector. The labour market variables are assumed to be exogenous to slaughterhouses because due to the relative low share of the total labour force employed by slaughterhouses. Moreover, we use the distance to the nearest slaughterhouse (*NEARS*) to account for the proximity effect in the upstream sector.

Lastly, pig production has an impact on the use of land as well as on the total amount of manure to be spread, implying that our environmental ratio is endogenous. As an instrumental variable we use soil quality (*SOILQ*). Soil types are time invariant and obviously exogenous to pig production. However, it is expected to influence the concentration of livestock production since it influence the

relative competitiveness of livestock (especially dairy production) and crop production.. We use environmental vulnerability as the instrumental variable for environmental regulation. As a proxy for environmental vulnerability we use share of land designated a Natura2000^t protected area or identified as a sensitive drinking water area within a municipality (*NATURA*). In these protected and sensitive areas there are stricter regulations on the environmental impacts of expanded livestock production than in other areas (Kørnø and Christensen, 2004). The designation of vulnerable areas is based on biodiversity and geological criteria and is therefore assumed to be exogenous with respect to pig production.

4. EMPIRICAL RESULTS

Tables 4 and 5 present the results of estimating the production equation for the above described FGS2SLS and the results of the OLS and the 2SLS estimations⁵. Table 6 summarizes the elasticities evaluated at the mean point, with the coefficient of the FG2SLS estimation, and for each year.

The spatial lag is positive and significant at the 1% level, confirming the existence of information spillovers. Moreover, the significance of the spatial lag increases when we control for endogeneity in the explanatory variables. Spatial lag is the most appropriate variable to explain the location of pig production, i.e. auto-agglomeration is evident. An increase of one point in pig density in a neighbouring municipality is associated with an increase of more than five points in 1999. The importance of self-sector impact becomes higher with time: elasticity at the mean point for 2004 increases to more than nine. Thus, pig production seems to be more spatially concentrated across municipalities in 2004 than it was in 1999. In our study, we distinguish pecuniary externalities from “black box” spatial externalities, implying that the spatial lag represents only technical externalities.

Therefore, the results indicate that technical externalities are important for the location of pig production. The existence of location economies in pig production is not surprising. Geographical proximity induces more frequent contacts among farmers and thus eases communication about technical or organizational innovations or new inputs (so-called *information spillovers*). It appears that technical externalities have become more important during the period analysed.

[Table 4 about here]

[Table 5 about here]

The effects of access to downstream and upstream sectors appear significant and positive when we used the FGS2SLS method. Access to slaughterhouses becomes significant at the 5% level for both years when we control the endogeneity. As explained in the introduction we do not expect a strong impact of access to slaughterhouses since the costs of transporting the pigs are only weakly dependent on distance and all co-operative members receive the same price for their pigs. But if we look at elasticities evaluated at the mean point (Table 6), it appears that the influence of nearness to the slaughterhouse has doubled during the studied period. The increasing influence of the slaughterhouses could be due to the opening of this market: in 1999 the restriction that all pigs had to be sold for slaughtering to the farmer's cooperative abattoir was relaxed. In 2002 these rules were relaxed even further to allow farmers to sell more pigs outside the cooperative. The variable for access to industrial feed is significant for the 2SLS and FGS2SLS models and is significant when the spatial lag is controlled for at 10% for 1999 and 1% for 2004. As expected, input access has a positive impact on the location of pig production, confirming that it is advantageous to be located close to the upstream sector: the coefficient of industrial feed accessibility is positive, significant and increases over time. However, the elasticity for access to industrial feed is moderate: in 2004,

an increase of one point for access to industrial feed implies an increase of less than 0.06 point in municipality pig density.

[Table 6 about here]

