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Solene Larue, Laure Latruffe. Agglomeration externalities and technical efficiency in pig production. 1. Journées GDR ASPE-INRA SAE2: Economie et Espace, Analyse des Phénomènes Spatiaux en Economie (GDR ASPE). FRA. Centre National de la Recherche Scientifique (CNRS), FRA.; European Workshop on Efficiency and Productivity Analysis (EWEPA).; North American Regional Science Council (NARSC). USA.; Société Française d'Economie Rurale (SFER). FRA., Jun 2007, Lille, France. 16 p. hal-02416809

HAL Id: hal-02416809

<https://hal.science/hal-02416809>

Submitted on 6 Jun 2020

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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 France is a typical example of how agglomeration externalities may have positive effects on farm performance in particular. However, negative externalities implied by concentration have lately appeared. They are due to increasing competition for land following the introduction of a law governing polluting activities according to which pig producers need to have a minimum area available where their manure can be spread.

We use a two-stage method, where the first stage consists in calculating pig activity's efficiency scores with the non-parametric method Data Envelopment Analysis (DEA), and the second stage is a truncated regression of these scores on agglomeration variables. Data are for one thousand French pig producers in 2004, provided by the French Institute of the Pig Sector (IFIP).

Results suggest that French pig producers were affected by both positive and negative agglomeration externalities at this period. Positive externalities are in the form of knowledge spillovers facilitated by the proximity of farms, and in the form of closeness to downstream market. Negative externalities suggest that agglomeration constrains farmers in their land demand due to legal disposition relating to manure spreading.

Keywords: technical efficiency, pig production, agglomeration externalities

* This research was supported by the French National Agency of the Research (ANR) program "Systems of Animal Production and Sustainable Development" (SPADD). The authors thank the French Institute of Pork Sector (IFIP), notably Michel Rieu, for helpful comments.

1. Introduction.

The French livestock production has expanded during the last decades, while at the same time as both structural and geographical changes have occurred. On the structural side, farms of reduced size have disappeared to the benefit of big structures. Besides, some farms have merged in order to optimise the control of outlets and to improve competitiveness.

If it is recognised that the concentration in the porcine sector is widely influenced by positive agglomeration externalities, the specific effect of such externalities on the productivity of the pig producers has never been investigated. In this context, our objective is to assess the effects of agglomeration on technical efficiency of French pig farms. Exploring the issue also enables us to consider the potential opposite effect of negative externalities that are specific to swine production.

French pig production: A brief history

The pig production in France 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 French production 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 structures. Similarly to 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 onwards the farms steadily expanded their size. Hence, small farms disappeared gradually: they were 250,000 in 1969 against 65,000 in 2000. Pig farms 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, accounted for 55% of this workforce in 2000, against 30% in 1969. Moreover, the production organised itself thanks to the grouping of producers.

Thus, the pig sector considerably evolved, as much in terms of structure as in terms of techniques. Today, pig farms have become more specialised and larger. However, there are now fewer farms, which have more and more concentrated in specific areas in order to benefit from a more favourable technical and economic environment, with the aim of 'productivity constantly stepped-up'.

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 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 the presence of specialised 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.

The specific issue of agglomeration effects on technical efficiency in agriculture has never been investigated. The only reference to this day is the study by Tveteras and Battese (2006), which deals with aquaculture. The authors examined the influence of agglomeration externalities at the regional level on the productivity of Norwegian salmon farming¹. They distinguished between the effects on the production possibility frontier (the hypothesis being that information spillovers lead to technological progress) and on the technical inefficiency (the hypothesis being that knowledge spillovers enable farms to reduce their optimisation errors). In their econometric model, the authors integrated two explanatory variables, namely regional size of industry and regional density of farms, in order to investigate how agglomeration externalities influenced technological change as well as technical efficiency.

The authors found that an increase of industry regional size lead to technological progress, and that farms located in regions with larger industry were more technically efficient. On the other hand, farm regional density had a negative effect on the shift of the frontier, but a positive effect on technical efficiency. The authors concluded that there were 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.

Their article is a cornerstone in the literature about the contemporary stakes of empirical spatial economics. The main stake 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).

The objective of our paper is to assess the effects of agglomeration on technical efficiency of French pig farms. The increasing concentration of pig production in western France is a typical example of how agglomeration externalities may have positive effects on farm performance. Daucé and Léon (2003) 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, more recently concentration seems to have had harmful consequences. Intensive pig production causes pollution due to manure, and environmental regulations in France require that pig producers spread their manure on a minimum area of land. Thus, there is now increasing competition for land in pig production, and thus there exist negative agglomeration externalities, which need to be taken into account in the analysis of the impact of agglomeration on pig farm technical efficiency.

