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THE FRENCH PIG PRODUCTION STRUCTURE: BETWEEN COMPETITIVENESS AND MANURE MANAGEMENT

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Abstract:

Nitrogen pollution resulting from agricultural activities is a major threat to the quality of European ground, surface and marine waters. Intensive livestock production is an important source of pollution, due to an insufficient area of land available to these farmers on which to apply manure. This is particularly relevant for pig production. The direct impact on the environment of the pig production is in some areas really severe. Along with an expansion of production, there have been significant structural changes in the pig sector. Pig farming has become more intensive with fewer farms producing a larger number of pigs and more specialised with feed obtained from off-farm sources and often with very little land. Developments in production technologies have allowed Abstract

This paper provides an evaluation of the degree of efficiency within and between each French pig farming system. The former measurement called intra-system efficiency captures gains that can be achieved both from a competitive and environmental point of view if all farms in each pig farming system improve their productive efficiency. The latter measurement called structural or composition efficiency shows gains that result from structural changes in the productive specialisation of the French pig sector. The efficiency evaluation is implemented by using a Data Envelopment Analysis. Results provide an illustration of the potential evolution of the French pig sector.

Key words

Directional distance function, Structural efficiency, Data Envelopment Analysis, Pig farming system, Manure management.

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The French Pig Production Structure: Between Competitiveness and Manure Management

1. Introduction

significant productivity gains, particularly for large-scale producers. Pig farming is becoming more regionally concentrated. A major factor encouraging the development and uptake of productivity enhancing technologies has been the intense competition in the meat market and the long run decline in real prices received by farmers, which in turn is driven by productivity improvements.

Disposal of pig manure is usually driven by lowering disposal cost rather than optimising the nutrient needs of crops and pasture, leading to detrimental environmental costs. Because pig manure is a low density nutrient fertiliser source and costly to transport over long distance compared to inorganic fertilisers, areas with high intensity in pig production usually have a surplus of nutrient manure. This has led to an increase in residual pig manure in the environment in these areas where they can degrade water and air quality and impose human health and environmental pollution costs on society. Policy measures to deal with that problems are predominately regulatory and are increasing in severity and complexity. Supports have been provided to offset the increased costs imposed by regulations. In particular, supports have often been given to reduce the level of capital expenditure required to bring production facilities into conformity with regulations. The impact of regulations depends upon the size of farms. It can influence producer behaviour and can have a direct effect on the resulting environmental benefit and on competitiveness of producers (OECD, 2003).

The aim of the paper is to provide an evaluation of the competitiveness of the French pig sector. A nonparametric frontier analysis which allows efficiency benchmarking, called Data Envelopment Analysis (DEA), is used. The efficiency evaluation is implemented in both economic and environmental terms. This paper used an approach proposed by Maudos *et al.* (2000) for obtaining productive efficiency measurements which enable two components to be differentiated : one associated with the degree of efficiency within each French pig farming system called intra-system efficiency and another associated with the structure of production in the pig sector called structural or composition efficiency. The former component captures gains that can be achieved both from a competitive and environmental point of view if all farms in each pig farming system improve their productive efficiency. This latter component shows gains that result from structural changes in the productive specialisation of the French pig farming system. As the livestock sector is highly constraint by environmental regulations in the European Union, DEA models used in this paper take into account the fact that animals produce manure. An undesirable output is introduced in the specification of the best-practice frontier of each pig farming system and performance benchmarks are defined in a direction that allows for a production increase jointly with a pollution decrease. The use of the directional efficiency measurement defined by Chung *et al.* (1997) allows us to evaluate improvements of the competitiveness of farms that can be achieved without increase of pollution and changes in the observed productive structure of French farms with a pig farming activity.

The paper is organised as follows. Section 2 provides a description of the impact of nitrogen pollution from intensive livestock units on the environment and of the main European directives to control and reduce nitrogen pollution. Section 3 presents formally the DEA

models implemented in this study. Section 4 characterises the data set and section 5 presents the main results. Finally, the section 6 concludes on the major findings of this paper.

2. Nitrogen emissions and European environmental regulation in the pig sector.

In Europe, the quality of available drinking water resources is one of the most important issues of environmental concern in areas with intensive livestock population. The European drinking water standard is a nitrate level less than 50 mg/l. It is expected that about 25 % of the agricultural soils in the European Union (EU) is above this standard (Brouwer and Van Berdum, 1996). This is due to either the high surplus of nitrogen from agriculture or due to vulnerability of the soil to leaching. Livestock production systems contribute to a significant proportion of the nitrogen pollution burden in large areas of Europe. High supply levels of animal manure from intensive livestock farming create problems of water and soil pollution.

