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Agglomeration Externalities and Technical Efficiency in Pig Production

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Abstract

The objective of the paper is to assess the effects of agglomeration on technical efficiency of French pig farms. The increasing concentration of pig production in Western of France is a typical example of the effects of positive agglomeration externalities, in particular on farm performance. However, negative externalities occasioned by the same concentration have lately appeared. This is due to competition of land following the law governing polluting activities, in which pig producers need to have a minimum area where their manure can be spread.

Using Data Envelopment Analysis (DEA) followed by an econometric second-stage, with data for one thousand French pig producers in 2004, we show that pig producers are affect by both positive and negative agglomeration externalities. While agglomeration at the county ('département') level induces favourable knowledge spillovers and matching labour force, agglomeration at the subcounty level ('canton') constrains farmers due to legal disposition relating to manure spreading, while regional concentration inducues congestion regarding the upstream and downstream levels.

Keywords: technical efficiency, pig production, agglomeration externalities

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1. Introduction.

The French pig production has considerably evolved since the 60s, when regulations for this production were introduced (following an important crisis during the creation of the Common Market). At that time, the production in France was not able to meet the increasing demand. Therefore a Plan of rationalisation of the pig sector was set up in 1970 in a view of modernising the production device. Similarly to the development of this sector in other countries, the driver behind this change was the grouping of producers, which gathered 90 % of production in 2000 against 31 % in 1972. Following this, the pig production in France increased from 1.1 million tons in 1962 to 1.5 in 1985 and 2.3 in 2000, and from the 80s the breeding units steadily expanded. Hence, small farms (at least one sow or five pigs) disappeared gradually: they were 250,000 in 1969 against 65,000 in 2000. Rearing units of more than 100 sows, which were not numerous in the 60s, represented one third of the livestock in 1988 and more than 70 % in 2000. At the same time, there was a geographical concentration of the production, mostly in the West. Today the Western regions (Brittany, Pays de la Loire and Basse-Normandie) collect three quarters of the workforce in pig production. Brittany, in particular, brought together 55 % of this workforce in 2000, against 30 % in 1969. At the same time, the production organised itself: the grouping of producers. Thus, the production device considerably evolved as much in terms of structure as in terms of techniques. Today, breeding farms have become more specialized and bigger. However, they are fewer units and they have more and more concentrated in specific areas in order to benefit from a more favourable technical and economic environment, the aim being 'productivity constantly stepped-up'.

The increasing concentration of pig production in Western of France is a typical example of the effects of positive agglomeration externalities. Daucé and Léon (2003) described the appearance of rural polarization, and proposed the underlying mechanisms of the geographical concentration. The authors noticed that farms tend to be larger in areas where the pig sector is more concentrated, and that the concentration of the sector is largely due to integrations which are as much horizontal as vertical. However, their analysis does not take into account the negative externalities occasioned by the same concentration. With the law governing polluting activities, pig producers need to have a minimum area where their manure can be spread. The competition for land is the main negative agglomeration externality that is behind the opposite pattern of swine production dispersion that is starting to occur in Western France.

If it is recognized that the concentration in the porcine sector is widely inferred by positive externalities, the specific effect of the agglomeration externalities on productivity of the pig producers has never been investigated. Our objective is exactly to assess the effects of agglomeration on technical efficiency of French pig farms. Exploring the issue will also allow us to consider the potential opposite effect of negative externalities that are specific to swine production.

The paper is structured as follows. The next section gives a background of the relationship between agglomeration and efficiency. The third and fourth section explain our methodology and the data used, respectively. Results are presented in the fifth section. The last section concludes.

2. Agglomeration and efficiency.

The economic space is often considered as the result of a system of strengths: the centripetal forces generate an agglomeration of activities, while the centrifugal forces cause a dispersion. The notion of agglomeration is linked with geographical economics, which has highlighted the competitive potential associated with demand and supply interlinks among regional clusters of allied industries. Moreover, increasing returns to scale are essential for explaining the spatial concentration of economic activities (Fujita and Thisse, 1996). Agglomeration externalities are an increasing function of the number and size of proximate firms. They may arise because of specialized local markets for labour and intermediate products. The most frequently cited sources of positive agglomeration externalities are knowledge spillovers, specialised labour supply, demand matching, and input sharing (Duranton and Puga, 2004). The economies of agglomeration are present under two main forms:

- Pecuniary externalities, resulting from interactions in prices on the final, intermediate and labour markets;
- Technical externalities (or Marshall's externalities), such as those stemming from information exchanges between similar firms or from training of the local manpower with shared skills.

One of the contemporary stakes of empirical spatial economics is to go beyond the analysis of economic agglomeration leaning on data that are geographically aggregated, and to estimate the benefits in terms of economic performance that the individual firms gain from the agglomeration (Rosenthal and Strange, 2004). Some papers have investigated how the agglomeration effects have an impact on individual firm performance in the industrial sector. For example Paul and Siegel (1999) found that agglomeration induces scale economies in the US manufacturing sector. Not only scale economies, but also technological progress, profitability increase and efficiency improvement might be consequences of agglomeration.