The ratio between demand for land for spreading manure at municipality level and the land available for spreading manure (the competition for land) at municipality level (E) and its spatial lag (WE) are both significant at the same levels, for 1999 and 2004. Indeed, the impact of the environmental ratio in the home-municipality is positive despite our expectations, while the effect of competition for land in neighbouring municipalities is negative as expected. The positive impact of the environmental proxy is due perhaps to positive spillovers from other production of other livestock (than pigs) at local level. In the construction E we take account of all manure generating livestock production. Although a high concentration of livestock production in a municipality implies strong competition for land for spreading manure, the negative impact on pig production may be dominated by urban externalities in the agricultural sector, i.e. positive spillovers from non-porcine livestock production. These externalities may be due to businesses sharing non-excludable inputs, such as public infrastructure, technical knowledge and labour matching, which are not specific to pig production. More direct measures of environmental regulations using indicators for stringency in the regional implementation of the regulation could help us to identify the mechanisms underlying the impact of environmental regulation on pig production location. Lawley and Furtan (2008) found that the pollution generated by livestock production receives less attention in rural areas (where the pig production is concentrated) and, as a consequence, there is weaker demand for more stringent environmental regulation. Despite this, the spatial lag of the environmental ratio has a negative impact on pig production: if producers are obliged to travel to

get rid of their manure they will prefer to reduce production to decrease spreading costs and thus reduce drains on their profit. Moreover, the sign indicates that a municipality with a high concentration of livestock production (a high level of E variable) will compete for land to spread manure in neighbouring municipalities which will have a negative impact on the production of pigs in these municipalities by increasing the price of land for spreading of manure.

The population variable representing the NIMBY effect appears negative and significant at the 10% level in 1999 and at the 1% level in 2004. The potential for conflicts between livestock producers and local residents, e.g. due to odours from pig production, increases as livestock production expands into populated areas (Abdalla et al., 1995, Lawley and Furtan, 2008). Our expectations about the spatial lag of population density are also confirmed: the coefficient of the neighbouring population, considered as a possible consumption basin, is significant and positive. The effect of local population is less important than the positive impact of its spatial lag: thus, population seems to be a fairly positive determinant.

Finally, the distance to the German border is only significant for 2004. This is consistent with increased exports of pigs to Germany during the period analysed, and the relaxation of the obligation to sell all the pigs produced to the cooperative to which the farmer belongs. However, we would expect that the variable would be negative, i.e. the cost of exporting pigs would increase with the distance to the border. However, the positive parameter may be due to increasing exports of piglets to Germany in the period studied, and the fact that we use the density of pigs as a left hand side variable. When piglets are not kept for fattening in Denmark, pig density decreases.

[Table 7 about here]

The use of the AR error model is justified in so far as it appears significant at the 1% level for 2004: the ρ parameter implies that a shock in a municipality is transmitted outwards, in a chain reaction, with diminishing force, to all other areas.

Finally, the choice of instrumental set seems to be appropriate when we look at the first stage R-square (Table 7): the endogenous variables, except access to a slaughterhouse, are explained. The lack of an explanation for the downstream sector variable may be due to an inappropriate choice of instruments for the location of slaughterhouse capacity. The skill level and unemployment ratio may be poor proxies for slaughterhouse labour costs.

5. CONCLUSION.

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 Denmark in 1999 and 2004. The results show that spatial externalities are important for the location of pig production, i.e. pig farms make higher profit if there is a high concentration of pigs in the neighbourhood. This indicates that pig farms benefit from input sharing, labour pool matching and knowledge spillovers. On the other hand we found a less important, but always positive, effect of accessibility to upstream and downstream industries. However, we did not expect to find a significant effect of access to a slaughterhouse due to the organizational structure of the Danish slaughterhouse sector, i.e. farmer-owned slaughterhouses and farmers' distance-independent payment of transport costs. Finally, we found that the effect of environmental regulations on pig production is ambiguous. On the one hand, the results indicate that so-called urban externalities, i.e. positive spillovers from other non-porcine livestock production, dominate the negative impact of strong competition for land on the local area. On the other hand, it seems that environmental regulation has a negative effect on nearby

municipalities. The econometric analysis shows that it is important to consider that the explanatory variables in a location model may be endogenous. The analysis also shows that it is important to consider potential spatial dependence in the error terms. Despite the introduction of environmental regulation, this econometric analysis shows that effects of location and urbanization externalities are predominant in decisions about where to locate pig production: agglomeration will endure.

Future research should consider changes in production by modelling the differences in the pig inventories for 1999 and 2004 (see e.g. Roe et. al., 2002; Isik, 2004). It may also be relevant to include other variables to represent the accessibility of other input factors in production, e.g. the local alternative costs of farm labour and taxation. Furthermore, it might be worthwhile to include more direct measures of environmental regulation using indicators for stringency in the regional implementation of such rules. This might identify some of the underlying mechanisms of the impact of the environmental regulation on pig production location.