2.1. Nitrogen emissions

Nitrogen is imported to the farm in feed and fertiliser and exported as part of pig and crop output. Nitrogen is lost through the production process but the substantial part of nitrogen emission from pig farms originates from the production of pig manure. Part of the nitrogen content of manure is lost in stalls and during storage through ammonia evaporation. When the remaining manure is utilised in plant production, the utilisation level is substantially lower than the utilisation level for chemical fertiliser. The part of the nitrogen content that is not ultimately incorporated into crops is washed out as nitrate or denitrified along with surplus nitrogen from chemical fertilisers. Although nitrogen losses are not a good indicator of the total environmental effect of emissions which are known to vary from locality to locality and across farms, it is usually used as an indicator of the local and global environmental effects of nitrogen losses. Major impacts of nitrogen emissions to the environment arise from leaching of nitrates to surface waters and ground waters, emissions of ammonia to the atmosphere, as well as denitrification. High levels of phosphate and nitrate cause eutrophication of surface waters and affect biodiversity through the depletion of plants and animals and growth of algae. Emissions of ammonia contribute to acidification of soils and waters. The environmental impact of livestock production varies across regions and farming types. Concentration of livestock production due to economies of scale makes the problem especially acute in some regions and in particular, in the western part of France.

There is a common understanding in Europe that major adjustments are required by livestock production in meeting targets formulated by governments, either at regional, national and community level. This implies mainly to regions with a high concentration of livestock production with an emphasis on pig production. A wide variety of adjustment processes can be considered including measures at source of pollution, as nutritional and fertiliser management, adjustment of farm structure by reducing intensity of production and by taking end-of-pipe measures as, processing and treatment of livestock manure. Member states of the EU generally design their policies by applying the Nitrates Directive¹.

2.2. The EU Nitrates Directive

¹ In the context of European policy, a directive is a legal instrument which informs Member states of goals and of a time frame for their achievement. The implementation of a directive is left to Member states, thus allowing them to achieve the common goal in ways that recognise their national character.

In December 1991, the directive concerning the protection of waters against pollution caused by nitrates from agriculture sources (91/676/EEC) was announced. One of the main elements of the directive was that the application of animal manure in the Nitrate vulnerable zones should not exceed 170 kg of nitrogen per hectare. This standard should be met at farm level by the year 2003. Two four-years periods up to the year 2003 was identified in the Nitrate directive, during which a gradual reduction in the level of application is allowed. By the end of the first period, from 1995 until 1999, it was possible to apply a maximum of 210 kg of nitrogen from manure. The application of nitrogen from livestock manure was reduced during the second four years period, for achieving the level of 170 kg by the year 2003. To fulfil these objectives, the directive contains three main provisions.

From December 1993, EU member states had monitored all water bodies and had identified areas where water quality is threatened by nitrate pollution from agriculture. These areas are designated as Nitrate Vulnerable Zones (NVZs). NVZs are identified as land areas where agricultural production contributes to drinking water quality problems when drinking waters contain more than 50 mg of nitrate per litre or to the eutrophication of aquifers when algae growth causes oxygen depletion and death or migration of higher level life forms.

By December 1993, member states had established voluntary codes of good agricultural practices in order to allow for farmers to fulfil the objectives of the Nitrates directive. Such codes cover, where relevant, issues such as the periods of the year when the application of fertiliser is inappropriate, the land application of fertiliser to steeply sloping ground and near water courses, the capacity and construction of storage vessels for livestock manure and the procedures for land application, including rate and uniformity of spreading, of both chemical fertiliser and animal manure, that will maintain nutrient losses to water at an acceptable level. In addition, member states may include in their codes of good agricultural practices measures regarding the land use management, the use of catch crop, the establishment of fertiliser plans and keeping record on a farm-by-farm basis on fertiliser uses or the management of irrigation systems.

By December 1995, member states had developed action programmes for their NVZs, to be implemented no later than December 1999. These mandatory programmes consist of the standards contained in the voluntary codes and include rules relating to the periods when the land application of certain types of fertilisers is prohibited, the capacity of storage vessels for livestock manure and the limitation of the land application of fertilisers, consistent with good agricultural practices and taking into account the characteristics of the concerned vulnerable zones as soil, climate or cropping practices.

2.3. The other EU Directives to control nitrogen pollution

The Integrated Pollution Prevention and Control (IPPC) directive was adopted on November 1995 (96/C 87/02). This directive lays down measures designed to reduce emissions in the air, water and land from certain activities, including measures concerning wastes in order to achieve a high level of protection of the environment. Regarding agricultural activities, the directive is applicable to installations for intensive rearing of pigs with more than 2,000 places for production pigs (over 30 kg) or 750 places for sows.