Regarding agriculture, the French animal production expanded during the last decades, at the same time as both structural and geographical changes occurred. On the structural side, farms of reduced size disappeared to the benefit of big structures. Besides, some farms merged in order to optimize the control of outlets and improve the competitiveness. The same change occurred in the US. Welsh and al. (2003) showed that the American pig production concentrated in the same conditions as the French production: decreasing number of farms especially those with small size, large development of the production. Furthermore, Roe and al. (2002) added that a horizontal, but also vertical integration developed in a purpose of independence. This indicates that such evolution of the porcine sector is not typically French. It developed following to the numerous crises that occurred in the sector and in the same conditions as for the poultry sector. As for geographical changes, geographical concentration of livestock production has been observed since the 70s in the US and in the European Union, but previous literature took little interest in the determinants of the location of the agricultural productions since the end of 1960s. The economists focused either on Thünen's approach¹ of this question, or on the approach of the comparative advantages (Daniel, 2005). It is only recently that the modern or erstwhile contributions of spatial economics (often considered in terms of industrial location) were called up again and applied to the field of agriculture. One of the few empirical works onto the determinants of the agricultural activities location.

The specific issue of the agglomeration effects on technical efficiency in agriculture has never

¹ The location of the agricultural productions is due to the transportation costs for products and to spatial variations in land returns.

been investigated. The only reference to this day is the study by Tveteras and Battese (2006) but for aquaculture. The authors examined the influence of agglomeration externalities at the regional level on the productivity of Norwegian salmon farming. They distinguished between the effects on the production possibility frontier (information spillovers lead to technological progress) and on the technical inefficiency (knowledge spillovers enable farms to reduce their optimization errors). For that purpose, the authors estimated a stochastic frontier production function on an unbalanced sample of 577 salmon farms during 1985 to 1995. In their econometric model they integrated two explanatory variables, namely regional size of industry and regional density of farms, to estimate how the agglomeration externalities influence technological change as well as technical efficiency. They found that an increase of industry regional size leads to technological progress, and that farms located in regions with larger industry are more technically efficient. On the other hand, farm regional density has a negative effect on the shift of the frontier, but a positive effect on technical efficiency. The authors conclude that there are positive externalities due to the transfers of knowledge and to an increased supply of specialised production factors, but negative externalities of congestion through fish diseases.

3. Methodology.

Our analysis about the impact of agglomeration externalities on technical efficiency of pig farms will be carried out in two stages.

First stage: Technical efficiency

Firstly Data Envelopment Analysis (DEA) will be used to measure farm technical efficiency. Based on the distance concept of Farrell (1957), DEA constructs a piece-wise frontier over data points with linear programming, so that all observations of the sample used lie on or below the frontier (Charnes et al., 1978)². The distance from a firm to the frontier enables to calculate its efficiency score, which lies between 0 and 1. Higher scores indicate larger efficiency, while a firm located on the frontier will be identified as totally efficient and attributed an efficiency score of 1.

As DEA is a deterministic method, deviation from the constructed frontier is interpreted purely as inefficiency. This is not the case of the stochastic frontier method. However, in this article, DEA has been privileged for several reasons.

- Contrary to the stochastic frontier method, DEA does not require specification of a functional form for the frontier or of distribution of disturbances. Therefore, misspecification errors are avoided.
- DEA allows the partition of total technical efficiency into pure technical efficiency and scale efficiency. Total technical efficiency is calculated assuming that the firms operate under constant returns to scale (CRS). By contrast, the term pure technical efficiency is used when computing efficiency under variable returns to scale (VRS) and represents management practices. As for the residual ratio between CRS efficiency and VRS efficiency, it is called scale efficiency and can be used to identify optimally sized firms. Additionally, DEA allows to determine the returns to scale of each firm: increasing (IRS) or decreasing (DRS).
- Finally, with DEA multiple outputs and inputs can be considered simultaneously, and they can thus be quantified using different units of measurement.

² A summary of the DEA linear programming is presented in Appendix 1.

DEA has two alternative orientations: input and output. The input-oriented model calculates the proportional decrease in the use of inputs as output remains unchanged, while the output-oriented model computes the proportional increase in outputs that could be attained with constant inputs. We have chosen to compare the output-oriented and the input-oriented model, for the following reasons:

- Pig production is considered as an intensive production, whose main objective is to maximize outputs (output-oriented model).
- However, as mentioned before, pig production is facing stricter and stricter environmental regulations regarding nitrogen discharge. Thus, pig producers are expected to try and reduce as much as possible their inputs (input-oriented model).

Our DEA model will be multi-output and multi-input. Inputs include the number of sows, labour use, feed, health expenditures, depreciation and other expenditures. When choosing the outputs, we had to separate the pig producers between three main orientations based on an expert typology given with the data: only-breeding orientation, breeding-and-fattening orientation, and after-weaning-and-fattening orientation. While all three orientations use the same inputs (except for the number of sows which are not employed by after-weaning-fattening farms), their outputs are different. Only-breeding farms' sole output is the number of piglets, and after-weaning-and-fattening farms sole output is the number of swine, while both outputs are included for breeding-and-fattening farms.