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FIGURES

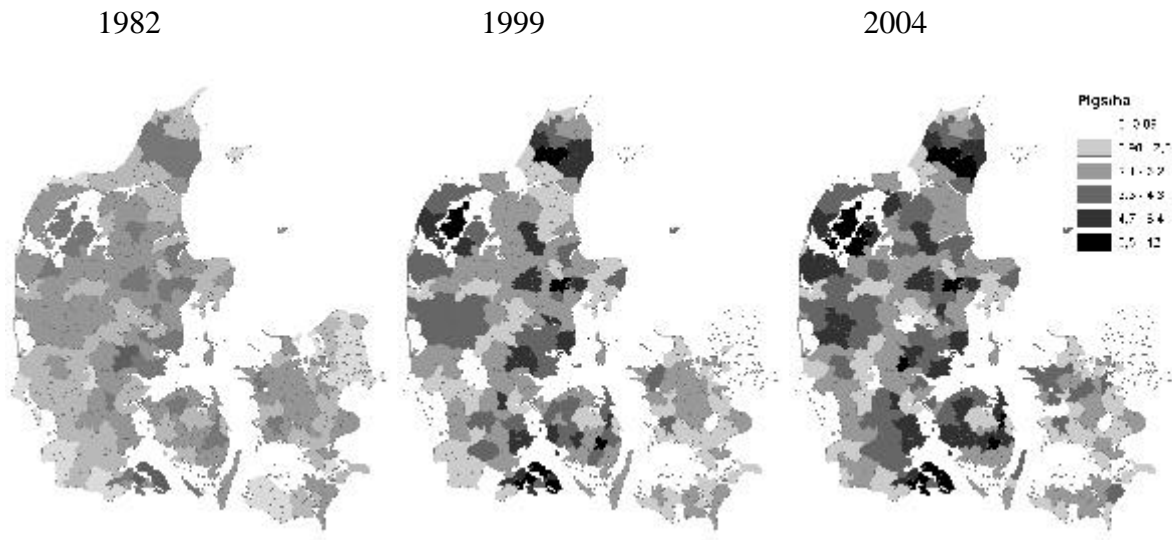


FIGURE 1. Development in spatial concentration of pig per hectare from 1982 to 2004 at municipality level in Denmark.

Source: Statistics Denmark.

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 ***
WY	2.4625 ***	5.2843 ***	5.4328 ***
(W+I)S	2.06 e-07	8.57 e-07 *	9.09 e-07 **
(W+I)X	0.0002	0.0011 *	0.0011 *
E	7.6555 ***	11.1763 ***	11.5943 ***
WE	- 9.2120 ***	- 19.1988 ***	- 19.9282 ***
P	- 0.0038	- 0.1511 **	- 0.1351 *
WP	0.1051 **	- 0.5287 ***	0.5326 ***
G	0.0009	0.0008	0.0010
?			- 0.1485
<i>Adjusted R²</i>	0.7411	0.5443	0.5519
<i>Sargan test^S</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 ***
WY	2.1662 ***	8.0114 ***	9.3943 ***
(W+I)S	1.94 e-08	2.01 e-06 ***	1.79 e-06 **
(W+I)X	0.0002	0.0030 ***	0.0037 ***
E	7.3059 ***	13.1600 ***	16.5441 ***
WE	- 7.9403 ***	- 27.7607 ***	- 32.4480 ***
P	- 0.0116	- 0.5493 ***	- 0.5858 ***
WP	0.1504 **	1.4187 ***	1.7966 ***
G	0.0011	0.0035	0.0058 *
?			- 0.3828 ***
<i>Adjusted R²</i>	0.6684	0.3700	0.3638
<i>Sargan test^S</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

¹NOTES

This assumption means we do not consider potential risk aversion among farmers.

² The data on slaughterhouses include butchers' 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 included in our analysis. This limit is necessary because we use distance to the 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.

³ If the Sargan test shows that the set of instruments is not valid (i.e. some ones are correlated with residuals), the residuals are regressed on all instrumental variables. This regression helps us to identify which ones are not valid: if their coefficient is significant, at 5% level, they are linked with residuals .

⁴ Natura 2000 is a European network of protected sites which represent areas of the highest value in terms of natural habitats and rare, endangered or vulnerable species of plants and animals, 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 sustainable development in areas included in the Natura 2000 network.

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