The Environmental Impact Assessment directive (EIA) concerns the effects of certain public and private projects on the environment. Regarding agriculture, it includes facilities for the intensive rearing of pigs more than 3,000 places for pig production (over 30 kg) or 900 places

for sows. It includes projects for the restructuring of rural land and holdings, the use of uncultivated land or semi-natural areas for intensive agricultural purposes, water management for agriculture, including irrigation and land drainage projects, initial afforestation and deforestation for the purposes of conversion to another type of land use and intensive livestock installation.

Now, all these directives are included in the Framework Directive on Water Quality in the EU from October 2000 which is an attempt to build a general policy framework concerning the improvement of water quality.

2.4. The implementation of these directives in France

The French system of nitrogen pollution reduction is built on the Act on Classified Installations for Environmental protection from 1976 which is a general framework in which polluting installations must be integrated. Regarding agriculture, only rearing activities are concerned. This act recognizes three legal systems for holdings which imply different restrictions on the application and spreading of animal manure and nitrogen balance sheets:

- Farms with less than 50 livestock equivalents (LE)² are managed by the Departmental Sanitary Regulation;
- Farms with a number of LE between 50 and 450 are managed by a statement system;
- Farms with more than 450 LE must obtain a production permit from their Prefecture (administrative headquarter). This procedure involves a public inquiry and an impact study of the rearing activity.

The implementation of the Nitrate directive in the French legislation was realized between 1993 and 1996. The nitrate vulnerable zones (NVZs) were identified and delimited. At this time, the France country is divided in three different zones: non vulnerable zones, vulnerable zones with a nitrate level which exceed 50mg/l or which is upper than 40 mg/l with an increasing trend and structural manure surplus zones (ZES) where the number of livestock units implies more than 170 kg of nitrogen per ha. At the same period, the Corpen organisation was in charge of the building of the good agricultural practice code. This code is mandatory in the NVZs and the ZES and voluntary in the other zone. The first four-years action program, called the Agricultural Pollution Control Program (PMPOA), was defined in November 1993. It only concerns intensive rearing activities. This program provides a financial support to farmers in order to adapt their holdings and manure storage capacities to fulfil the code of good agricultural practices and the standard of 170 kg of nitrogen per hectare. Furthermore, a farmer who enters the program and does not respect its obligation could pay a fine. The second four-year action program was defined by a enforcement order from January 2001. A more stringent action program was defined for the ZES in January 1998. It implies no increase in livestock numbers, nitrogen emissions are restricted to 140 kg per hectare and the implementation of end-of pipe measures as processing and treatment of livestock manure are made compulsory. Approximately half of Brittany is included in the ZES.

Furthermore, a program had been set up in which all farms could pay a graduated pollution tax. This affects the larger farms since 2000 and the smaller farms since 2001 and 2002. The amount of the tax charged depends on the degree of pollution, equipment used, manure

² One livestock equivalent (LE) corresponds to one fattening pig. A sow or a boar corresponds to 3 LE and a piglet to 0.2 LE.

storage, manure use and scale of production. In 2002, it could be based partly on nitrogen levels.

3. Evaluation of the competitiveness and manure management of French pig farms: a DEA modelling.

The Data Envelopment Analysis approach is a nonparametric mathematical programming approach. This method explicitly includes the inefficient use of resources. It allows for defining a best-practice frontier on the most efficient firms and then, an individual inefficiency measurement can be defined which describes the distance of each observation in the data set from the best-practice frontier (Farrell, 1957; Charnes *et al.*, 1978). In this paper, we extend previous studies by taking into account that agricultural production creates polluting emissions (Färe *et al.* 2001; Chung *et al.*, 1997) and by distinguishing productive efficiency measurements between an intra-system efficiency and a structural efficiency (Maudos *et al.*, 2000). These measurements allow for studying the efficiency of the main French pig farming activities at an individual level and for studying the efficiency of the pig sector.

3.1. Modelling technology with polluting emissions

Generally, agricultural production analysis is concerned with describing the relationships that characterise the transformation of inputs as, land, labour or purchased materials, into marketable outputs as, wheat, milk or meat. Such outputs are designed as desirable in the sense that they are demanded by consumers and yield utility in consumption. However, agricultural products processes also create outputs which society deems undesirable because they yield disutility in consumption. These bad outputs as, ground and surface water contamination, runoff and leaching of nitrogenous fertilisers and pesticides or greenhouse gas emissions to the atmosphere, impose costs. These costs can be either in monetary terms when, for example, water supply companies are faced with the cost of removing contaminants from supplies or in indirect terms such as rural landscape damages.