Second stage: Impact of agglomeration on technical efficiency

In the second stage the efficiency scores obtained in the first stage will be regressed with Ordinary Least Squares on several explanatory variables. This second stage (widely used in the literature, for example in Latruffe *et al.*, 2005) allows to estimate the impact, on efficiency, of variables on which the farmer has no control. For example, these variables concern generally the type of firm (public or private), the governmental regulations, the location, etc, in the sectors of hospital and transportation. In agriculture, the variables used will be rather the location and socioeconomic variables (such as the age of the farmer). But other variables which represent the quality of the production factors are also often included in the second step, such as the share of hired labour (generally better educated than family labour) in the total labour force.

In our study, agglomeration and other explanatory variables will be considered. Agglomeration variables include various density ratios at several administrative levels: municipality, sub-county ("canton"), county ("département"), and region. Besides the standard variables such as inhabitants density or unemployment rate, the ratios relate some farming sector's characteristics (total number of farms, number of pig farms, number of workers in pig production, volume of slaughtered pig meat, production of industrial pig feed, nitrogen quantity discharged, etc.) to the utilised agricultural area (UAA) and the population of the administrative level. Such ratios capture the pollution externalities on the population, the legal constraints faced by farms for nitrogen discharge (they are allowed to spread the manure on only 70% of the UAA), and the possible positive spillovers effects or congestion problems implied by farm proximity. Dummies for the location in urban, periurban or rural area, or in an area officially characterised by excessive nitrogen discharge, will also be tried. Among the other explanatory variables tested in the model are the age of the head farmers, the number of partners on the farm, the utilised agricultural area, the share of hired labour, whether the farm is specialised in pig production or diversifies in other livestock productions,

whether the farm can be expanded (in order to increase the permitted area for nitrogen discharge), etc.

4. Data used.

This study employs farm-level data from a technical survey and an economical survey of pig farms carried out by the French Institute of the Pig Sector (IFIP) in 2004. Both surveys enclosed a large range of data about outputs, inputs, management, as well as technical and social variables for a sample of about 3,600 farms. Only those farms that had non-missing information for the selected outputs and inputs (see Section 3) were included in the DEA model. From this reduced sample, the three subsamples according to the orientation (only-breeding, breeding-and-fattening, after-weaning-and-fattening farms) were created and one DEA frontier constructed for each subsamples. This separation is due to the difference in their production technologies.

The data corroborate well-known facts (see Section 1): 43.1 % of the sample's pig producers are located in Brittany and about 72 % in Western regions (Brittany, Pays de la Loire, Basse-Normandie, Poitou-Charentes). Moreover, Midi-Pyrénées (in South East France) and the large central area (Centre, Limousin and Auvergne "départements") gather respectively 8.4 % and 9.3 % of the sample farms. Regarding the three orientations, 74% of the sample are breeding-and-fattening units (of which more than three quarter are located in Western regions), 9.5% are only-breeding farms (concentrated more in Centre and Poitou-Charentes) and 16.5% are after-weaning-and-fattening herds (located mainly in Western regions). The sample is however not representative of the French pig production in the sense that it is biased toward breeding-and-fattening units. The IFIP statistical yearbook indicated that in 2005 46.1% of the French pig farms had a breeding-and-fattening activity, 44.4% had a after-weaning-and-fattening orientation, and 9.6% were only-breeding farms (IFIP, 2006). This bias is mainly due to the non representative way of collecting of data. As we analyse subsamples by orientation, the representativity bias is not a major problem.

First-stage data

Descriptive statistics of the three subsamples' DEA outputs and inputs, extracted from the economical survey, are presented in Table 1. These outputs and inputs are for the porcine activity only, even for farms not fully specialised in pig production. Only-breeding farms produced on average more piglets than breeding-and-fattening farms, which is intuitive as the latter have a dual production. However, the standard deviations indicated that breeding-and-fattening farms were clustered more closely around the mean of this output than only-breeding ones, suggesting less homogeneity in the latter orientation. By contrast, although breeding-and-fattening farms produce two outputs, they produce on average more of the second output (swines) than the fully specialised after-weaning-and-fattening farms. One explanation is that it is easier to produce swines and piglets at the same time. Regarding the inputs, except for the number of sows, breeding-and-fattening farms use much more of any input than only-breeding farms, which is consistent with the fact that input values are calculated with the average input use per livestock head times the number of heads. Among all three orientations, after-weaning-and-fattening farms used the least of inputs, except for other expenditures (energy, water, maintenance and repair, etc).

Table 1
DEA outputs and inputs: Descriptive statistics of the sample farms.