Based on existing literature (including Roe and Sharp, 2002) and background of the pig sector in France, we have three theoretical expectations.

- 1) Technical efficiency is increased by the concentration of farms, due to farmers' spatial proximity. This implies relationships between farmers and thus creates knowledge spillovers (information, social capital) and matching labour force.

¹ For that purpose, the authors estimated a stochastic frontier production function on an unbalanced sample of 577 salmon farms during the period 1985-1995.

2) Technical efficiency is increased by the closeness to upstream and downstream sector. Concentration of the pig sector is largely due to integrations which are as much horizontal as vertical, and thus we expect that better market access increases technical efficiency because of input sharing (upstream sector: industrial or non-industrial pig feed) and demand matching (downstream sector: capacity of slaughtering houses).

3) Technical efficiency is reduced by farm concentration, due to the negative externalities that have lately appeared. As mentioned above, these are due to increasing competition for land following the introduction of a law governing polluting activities.

The paper is structured as follows. The next section gives some details about our methodology. The third section explains the data used. The fourth section present the results. The last section concludes.

2. Methodology.

A general definition of productivity is the ability of production factors to produce the output (Thiry and Tulkens, 1989). Potential productivity improvement can be evaluated for firms in a comparison framework. In the spatial framework, a firm can increase its productivity in comparison with other firms by improving its efficiency or/and by reaching an optimal farm size. In the time framework, productivity improvement can not only consist in efficiency increase, but also in technological change. In this paper, we focus on efficiency at one point in time, and in particular on technical efficiency. The concept of efficiency is based on the distance of a firm to the production frontier. Technical efficiency refers to a physical notion, independent of inputs and output prices as well as the availability of inputs². It indicates whether a firm is able to attain the maximum outputs from a given set of inputs. Clearly, the closer a firm operates to the frontier, the more technically efficient it is.

Measuring efficiency implies therefore measuring the potential input reduction or potential output increase, relative to a reference. A crucial issue is therefore to define this reference, that is to say, to construct the efficient frontier. In this paper, we use a non-parametric approach to define the frontier. This choice is based on the fact that, in practice, only inputs and their output realisations are observed, and thus the production function is unknown. Rather than specifying a production function with parametric methods, we constructed the frontier in the output-input space by enveloping all observations of our sample. With such non-parametric method, misspecification errors are avoided.

In order to fulfil our objective, namely to investigate the impact of agglomeration externalities on technical efficiency of pig farms, our analysis will be carried out in two stages.

First stage: Calculation of technical efficiency

In the first stage, the non-parametric method Data Envelopment Analysis (DEA) is used to calculate 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 lie on or below the frontier (Charnes et al., 1978)³. 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 is identified as totally efficient and is attributed an efficiency score of 1.

² In opposition, a firm is allocatively efficient if its outputs and inputs maximise its profit (or minimize its cost) at given prices.

³ A summary of the DEA linear programming is presented in Appendix 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 we have privileged DEA for several reasons.

- As mentioned above, DEA does not require specification of a functional form for the frontier or of the 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 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. Moreover, with DEA it is possible to identify whether farms that are not scale efficient have decreasing (DRS) or increasing returns to scale (IRS).
- Finally, multiple outputs and inputs can be considered simultaneously with DEA, and they can thus be quantified using different units of measurement.

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. Both orientations can be used for pig production, 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).

Thus, we have chosen to calculate efficiency from both orientations in order to compare them.

Our DEA model is multi-output and multi-input. Inputs include the number of sows, labour use, feed expenditures, depreciation and other expenditures (energy, water, maintenance and repair, health expenditures, etc). Pig producers in our sample must be separated between three main orientations, due to a discrepancy in their production technologies. The inputs are the same for all three orientations, but their outputs are different. Based on a typology given by experts, the three sub-samples of farms are: only-breeding farms, breeding-and-fattening farms, and after-weaning-and-fattening farms. 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 are regressed on several explanatory variables capturing agglomeration. Due to the bounded nature of DEA efficiency scores (bounded on the right at 1), a truncated regression is used instead of Ordinary Least Squares (OLS). Truncated regression models are employed in cases where some observations are fully missing, so that neither the dependent nor the independent variables are known. These models are often confused with censored regression models where only the value of the independent variable is unknown, while the value for dependent variables is available. In other words, truncated data occur when some observations are not included in the analysis.