To be formal, let us denote the good outputs by $y \in R_+^M$, the undesirable or bad outputs by $b \in R_+^S$ and inputs by $x \in R_+^N$. Then, the technology can be described in a very general way via the output set:

$$P(x) = \{(y, b) : x \text{ can produce } (y, b)\} \quad (1)$$

In words, for each input vector x , the output set $P(x)$ consists of all the combinations of good and bad output vector (y, b) that can be produced by the input vector. Following Färe *et al.*(1994), we model the idea that it is costly to reduce the bad outputs by imposing the assumption of weak disposability of undesirable outputs as:

$$(y, b) \in P(x) \text{ et } 0 \leq \theta \leq 1 \text{ imply } (\theta y, \theta b) \in P(x) \quad (2)$$

This assumption states that a reduction in undesirable outputs is feasible only if goods are simultaneously reduced, given a fixed level of inputs. This means that abatement uses resources that otherwise could have been used to expand pig production. In addition, we

assume that the good or desirable outputs are freely disposable which means that good outputs may be reduced without the reduction of the undesirable outputs.

$$(x, y) \in P(x) \text{ et } y' \leq y \text{ imply } (y', b) \in P(x) \quad (3)$$

The basis problem with pollution is that the production of goods such pig meat is accompanied by the joint production of undesirable by-products such as manure. The notion of joint production of good and bad outputs is modelled by:

$$\text{if } (y, b) \in P(x) \text{ and } b = 0 \text{ then } y = 0 \quad (4)$$

This means that no undesirable outputs are produced ($b=0$) only if none of the good outputs are produced ($y=0$). Alternatively, if some good outputs are produced then some bad outputs must also be produced.

We assume that there are $k=1, \dots, K$ observations of inputs and outputs (x_k, y_k, b_k) . Following Färe *et al.* (1994), we can construct an output set that satisfies above conditions:

$$P(x) = \left\{ (y, b) : \begin{aligned} \sum_{k=1}^K z_k y_{km} &\geq y_m \quad m = 1, \dots, M \\ \sum_{k=1}^K z_k b_{ks} &= b_s \quad s = 1, \dots, S \\ \sum_{k=1}^K z_k x_{kn} &\geq x_n \quad n = 1, \dots, n \\ z_k &\geq 0 \quad k = 1, \dots, K \end{aligned} \right\} \quad (5)$$

In this DEA formulation, the inequalities for inputs and desirable outputs in (5) make them freely disposable. The undesirable outputs are modelled with equalities; this makes them weakly disposable. Furthermore, the intensity variables $z_k, k=1, \dots, K$ are taken to be nonnegative. This imply that the production technology (5) exhibits constant returns to scale (CRS).

3.2. Individual productive efficiency measurement

A noticed above, desirable outputs are credited positively by society since they increase utility in consumption while undesirable outputs are credited negatively since they involve either monetary costs or indirect disutility in consumption or in health. Thus, the productive efficiency measurement used herein is defined in a sense that allows for the possibility of crediting firms for the reduction of undesirable outputs and expansion of desirable outputs by using a directional output distance function. Following Chung *et al.* (1997), it is defined as:

$$\bar{D}_o(x, y, b) = \sup \{ \beta : (y, b) + \beta g \in P(x) \} \quad (6)$$

where g is the vector of direction in which outputs are scaled. In our case, the good and bad outputs are treated asymmetrically, thus $g = (y, -b)$. β is the maximum feasible expansion of the desirable outputs and contraction of the undesirable outputs in identical proportions for a given level of inputs.

For each observation, the directional distance function is computed as the solution to a linear programming problem. For example, for k' ,

$$\begin{aligned}
\bar{D}_o(x_{k'}, y_{k'}, b_{k'}; y_{k'}, -b_{k'}) &= \max \beta \\
s.t. \quad \sum_{k=1}^K z_k y_{km} &\geq (1 + \beta) y_{k'm} \quad m = 1, \dots, M \\
\sum_{k=1}^K z_k b_{ks} &= (1 - \beta) b_{k's} \quad s = 1, \dots, S \\
\sum_{k=1}^K z_k x_{kn} &\geq x_{k'n} \quad n = 1, \dots, n \\
z_k &\geq 0 \quad k = 1, \dots, K
\end{aligned} \tag{7}$$

Thus, the individual productive efficiency measure ($IPE = 1 + \beta$) under constant returns to scale (CRS), also called the overall technical efficiency measure, is obtained by solving the above linear programming model. The vector of weights z is attached to each of the efficient observations and allows for characterising benchmark peers. A separate linear programming problem is solved to obtain the IPE score for each observation in the sample. If $IPE = 1$, the observation is on the best-practice frontier and is efficient under CRS. The observation is one of the benchmark peers of the sample. If $IPE < 1$, the observation lies below the best-practice frontier and is inefficient relatively to benchmark peers.