	Mean	Standard deviation	Minimum	Maximum
<i>Only-breeding farms (180 farms)</i>				
<i>Outputs</i>				
Number of piglets	3,032	3,620	536	27,927
<i>Inputs</i>				
Number of sows	144	158	32	1,189
Labour (euros)	1,816	1,738	395	13,377
Feed (euros)	45,417	57,173	9,618	384,425
Health expenditures (euros)	7,459	13,235	249	109,472
Depreciation (euros)	11,948	20,223	29	170,986
Others expenditures (euros)	20,127	26,194	1,902	183,342
<i>Breeding-and-fattening farms (660 farms)</i>				
<i>Outputs</i>				
Number of piglets	330	519	1	5,675
Number of swines	2,475	1,826	380	17,183
<i>Inputs</i>				
Number of sows	141	92	33	771
Labour (euros)	2,744	1,743	367	13,993
Feed (euros)	173,895	115,040	39,399	956,223
Health expenditures (euros)	13,321	12,361	641	94,076
Depreciation (euros)	24,485	23,265	103	204,014
Others expenditures (euros)	28,411	22,188	2,719	204,214
<i>After-weaning-and-fattening farms (161 farms)</i>				
<i>Outputs</i>				
Number of swines	1,808	1,343	315	8,334
<i>Inputs</i>				
Labour (euros)	992	640	197	4,321
Feed (euros)	96,768	66,229	18,983	408,613
Health expenditures (euros)	4,119	3,900	88	30,549
Depreciation (euros)	11,080	11,132	229	60,604
Others expenditures (euros)	81,285	63,900	15,162	381,133

Second-stage data

In the second-stage regression of efficiency scores, we included farm and farmers' variables extracted from the IFIP technical survey. Table 2 gives a few descriptive statistics. As for the agglomeration variables, they were calculated at different administrative levels with data from the 1999 Agricultural Census and other surveys, that give detailed information about the farm environment and the upstream and downstream sectors.

Table 2

Second-stage variables: Descriptive farm and farmer's characteristics of the sample farms.

	Only-breeding farms (180 farms)	Breeding-and- fattening farms (660 farms)	After- weaning-and- fattening farms (161 farms)
Average age	40.6	41.9	42.7
Average number of partners	1.4	1.8	1.4
Average share of hired labour (%)	6.6	23.3	11
Share of farms with possible expansion (%)	73	69.5	77.4
Share of farms fully specialised in pig (%)	16.2	26.6	12.9

5. Main results.

5.1. Total technical efficiency and its components.

Descriptive statistics of total technical, pure technical and scale efficiency for the output-orientation are presented in Table 3. Due to the way DEA constructs the efficient frontier, the maximum score found was unity for each DEA model. Therefore only minima are reported in this table. The share of farms with efficiency score of unity, that is to say on the frontier, is given too.

The lower homogeneity in output identified for only-breeding farms (see Section 4) is not reflected in efficiency, as this sub-sample has a larger average technical efficiency score than the breeding-and-fattening sample, suggesting stronger homogeneity in management practices. After-weaning-and-fattening farms were however the most technically efficient on average. The after-weaning-and-fattening farms had a total technical efficiency of 0.89 on average, indicating that they could increase their outputs by 11 % and still use the same level of inputs. The average efficiency scores for the other specializations were 0.85 and 0.82, respectively.

Scale efficiency was high and similar for all specializations (averages of 0.96 and 0.97), suggesting that bad management practices cause more inefficiency than sub-optimal scale. Nevertheless, the shares of farms operating under CRS (i.e. scale efficient), IRS and DRS, presented in Table 4, indicate that the majority of farms operate at sub-optimal size, particularly in the breeding-and-fattening subsample (15 % farms scale efficient against more than 20 % in the two other subsamples). Interestingly, breeding farms (i.e. the two subsamples only-breeding and breeding-and-fattening) operated mostly under IRS, that is to say they were too small, suggesting that these orientations could gain efficiency by increasing in size. By contrast, more than half of the after-weaning-and-fattening farms were operating under DRS, implying that this orientation has too large farms.

Graphs 1 to 6 in Appendix 2 illustrate how farms in each of the three subsamples perform in terms of pure technical efficiency (Graphs 1 to 3) and of scale efficiency (Graphs 2 to 6) according to their size. The latter was measured in terms of total output produced evaluated as

livestock units (standard coefficients for piglets and swines were provided by IFIP), and farms were separated in five size classes. The results indicate that for all three orientations, larger farms are more pure technically efficient but less scale efficient.

Input-oriented results are not presented here, as they are extremely similar to output-oriented results. Spearman correlation coefficients indicate an almost perfect correlation (coefficient close to one) between scores of both orientations.

Table 3
Descriptive statistics of DEA efficiency scores: output-oriented model.