The econometric second stage is widely used in the literature (for example see Latruffe *et al.*, 2005), although usually the bounded nature of DEA scores is not considered, and thus standard OLS are used. The second stage allows estimate the impact, on efficiency, of

variables on which the farmer has no control. For example, in the sectors of hospital and transportation, these variables concern generally the type of firm (public or private), the governmental regulations, the location, etc. In agriculture, the variables used will be rather the location and socioeconomic variables (such as the age of the farmer), as well as other variables which represent the quality of the production factors when it is available.

In our study, several agglomeration variables are considered. Agglomeration variables that are tested include various density ratios at several administrative levels: municipality, sub-county (“canton”), county (“département”), and region. Some ratios relate some farming sector’s characteristics (upstream and downstream sectors) to the number of farms in the administrative sections. Additionally, some ratios capture the pollution externalities on the population, the legal constraints faced by farms for nitrogen discharge (e.g. farmers are allowed to spread the manure on 70% only of their utilised agricultural area), and the possible positive spillovers effects or congestion problems implied by farm proximity.

As for the other explanatory variables usually used in efficiency papers (such as human capital variables), we do not include them in our model, as they are available for few observations only (see next section).

3. Data used.

This study employs farm-level data from a technical survey and a bookkeeping survey of pig farms carried out by the French Institute of the Pig Sector (IFIP) in 2004. Both surveys enclose a large range of data about outputs, inputs, management, as well as technical and social variables for a sample of about 3,600 farms (IFIP, 2006). Only farms that had non-missing information for the selected outputs and inputs (see above section) are included in the DEA model. From this reduced sample of 1,005 farms, the three sub-samples (only-breeding farms, breeding-and-fattening farms, after-weaning-and-fattening farms) are created, and one DEA frontier is constructed for each sub-sample.

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 (regrouping the three regions Centre, Limousin and Auvergne) gather respectively 8.4% and 9.3% of the sample farms. This is consistent with the location of pig production in France. Regarding the three orientations, 74% of the sample is breeding-and-fattening farms (of which more than three quarters 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 farms (located mainly in Western regions).

First-stage data

Descriptive statistics of the three sub-samples’ outputs and inputs used in DEA 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 (swine) than the fully specialised after-weaning-and-fattening farms. One explanation is that it is easier to produce swine 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, health expenditures, etc).

Table 1
DEA outputs and inputs: Descriptive statistics of the three sub-samples.

	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 (hours)	1,816	1,738	395	13,377
Feed (euros)	45,417	57,173	9,618	384,425
Depreciation (euros)	11,948	20,223	29	170,986
Other expenditures (euros)	27,585	38,402	2,518	264,769
<i>Breeding-and-fattening farms (661 farms)</i>				
<i>Outputs</i>				
Number of piglets	329	519	1	5,675
Number of swine	2,475	1,825	380	17,183
<i>Inputs</i>				
Number of sows	141	92	33	771
Labour (hours)	2,742	1,743	367	13,993
Feed (euros)	173,811	114,973	39,399	956,223
Depreciation (euros)	24,449	23,265	103	204,014
Other expenditures (euros)	41,674	32,972	3,483	280,610
<i>After-weaning-and-fattening farms (164 farms)</i>				
<i>Outputs</i>				
Number of swine	1,796	1,336	315	8,334
<i>Inputs</i>				
Labour (hours)	983	638	197	4,321
Feed (euros)	95,937	65,990	18,983	408,613
Depreciation (euros)	10,910	11,100	229	60,604
Other expenditures (euros)	84,780	66,106	15,462	411,681

Second-stage data

For the regression of efficiency scores, agglomeration variables at different administrative levels are calculated with data from the 1999 Agricultural Census and data from other surveys, which give detailed information about farm environment and upstream and downstream sectors.

Table 2
Second-stage variables: Descriptive characteristics of the whole sample.

	Mean	Standard deviation	Minimum	Maximum
Regional production of industrial pig feed (1000 t) per farm	548	1,181	7	4,482
Regional available non-industrial pig feed (ha) per farm	4,769	4,059	3	19,686
County's number of slaughtered heads per farm	553	881	0	3,760
County's density of pig farms (number/ha)	0.06	0.06	0	0.36
Sub-county's nitrogen discharged by livestock (kg/ha)	104	53	1	229

4. Main results.

4.1. 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 presented too.