3.3. Intra-farming system and structural efficiency measurements

There is various way of producing pig meat in France. Some farms are specialised in pig production while others are crop, beef or dairy producers. In the latter case, pig production is only one additional activity on farms. Furthermore, the scale of production of these farms is very large. It ranges from small size to very-large size as noticed by XXX *et al.*, 2003. It is also obvious that providing productive efficiency measurements for the pig sector is complicated. Most of the time, the sector analyses consider an aggregate product from aggregate inputs and study the aggregate inefficiency by defining an aggregate best-practice frontier. The multiproduct nature of the pig sector is ignored. To measure correctly the productive efficiency of the pig sector, the paper considers the existence of different systems of pig production, each one with different technologies and different degrees of inefficiency. By doing this, our analysis allows for defining two sources of inefficiency at the sector level: the intra-system inefficiency which is associated with deficient use of resources allocated to each pig farming system and the structural inefficiency which is due to incorrect allocation of resources among systems given their particular technologies of production. According to the latter component of productive efficiency, the pig sector can gain efficiency simply by decreasing the weight of pig farming systems in the sector with the less productive technology and vice versa.

In our DEA context, these measurements are defined by using the direction output distance function developed in Chung *et al.* (1997). Firstly, the productive inefficiencies in each pig farming system are obtained by implementing the linear programming defined in (7). Secondly, we calculate, the aggregate level of production that could have been achieved by each pig farming system if they were efficient. This step enables us to measure the true productive efficiency of the pig sector and to divide this measurement into the part of

inefficiency that is due to unsuitable productive specialization at the sector level and the other part that is due to inefficient use of the resources allocated to each pig farming system. This breakdown allows us to analyze the contribution of productive efficiency and of each of its components to the evolution of the pig production structure among the actual farming systems.

Let us assume that there is R pig farming systems. The aggregate output of the pig sector ($Y \in R_+^M$) is obtained as a sum of the outputs of each pig farming system in the sector:

$$Y = \sum_{r=1}^R Y_r = \sum_{r=1}^R \sum_{j=1}^J y_{rj} \quad (8)$$

As noticed above the aggregate best-practice frontier should not be obtained from data of aggregate production. The efficient aggregate production at the sector level is obtained as the sum of the pig farming system outputs once the inefficiencies in each of them had been eliminated:

$$\hat{Y} = \sum_{r=1}^R \hat{Y}_r = \sum_{r=1}^R \sum_{j=1}^J y_{rj} \beta_{rj} \quad (9)$$

where β_{rj} is the inefficiency of each farm j from the pig farming system r previously calculated in (7). Being efficient in each production system does not guarantee being efficient in aggregate production level since it could subsist an inefficiency associated with the sector composition. Being efficient at the sector level implies being efficient in each and every production system (intra-system efficiency) and having a efficient structure of production at the sector level (structural efficiency).

Thus, for each pig farming system, the total productive efficiency (*TPE*) measurement is obtained by solving the following linear programming problem. For example, for r' ,

$$\begin{aligned} TPE_{r'} &= \bar{D}_o(X_{r'}, Y_{r'}, B_{r'}; Y_{r'}, -B_{r'}) = \max \beta_{r'} \\ \text{s.t.} \quad &\sum_{r=1}^R \lambda_r \hat{Y}_{rm} \geq (1 + \beta_{r'}) Y_{r'm} \quad m = 1, \dots, M \\ &\sum_{r=1}^R \lambda_r \hat{B}_{rs} = (1 - \beta_{r'}) B_{r's} \quad s = 1, \dots, S \\ &\sum_{r=1}^R \lambda_r X_{rn} \geq X_{r'n} \quad n = 1, \dots, n \\ &\lambda_r \geq 0 \quad r = 1, \dots, R \end{aligned} \quad (10)$$

and the structural efficiency measurement by solving the following linear programming problem:

$$\begin{aligned}
STE_{r'} &= \bar{D}_o(X_{r'}, Y_{r'}, B_{r'}; Y_{r'}, -B_{r'}) = \max \beta_{r'}^{STE} \\
s.t. \quad &\sum_{r=1}^R \lambda_r \hat{Y}_{rm} \geq (1 + \beta_{r'}^{STE}) \hat{Y}_{r'm} \quad m = 1, \dots, M \\
&\sum_{r=1}^R \lambda_r \hat{B}_{rs} = (1 - \beta_{r'}^{STE}) \hat{B}_{r's} \quad s = 1, \dots, S \\
&\sum_{r=1}^R \lambda_r X_{rn} \geq X_{r'n} \quad n = 1, \dots, n \\
&\lambda_r \geq 0 \quad r = 1, \dots, R
\end{aligned} \tag{11}$$

Finally, the intra-farming system efficiency measurement can be derived from:

$$ISE = \frac{TPE}{STE} \tag{12}$$

4. Data

The data set is drawn from the Farm Accountancy Data Network (FADN) for France and covers the production year from 1996 to 2000. The FADN is an annual survey of farms that is stratified according to region, economic size and type of farming. A sub-sample of farms with a pig farming activity was extracted from this data set to form an unbalanced panel of around 600 individuals per year (3,000 observations).