	Mean	Standard deviation	Minimum
Total technical efficiency			
Only-breeding farms (180 farms)	0.85	0.12	0.46
Breeding-and-fattening farms (660 farms)	0.82	0.11	0.38
After-weaning-and-fattening farms (161 farms)	0.89	0.09	0.57
Pure technical efficiency			
Only-breeding farms (180 farms)	0.88	0.12	0.46
Breeding-and-fattening farms (660 farms)	0.85	0.11	0.40
After-weaning-and-fattening farms (161 farms)	0.92	0.09	0.61
Scale efficiency			
Only-breeding farms (180 farms)	0.96	0.06	0.58
Breeding-and-fattening farms (660 farms)	0.97	0.04	0.75
After-weaning-and-fattening farms (161 farms)	0.97	0.04	0.78

Table 5
Shares of farms operating under CRS (scale efficient), IRS and DRS (%): output-oriented model.

	CRS	IRS	DRS
Only-breeding farms (180 farms)	22.2	63.3	14.5
Breeding-and-fattening farms (660 farms)	14.6	56.8	28.6
After-weaning-and-fattening farms (161 farms)	20.5	25.5	54.0

5.2. Impact of agglomeration.

The second-stage regression was performed on the output-oriented scores. The final models were also run on input-oriented scores, but gave very similar findings. Thus, only results with output-orientation are presented and discussed here. The three subsamples were merged for the estimation, as carrying out the regression on each separately did not return any significant findings. The merged sample therefore consists of 1,001 farms. Two models are presented below, both for pure technical efficiency. The first one does not include any farm or farmer's

characteristics (Table 6), while the second one does (Table 7). The reason is that those characteristics, present in the technical survey from IFIP, are available for a limited number of farms only (245 farms out of the 1,001). We therefore wanted to see whether the impact of agglomeration was the same for the large sample than for the reduced sample.

Table 6 shows that among the three orientations, after-weaning-and-fattening farms are the most pure technically efficient on average, while breeding-and-fattening farms are the least. However, caution is needed when interpreting this finding. As separate frontiers per orientation were constructed, the regression results indicate that the after-weaning-and-fattening subsample (respectively the breeding-and-fattening subsample) is the most (respectively the least) homogenous in terms of pure technical efficiency, that is to say in terms of management practices. Regarding agglomeration effects, the results suggest that they are present at three administrative levels. (i) At the sub-county's level ('canton'), the higher the yield of discharged nitrogen, the less efficient farms in this sub-county are. (ii) At the county's level ('département'), the more numerous pig farms in a county, the more efficient they are. (iii) Finally, at the regional level, in the regions where the concentration of pig farms is higher (that is to say in regions where more feed is produced, and in the Western and South-East areas), the lower their efficiency. Both results (ii) and (iii) are confirmed for the reduced sample, as Table 7 shows: pig farm concentration at the county - respectively regional level -, increases - respectively reduces - the efficiency (number of pig farms in the county, respectively pig slaughtered quantity in the region). Table 7 additionally confirms that the breeding-and-fattening subsample is the least homogenous orientation in terms of management practices, and further suggests that more numerous partners on the farms allow to increase the pure technical efficiency.

Table 6
Results of the regression on pure technical efficiency for the whole sample

	Parameter	t-test	Significance
Intercept	0.851	93.81	***
Only-breeding farm (d)	0.035	3.80	***
After-weaning-and-fattening farm (d)	0.062	6.56	***
Sub-county's nitrogen discharged by livestock per ha	-0.0002	-2.07	**
County's number of pig farms per ha	0.003	4.86	***
Regional production of industrial pig feed	-0.00001	-3.58	***
Farm in Western regions (d)	-0.046	-3.66	***
Farm in South-West county (d)	-0.050	-4.78	***
Number of observations		1001	
F-test		15.67	***
R-square		0.10	

(d): dummy variable

***, **, *: 10, 5, 1 percent

Table 7
Results of the regression on pure technical efficiency for the reduced sample

	Parameter	t-test	Significance
Intercept	0.910	21.47	***
Head farmer's age	0.0004	0.47	
Number of partners	0.127	2.07	**
UAA	-0.0001	-1.03	
Breeding-and-fattening farm (d)	-0.05	-3.23	***

Sub-county's nitrogen discharged by livestock per ha	-0002	-1.25	
County's number of pig farms per ha	0.002	1.75	**
Regional quantity of slaughtered pig meat	-0.005	-2.86	***
Number of observations		226	
F-test		3.67	***
R-square		0.11	

(d): dummy variable

***, **, *: 10, 5, 1 percent

Regarding the impact of agglomeration on scale efficiency, only results for the reduced sample are presented (Table 8), as no significant variables were identified for the whole sample. Table 8 indicates that, as in the case of pure technical efficiency, the main farmer's age and the number of partners have a non significant, respectively significant, influence on scale efficiency. However, the latter's influence is negative, suggesting that, while having partners on farm enable farmers to improve their management practices, it constraints them in their size decisions. Two other constraints in reaching the optimal farm size is the share of hired labour. As for the positive influence of current UAA, it suggests that larger farms in terms of land are more scale efficient.