Total technical efficiency scores are on average between 0.80 and 0.86, depending on the sub-samples. For example, the after-weaning-and-fattening sample had an average total technical efficiency score of 0.86. This score indicates that these farms could have increased their outputs by 14% on average and still used the same level of inputs. Despite this, this sub-sample is the most efficient on average, in terms of total technical efficiency and pure technical efficiency. This suggests a larger homogeneity in management practices. Scale efficiency was high and similar for all specialisations (averages of 0.96), suggesting that bad management practices caused more inefficiency than sub-optimal scale. Regarding the share of farms with efficiency score of 1, breeding-and-fattening farms had the smallest share of all sub-samples, possibly be due to their dual output (more activities implying worse management practises).

The shares of farms operating under CRS (i.e. scale efficient), IRS and DRS, presented in Table 4, indicate that the majority of farms operated at sub-optimal size, particularly in the breeding-and-fattening sub-sample: only 9.7% farms were scale efficient, against more than 13% in the two other sub-samples. Both breeding samples (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 their size. By contrast, more than half of the after-weaning-and-fattening farms were operating under DRS, implying that this orientation had too large farms.

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 1) between scores of both orientations.

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

	Mean	Standard deviation	Minimum	Share of farms with efficiency score of 1 (%)
Total technical efficiency				
Only-breeding farms (180 farms)	0.83	0.13	0.45	11.7
Breeding-and-fattening farms (661 farms)	0.80	0.11	0.38	4.8
After-weaning-and-fattening farms (164 farms)	0.86	0.09	0.57	9.8
Pure technical efficiency				
Only-breeding farms (180 farms)	0.86	0.13	0.45	23.3
Breeding-and-fattening farms (661 farms)	0.83	0.11	0.40	9.4
After-weaning-and-fattening farms (164 farms)	0.90	0.09	0.60	23.2
Scale efficiency				
Only-breeding farms (180 farms)	0.96	0.06	0.63	13.3
Breeding-and-fattening farms (661 farms)	0.96	0.04	0.75	9.4
After-weaning-and-fattening farms (164 farms)	0.96	0.05	0.73	14.6

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

	CRS	IRS	DRS
Only-breeding farms (180 farms)	13.2	71.7	15.1
Breeding-and-fattening farms (661 farms)	9.7	63.5	26.8
After-weaning-and-fattening farms (164 farms)	15.2	32.3	52.5

4.2. Impact of agglomeration on farm efficiency.

The second-stage regression was performed with output-oriented efficiency scores as well as with input-oriented scores, and gave very similar findings. Thus, only results with output-orientation are presented and discussed here. The three sub-samples 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 1,005 farms. However, to control for the difference in orientation, we included one dummy variable for the biggest sub-sample, the

breeding-and-fattening sub-sample. Results presented in Table 7 show that this orientation is the least efficient in terms of pure technical efficiency, as the coefficient for the dummy variable is negative and significant. This confirms that this sub-sample is the least homogenous orientation in terms of management practices. As mentioned above, this can be explained by the diversification of activities (breeding and fattening activities) for such farms. However, this sub-sample is as homogenous as the two other sub-samples in terms of optimal size (scale efficiency), as was identified in Table 3.

Regarding agglomeration effects, results in Table 7 suggest that they are present at various administrative levels. However, not all our theoretical expectations are validated.

- 1) Our first theoretical expectation is confirmed, as county's pig farm density has a positive and significant influence on total and pure technical efficiency. This indicates that proximity of farms increases knowledge spillovers, and is consistent with the study by Tveteras and Battese (2006) on salmon farms.
- 2) As for the second theoretical expectation regarding market access, it is confirmed for the downstream market: the county's number of slaughtered heads per farms has a positive and significant impact on technical efficiency. However, regarding the upstream market, there is no clear-cut conclusion: on the one hand, regional available non-industrial pig feed seems to have a positive impact, while on the other hand, regional production of industrial pig feed has an unexpected negative impact.
- 3) Regarding the last theoretical expectation, it is partly confirmed. The quantity of nitrogen discharged per ha has a negative effect on total technical efficiency, suggesting that the need of land decreases efficiency, but the effect is not highly significant.

Table 7
Influence of agglomeration on efficiencies: results of the regression (elasticities)

	Total technical efficiency		Pure technical efficiency		Scale efficiency
Intercept	0.70805	***	0.66420	***	0.03302
Regional production of industrial pig feed (1000 t) per farm	- 0.12565	***	- 0.14723	***	0.03166
Regional available non-industrial pig feed (ha) per farm	0.00001	**	0.00001	***	- 5.47 e-08
County's number of slaughtered heads per farm	0.00961	***	0.00900	***	0.00088
County's density of pig farms (number/ha)	0.34466	***	0.34580	***	0.00841
Sub-county's nitrogen discharged by livestock (kg/ha)	- 0.00016	*	- 0.00010		- 1.07 e-06
Breeding and fattening farm (dummy)	- 0.03929	***	- 0.02906	***	0.00048
Wald χ^2	54.61	***	40.33	***	0.65

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

Table 7 indicates that there is no agglomeration effect on scale efficiency. This might be explained from a methodological point of view: scale efficiency scores are very high for most

of the farms, and therefore the variation in the dependent variable might not be sufficiently large. However, in order to get some insights into the impact of agglomeration on farm size, results from two additional analyses are presented below.