4.1. Main French pig farming systems

In order to obtain a structural information on main pig farming systems in France, an Explanatory Data Analysis was implemented. The extraction of this structural information from the data set had provided different clusters of farms with a homogenous productive structure, built on three items : intensity of production (production per hectare), intensity of labour (production per worker) and diversity of production (level of specialization in pig production). A classification in 8 classes was obtained. The statistical stability of the classification was confirmed by an Evolutionary Data Analysis over the time period 1996-2000. Then, a Discriminant Analysis was applied for allocating each farm in a cluster (XXX *et al.*, 2003). This classification is presented in Table 1.

Table 1. Classification of French farms with a pig farming activity in 8 classes

Class 1	Large-scale farms specialized in crop production
Class 2	Medium-scale farms specialized in crop production
Class 3	Very large-scale farms specialized in pig production
Class 4	Large-scale farms specialized in pig production
Class 5	Medium-scale farms specialized in pig production
Class 6	Large-scale farms specialized in dairy production
Class 7	Small-scale farms specialized in beef and dairy production
Class 8	Small-scale farms specialized in beef production

French pig production is provided by different types of farming systems. Production specialisation of farms are pig, crop, beef or dairy production. The scale of the production activity ranges from small to very large farms. Thus, this classification highlights the diversity of pig farming systems in France. Furthermore, this classification of the data set in homogeneous clusters of farms allows us to implement a *Data Envelopment Approach* on each cluster since they describe homogeneous productive structures.

4.2. Description of DEA variables

In this analysis, we consider only one desirable output: the total production of each farm (y) which is a catch-all variable defined as revenue derived from all farm enterprises. Livestock and crop products used on farm are deducted from this variable.

Four inputs are considered: agricultural land (x_1) which is defined as total utilised agricultural area (in hectares) for each farm; livestock herd (x_2) which represents the size of the livestock farming activity (in livestock units) of the farm; Labour which is defined as total annual worker units (x_3); and variables costs (x_4) which is made up of annual expenditure for crop and livestock production.

Only one undesirable output is represented within this modelling. It is defined as an estimate of excess nitrogen (b). Individual nitrogen balances are constructed by using estimates of flows of nitrogen across the farm boundary. It is a tool used to provide insight into flows of nitrogen. Mineral balances are defined as the difference between input and output flows. Input flows compare: nitrogen from inorganic fertilisers; nitrogen from organic manure (exclusive of losses due to emissions of ammonia); and nitrogen by deposition from the atmosphere. Output flows include the uptake of harvested crops and livestock sold (Meisinger and Randall, 1991).

5. Main results

The average values for the individual productive efficiency measurements which are based on the directional distance functions as specified in (7) are reported in Table 2. Due to a problem of sample size relatively to DEA model size, farms from class 3 have been grouped with farms from class 4 which are the most similar in terms of size, productive specialization and technological processes.

On average, the *individual productive efficiency* in our sample is 1.175. Thus, desirable outputs (total production) can be increased from around 17 % jointly with a decrease in the production of undesirable outputs (nitrogen emissions) from the same amount. This results is variable along the time period. On average, the most efficient years were 1996 and 2000 with an inefficiency rate of 15 %. The most inefficient year was 1998 with a rate of 20 %. These last results reflect the economical context of production. The time period 1996-2000 corresponds to the higher part of the pig production cycle. From 1996 to 1998, producers were affected by a very important decrease in production prices. Prices are so low that production costs were not covered. Furthermore, a more restrictive environmental regulation was implemented in France in 1998. It affects the most polluted areas from France (ZES), with the most intensive and concentrated pig production systems, mainly the western part of France.

Among the productive systems, the most efficient one is, on average, the type 5 (pig producers with medium-sale farms) with an inefficient rate of 8 %. A good performance is obtained by farms from class 1 (crop producers with large-scale farms) and from class 3 and 4 (pig producers with very large and large-scale farms) with an inefficient rate of 11 %. Thus, the most efficient farms are those specialised in pig or crop production with a relatively large-scale of production. At the opposite, the less efficient farms are those from class 7 with a mixed activity of beef and dairy production, from class 8 with a beef production activity and from class 2 with a crop production activity. These three types of farms have in common a small-sale of production. Thus, large pig farms seem enjoying competitive advantages of scale while small-scale pig farms seem to be more affected by costs imposed on producers by manure management regulations.