Table 8

Results of the regression on scale efficiency for the reduced sample

	Parameter	t-test	Significance
Intercept	0.979	79.37	***
Head farmer's age	-0.00009	-0.32	
Number of partners	-0.004	-2.05	**
UAA	0.00010	3.03	***
Share of hired labour	-0.0001	-2.13	**
Only-breeding farm (d)	-0.014	-2.10	**
After-weaning-and-fattening farm (d)	0.003	0.46	
Number of observations		205	
F-test		3.28	***
R-square		0.09	

(d): dummy variable

***, **, *: 10, 5, 1 percent

Analyses of Variances (ANOVA) were performed in order to highlight some further influence of agglomeration. Table 9 displays the results for the ANOVA of pure technical efficiency scores per specific region. The results show that farms are less efficient, in terms of their management practices, in the Western regions, and among them in Brittany, confirming the regression results that concentration in these regions have a negative effect on efficiency. Moreover, farms in areas where the pollution level is high are less efficient than other farms, confirming the negative impact of the nitrogen discharged by livestock identified in the regression. Finally, Table 10 presents the results for an ANOVA carried out for two agglomeration variables on the returns to scale categories. The significant F-statistics indicate that farms operating under IRS are located in areas more concentrated in pig production (higher density of pig farms, more discharged nitrogen) than farms having DRS or being scale efficient. This suggests that too small farms (under IRS) are constrained in their expansion by the farm geographical concentration.

Table 9
ANOVA for pure technical efficiency and regions

	Average efficiency for farms in the region	Average efficiency for farms not in the region	F-statistics
Western Regions	0.848	0.872	9.73***
Brittany	0.829	0.868	9.32***
Area with nitrogen excess	0.832	0.867	7.71***

***, **, *: 10, 5, 1 percent

Table 10
ANOVA for agglomeration characteristics and farms' returns to scale

	Average for IRS	Average for DRS and CRS	F-statistics
Sub-county's nitrogen discharged by livestock (kg/ha)	110	98	12.42***
Sub-county's density of pig farms (number/ha)	0.00162	0.00128	14.36***

***, **, *: 10, 5, 1 percent

6. Conclusion.

This paper investigated the impact of agglomeration on technical and scale efficiency of French pig producers in 2004. The results indicate that agglomeration has no effect on scale efficiency, the latter being mainly due to individual farm characteristics. By contrast, management practices are affected by agglomeration externalities, both in a negative and a positive way. Negative externalities are present at the subcounty level ('canton') and at the regional level, while positive externalities occur at the county ('département') level. This suggests that while agglomeration at the county level induces favourable knowledge spillovers and matching labourforce, for example, agglomeration also constrains farmers due to legal disposition relating to manure spreading (subcounty) and to congestion regarding the upstream and downstream levels (region).

We demonstrated in this article that the Porter's hypothesis ("environmental regulations might lead to improved competitiveness", 1995) can be questioned. However to confirm this result, it would be interesting to use the methodology of the undesirable outputs (Hailu and Veeman, 2001) which allowed to take into account better the effects of the negative externalities.

Moreover, if our agglomeration externalities affect effectively the technical efficiency, they are all on an aggregated level. That's why it would be interesting to see if these effects are always identical when we use the aggregated scores of efficiency *via* the directional distance functions (Chambers *et al.* (1998), Färe and Zelenyuk (2003)).

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Appendix A: Linear programming model for the input-oriented model

The technical efficiency score $\hat{\theta}_i$ for the i -th firm under CRS assumption is the solution of the following linear programming model:

$$\min_{\lambda, \theta_i} \theta_i \quad (1)$$

subject to

$$-Y_i + Y\lambda \geq 0 \quad (2)$$

$$\theta_i X_i - X\lambda \geq 0 \quad (3)$$

$$\lambda \geq 0 \quad (4)$$

where

X and Y are respectively the input and output matrices of all observed firms;

X_i and Y_i are respectively the input and output vectors of the i -th firm;

λ is a vector of constants;

θ_i is a scalar such that $0 \leq \theta_i \leq 1$.

To incorporate the possibility that firms operate under VRS the following constraint is added to the CRS model:

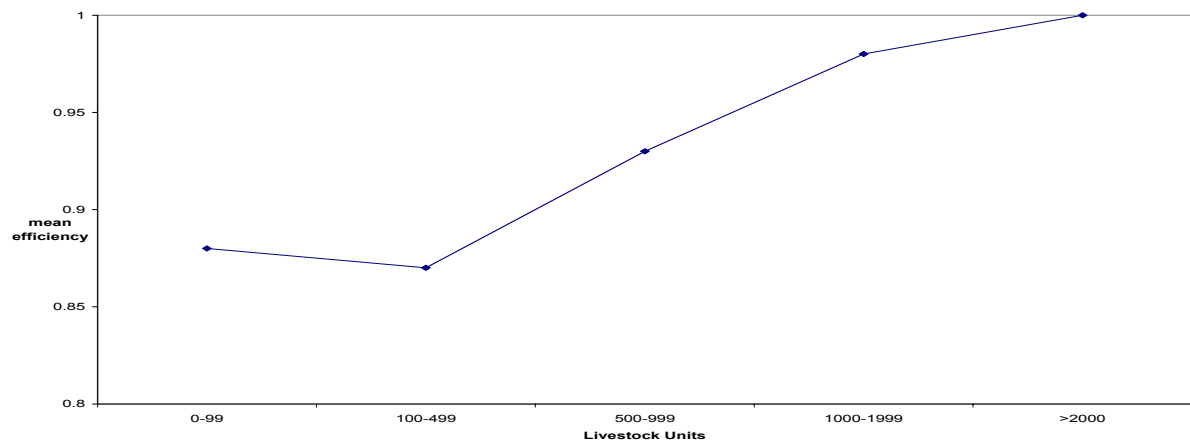
$$n1 \times \lambda = 1 \quad (5)$$

where

$n1$ is a $n \times 1$ vector of ones, whose components' sum is equal to 1, and with n the number of firms in the sample.