Firstly, Table 8 presents the correlation coefficients between farms' utilised agricultural area and their three efficiency scores (total technical, pure technical, scale). This investigation was carried out on a reduced sample of 245 farms only (out of 1,005), as the land area was available for a limited number of farms. For this reduced sample, the average area is 87 ha, with a minimum and a maximum of 0 and 500 ha. Table 8 shows that only the relationship between farm's area and scale efficiency is statistically significant. The coefficient is positive, suggesting that larger farms are more scale efficient.

Table 8
Correlation between farms' efficiency and utilised agricultural area (245 observations).

	Total technical efficiency	Pure technical efficiency	Scale efficiency
Spearman coefficient	0.0713	0.0240	0.1474
Probability	0.2664	0.7086	0.0210 **

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

It is therefore interesting to investigate whether agglomeration conditions are one reason why farms do not increase in size, as this could make them more efficient. Our second additional analysis has this objective. Table 9 presents the results of an ANOVA (Analysis of Variance) carried out for all agglomeration variables introduced in the regression, on two farm categories, depending on their returns to scale (IRS on the one hand, DRS and CRS on the other hand).

Table 9
ANOVA for agglomeration characteristics on farm categories according to returns to scale.

	Average for farms under IRS	Average for farms under DRS or CRS	F-statistics
Regional production of industrial pig feed (1000 t) per farm	0.23	0.21	5.2 **
Regional available non-industrial pig feed (ha) per farm	831	1,101	18.6 ***
County's number of slaughtered heads per farm	1.01	1.30	15.5 ***
County's density of pig farms (number/ha)	0.06	0.05	4.4 **
Sub-county's nitrogen discharged by livestock (kg/ha)	109	98	9.7 ***

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

The significant F-statistics indicate that all agglomeration characteristics are statistically different between both farm categories. The larger value of regional available non-industrial pig feed per farm, for farms operating under IRS, is intuitive: farms under IRS are small and therefore they do not have much land available for feed. For this reason, they rely more on

industrial feed, and thus the higher value of regional production of industrial pig feed per farm for farms under IRS. The larger value of county's density of pig farms, for farms operating under IRS, may indicate that farms' expansion is constrained by the farm geographical concentration. Such concentration is also reflected by the lower availability of slaughterhouses (lower value of county's number of slaughtered heads per farm, for farms under IRS) and the larger nitrogen discharged per ha at the sub-county level (higher value for farms under IRS).

5. Conclusion.

This paper investigated the impact of agglomeration on technical and scale efficiency of French pig producers in 2004. The results indicate that efficiency is affected by agglomeration externalities, both in a positive and a negative way. Positive externalities are in the form of knowledge spillovers facilitated by the proximity of farms, and in the form of closeness to downstream market (in terms of slaughterhouses). Negative externalities are present at the subcounty level ('canton'), and suggest that agglomeration constrains farmers in their land demand due to legal disposition relating to manure spreading.

One of our findings is that environmental regulations in France reduce pig producers' technical efficiency, which may question Porter's hypothesis that 'environmental regulations might lead to improved competitiveness' (Porter and Van der Linde, 1995). This is opposite to Piot-Lepetit and Le Moing's (2007) findings, that there was a positive relationship between technical efficiency and environmental regulation in the French pig sector for the period 1996-2001. However, the authors investigated this relationship over a 5-year period, and were thus able to highlight the absorption of inefficiency due to changes in the production process. By contrast, our study investigates the issue at one point in time.

Nevertheless, further research needs to be carried out for confirmation, using the methodology of undesirable outputs (Hailu and Veeman, 2001) for example. This method can better account for the effects of negative externalities, as it relies on including manure in the production function and on minimising this undesirable output. Moreover, although we showed in this study that agglomeration externalities affect efficiency, they were measured at an aggregated level while efficiency scores were individual. Therefore, further research could be to investigate whether these effects are identical when aggregated scores of efficiency are employed, using for example the directional distance functions (Chambers *et al.*, 1998; Färe and Zelenyuk, 2003).

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Appendix 1: 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.