Intra-pig farming system efficiency (ISE) measurements indicate the percentage increase of production that each farming system could achieve if it were efficient within each farm. They are presented in Table 3. The pig farming system with the lowest intra efficiency score is the number 8, small-scale farms specialized in beef production. Thus, a reduction in efficiency in this productive class, which is among the most inefficient one at the individual level (see, Table 2), will induce at the sector level an increase of around 11 % of the total production simultaneously with a decrease of manure emissions from the same amount. At the opposite, farms from class 1 (large-scale farms specialized in crop production) which are among the most efficient at the individual level, could, on average, increase desirable outputs jointly with a decrease in undesirable outputs of 48 % by reduction of their inefficiency. Thus, the potential impact of these farms on the improvement of competitiveness of the French pig sector under manure management regulation is more important.

Furthermore, we can notice that the year 1998 had an impact on intra-system efficiency. The change in the economic context of production and in the environmental regulation has induced improvement of farms' efficiency. The additional cost involved by production price decrease and by manure management regulation was best integrated by the largest-scale farms of the sample than by the smallest-scale ones.

Structural efficiency (STE) measurements indicate the percentage increase of production that can be obtained by modifying in the best possible way the productive specialisation of each pig farming system. Over the entire time period, mixed farms with crop and pig production are the most efficient. Due to the joint management of confined animal manure and plant nutrient needs, animal manure can provide a valuable nutrient source for crop growth. The more intensive pig rearing activities are the less efficient. Without any technical or manure management change, it would be difficult for these farms to increase their production level with a joint decrease of their environmental impact.

After the year 1998, farms from class 8, small-size farms specialised in beef production are more efficient than farms specialised on pig production whatever their size. In modifying their productive specialisation, they can contribute to an average increase of 16 % to the pig sector production while farms from classes 3 and 4, large and very large-scale farms specialised in pig production, can contribute for 80 %. This last result is very high but it highlights a very important point which is the high environmental restriction on these pig farming systems. As they produce a high level of production on a very small land area, they can contribute to the competitiveness of the pig sector. However, as there exists constraints on manure spreading and in general, on manure management, a change of their productive specialisation would be a real advantage to expand production without pollution increase.

Total productive efficiency (TPE) measurements, which is the product of intra-system efficiency and structural efficiency, represents the potential increase in output that the pig sector could obtain by elimination both the inefficiency with which it operates in each pig farming system (intra-pig farming system efficiency, *ISE*) and that resulting from the choice of an inefficient specialisation (structural efficiency, *STE*). The levels of total productive efficiency whose values appear in Table 4 show that at the beginning of the time period (1996), only farms from class 1, large-sale farms specialized in crop production, appear to be efficient. With the change in the economic context, mainly the fall in production prices, this advantage disappear. After the year 1998 and the implementation of a more stringent environmental regulation on rearing activities in manure surplus zones (ZES), farms specialised in crop production and in beef production become efficient. These farms have the higher land area of the different farming systems, thus the change in the regulation does not involve an incitation for production improvement mainly in manure management as higher as for the other productive systems.

Table 2. Individual productive efficiency (*IPE*) measurements

Pig farming systems:	1996	1997	1998	1999	2000	<i>Mean</i>
1: Large-scale farms specialized in crop production	1.109	1.163	1.208	1.256	1.082	<i>1.116</i>
2: Medium-scale farms specialized in crop production	1.200	1.177	1.216	1.288	1.184	<i>1.213</i>
3 and 4: Large and very large-scale farms specialized in pig production	1.081	1.110	1.133	1.072	1.111	<i>1.110</i>
5: Medium-scale farms specialized in pig production	1.065	1.113	1.053	1.080	1.090	<i>1.080</i>
6: Large-scale farms specialized in dairy production	1.100	1.181	1.192	1.165	1.153	<i>1.158</i>
7: Small-scale farms specialized in beef and dairy production	1.273	1.298	1.393	1.256	1.275	<i>1.299</i>
8: Small-scale farms specialized in beef production	1.263	1.182	1.252	1.205	1.197	<i>1.219</i>
<i>Mean</i>	<i>1.156</i>	<i>1.175</i>	<i>1.207</i>	<i>1.189</i>	<i>1.156</i>	<i>1.175</i>

Table 3. Intra-pig farming system efficiency (*ISE*) and structural efficiency (*STE*) measurements