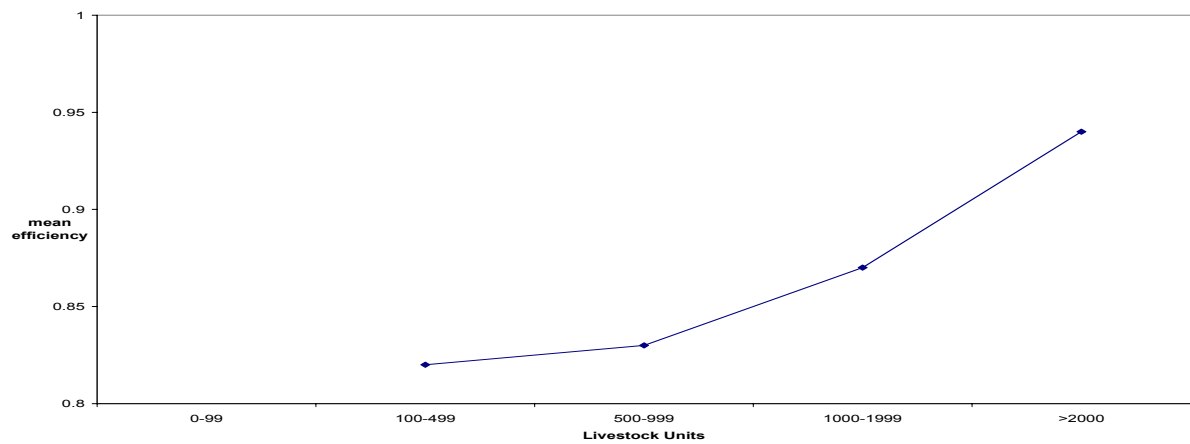
Appendix B: Relationship between efficiency and farm size

Graph 1: Size and technical efficiency for only-breeding farms



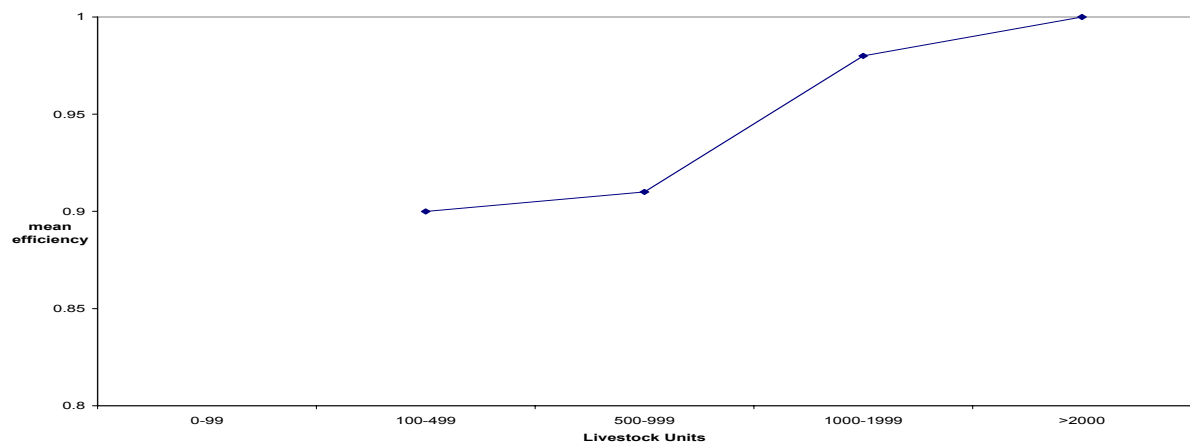
F-test: 1.95

Graph 2: Size and technical efficiency for breeding-and-fattening farms



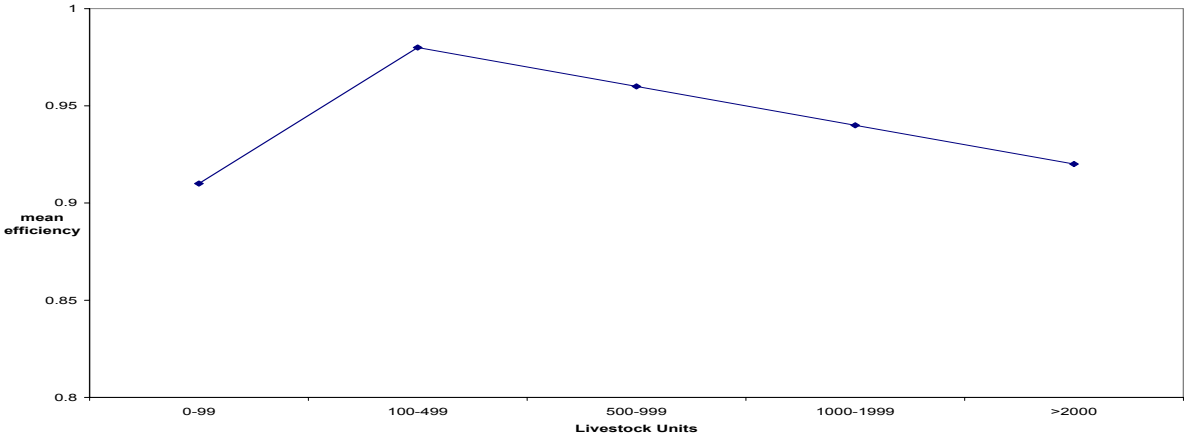
*F-test: 21.92****

Graph 3: Size and technical efficiency for after-weaning-and-fattening farms



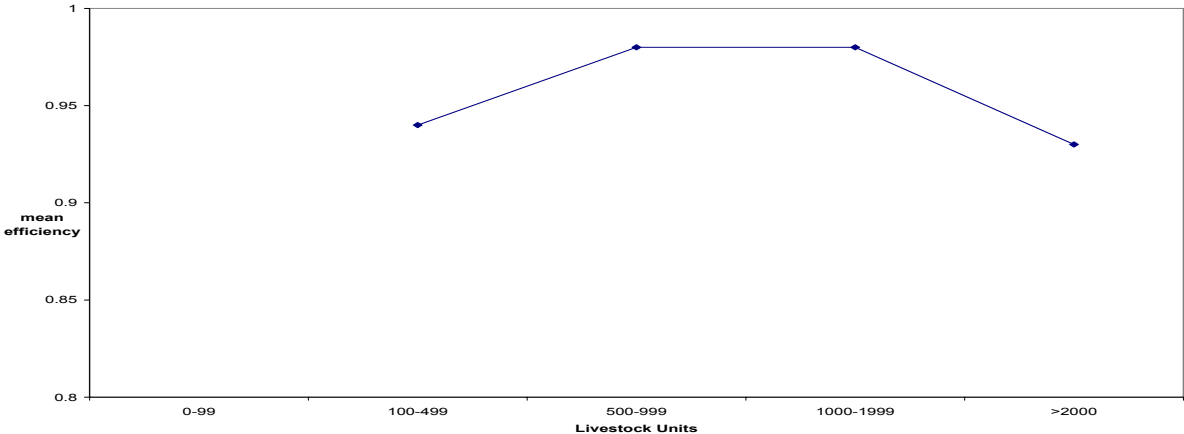
*F-test: 6.11****

Graph 4: Size and scale efficiency for only-breeding farms



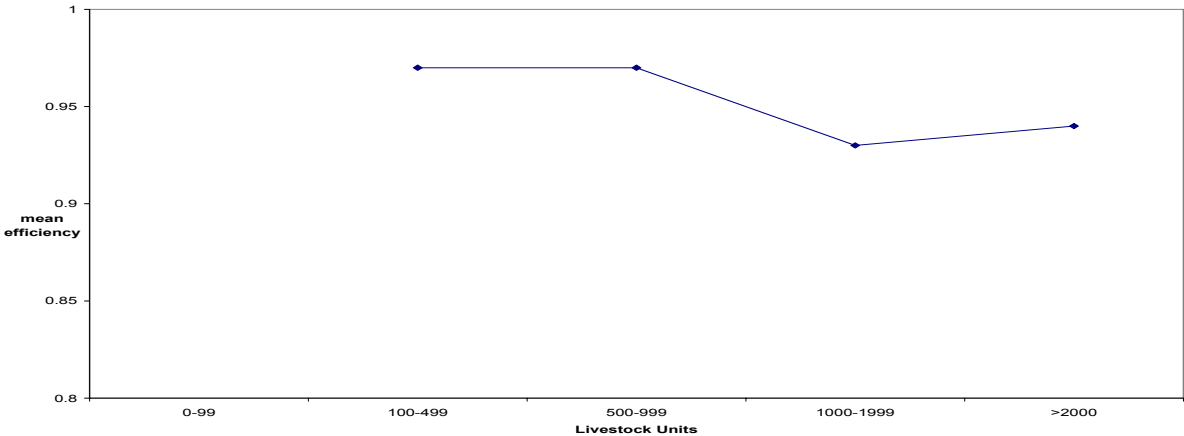
F-test: 12.88***

Graph 5: Size and scale efficiency for breeding-and-fattening farms



F-test: 68.6***

Graph 6: Size and scale efficiency for after-weaning-and-fattening farms



F-test: 7.93***