Pig farming systems:	<i>ISE</i>						<i>STE</i>					
	1996	1997	1998	1999	2000	<i>Mean</i>	1996	1997	1998	1999	2000	<i>Mean</i>
1: Large-scale farms specialized in crop production	1.000	1.748	1.883	1.770	1.000	<i>1.480</i>	1.000	1.000	1.000	1.190	1.000	<i>1.038</i>
2: Medium-scale farms specialized in crop production	1.121	1.015	1.877	1.000	1.000	<i>1.202</i>	1.371	1.382	1.877	1.000	1.000	<i>1.326</i>
3 and 4: Large and very large-scale farms specialized in pig production	1.000	1.163	2.650	1.000	1.000	<i>1.362</i>	1.310	1.664	2.491	2.010	1.725	<i>1.840</i>
5: Medium-scale farms specialized in pig production	1.000	1.000	2.246	1.000	1.000	<i>1.249</i>	1.610	1.705	2.246	2.308	1.133	<i>1.800</i>
6: Large-scale farms specialized in dairy production	1.057	1.000	1.456	1.086	1.165	<i>1.153</i>	1.342	1.993	1.456	1.670	1.373	<i>1.567</i>
7: Small-scale farms specialized in beef and dairy production	1.192	1.265	1.440	1.441	1.200	<i>1.307</i>	1.000	1.011	1.000	1.248	1.407	<i>1.133</i>
8: Small-scale farms specialized in beef production	1.038	1.038	1.463	1.000	1.000	<i>1.108</i>	1.366	1.000	1.463	1.000	1.000	<i>1.166</i>
<i>Mean</i>	<i>1.107</i>	<i>1.176</i>	<i>1.859</i>	<i>1.185</i>	<i>1.052</i>	<i>1.276</i>	<i>1.286</i>	<i>1.394</i>	<i>1.648</i>	<i>1.489</i>	<i>1.234</i>	<i>1.390</i>

Table 4. Total productive efficiency (*TPE*) measurements

Pig farming systems:	1996	1997	1998	1999	2000	<i>Mean</i>
1: Large-scale farms specialized in crop production	1.000	1.748	1.883	2.106	1.000	<i>1.547</i>
2: Medium-scale farms specialized in crop production	1.537	1.404	1.877	1.000	1.000	<i>1.363</i>
3 and 4: Large and very large-scale farms specialized in pig production	1.310	1.935	2.650	2.010	1.725	<i>1.926</i>
5: Medium-scale farms specialized in pig production	1.610	1.705	2.246	2.308	1.133	<i>1.800</i>
6: Large-scale farms specialized in dairy production	1.418	1.993	1.456	1.814	1.600	<i>1.656</i>
7: Small-scale farms specialized in beef and dairy production	1.192	1.279	1.440	1.798	1.688	<i>1.479</i>
8: Small-scale farms specialized in beef production	1.881	1.038	1.463	1.000	1.000	<i>1.276</i>
<i>Mean</i>	<i>1.421</i>	<i>1.586</i>	<i>1.859</i>	<i>1.719</i>	<i>1.306</i>	<i>1.578</i>

6. Conclusions

The aim of the paper is to provide an evaluation of the competitiveness of the French pig sector together with an improvement in manure management. A nonparametric frontier analysis which allows efficiency benchmarking, called Data Envelopment Analysis (DEA), is used. The efficiency evaluation is implemented in both economic and environmental terms. As the livestock sector is highly constraint by environmental regulation in the European Union, the DEA models used in this paper take into account the fact that animals produce manure. An undesirable output is introduced in the specification of the best-practice frontier and performance benchmarks are defined in a direction that allows for a production increase jointly with a pollution decrease. The use of the directional efficiency measurement allows us to evaluate improvements of the competitiveness of farms that can be achieved without increase of pollution.

Furthermore, a productive efficiency measurement is defined which enables two components to be differentiated: one associated with the degree of efficiency within each French pig farming system called intra-system efficiency and another associated with the structure of production in the pig sector called structural or composition efficiency. The former component captures gains that can be achieved both from a competitive and environmental point of view if all farms in each pig farming system improve their productive efficiency. This latter component shows gains that result from structural changes in the productive specialisation of the French pig sector.

These results provide an illustration of the potential evolution of the French pig sector. At the individual level, large pig farms seem enjoying competitive advantages of scale while small-scale pig farms seem to be more affected by costs imposed on producers by manure management regulations. They have less production across which to spread the cost of standard regulations. However, at the sector level, farms with the highest land area are the more efficient. This point highlights the impact of environmental regulations, mainly by the targeted limit on the application of animal manure specified in the Nitrate Directive, which set a maximum rate of 170 kg of nitrate per hectare and of all manure management restrictions. Concerning the structural efficiency of farms, mixed farms with crop and pig production are more efficient. Due to the joint management of confined animal manure and plant nutrient needs, animal manure can provide a valuable nutrient source for crop growth. The most intensive pig rearing activities are less efficient. Without any technical or manure management change, it would be difficult for these farms to increase their production level with a joint decrease of their environmental impact.

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