Nitrate pollution control policy and its impact on Farm's performance: A nonparametric approach

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Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, July 24-27, 2005

Abstract

The purpose of this paper is to develop models with an individual and a collective management of the European Nitrate directive. The objective is to compare productive efficiency of farms under the two regimes. First, we develop a model that explicitly integrate the individual constraint on organic manure spreading. The individual threshold is introduced as a productive right. Then, we develop a framework that allows for modelling exchange of productive rights among producers. The simulation of a management of the spreading constrainst on organic manure at the regional level give an estimate of the potential gains that can be realised by allowing a collective maagement of the European environmental regulation. Models are based on a nonparametric frontier approach (Data Envelopment Analysis). An illustration is provided on a sample of farms from the French pig sector. Results highlights gains that would have been made if collective management had been allowed instead of an individual regulation as stated in the Nitrate directive.

Key words

Environmental regulations, Manure management, pig farming, Data Envelopment Analysis.

JEL Classification

C61, D21, Q12, Q52

1. Introduction

In Europe, water quality problems associated with the use of synthetic fertilizers and the disposal of animal wastes have become a major environmental policy issue in many countries. Nitrates in drinking water supplies and eutrophication of inland and coastal waters are especially of concern. High levels of nitrate in water may adversely affect human health as well as the metabolism of livestock. Increasing concentrations of nitrates in groundwater, the primary source of drinking water in many regions, have been observed, notably in France. Agriculture is not the only source of nitrates in ground and surface waters but it is one of the most concern. There is widespread interest in implementing policies that will be more effective in protecting water quality without causing undue economic harm to agricultural producers.

The two farming practices that most concern policy makers are the use of large amounts of fertilizers for crop growth and the disposal of livestock manure. Both materials are sources of nitrogen, which transformed into nitrate once in the soil. Nitrate that is not used by plants or transformed back into atmospheric nitrogen leaches through the soil or runs off into water supplies. 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 specialized with feed obtained from off-farm sources and often with very little land. Developments in production technologies have allowed significant productivity gains, particularly for large-scale producers. Pig farming have became 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.

In response to high levels in water supplies, the European Union passed its Nitrate directive in 1991. Its objective is to limit the amount of nitrogen remaining in the soil as a residual after uptake by crops. The directive limits the spreading of organic nitrogen per farm to 170 kilograms per hectare in the vulnerable zones. The implementation of this directive have been organized by each European member states. They have defined a set of constraints relevant for thier own country on the use of nitrogen fertilizer, the numbers of livestock, and the storage and disposal of manure. In France, this implementation is effective since 1993.

The purpose of this paper is to analyze the impact on farm performance of the Nitrate directive, mainly the mandatory threshold on the spreading of organic manure. In the first step, we construct a nonparametric frontier model that explicitly integrate the individual constraint from the Nitrate directive on manure spreading. This individual threshold is considered as a productive rights allocated to each farmer. In regards with the activity of each farm some of them are highly constraint while some others are not. The question is to consider how producer will individually adapt their production activity both to fulfil the regulation and to maintain their activity in a good economic performance level. Then, in a second step, we built a model at a regional level that integrates the same constraint on the spreading of organic manure but allowing for trading of production rights among producers. The question is how producers from a specific region will fulfil the regulation if they “collectively” manage their productive rights. The aim is to evaluate the impact of a collective manure management on the individual and regional performance of farms through potential gains that can be made from a trading of productive rights, i.e., of spreading rights.

Nonparametric frontier models are constructed that explicitly introduces the constraint of 170 kg/ha of organic manure. A distance function is used for the measurement of productive efficiency. For an illustrative purpose, the empirical application is made on a sample of French farms with a pig farming activity in 1996 and located in Brittany. Results suggest potential gains that can be achieved if productive right trading or exchange is used instead of individual rights to achieve the same total spreading target. The paper is organised as follows. The theoretical framework is developed in section 2. Then, we turn to the data set and the presentation of the empirical model in section 3. Results are report in section 4. Section 5 concludes the paper.

2. The individual and collective models

In this section, we explicitly set up the models we use. In a first step, we define the individual model uses to evaluate production efficiency of individual farms constrained to fufil the European Nitrate directive. In a second step, we define a model where the constraint is “collectively" manage among a group of farms located in a same region. This simulation would allow us to evaluate gains resulting from an evolvement of the European regulation on manure mangement from an individual setting by allowing trade of spreading rights between producers who are binding or not the individual constraint on organic manure.

As mentioned in the introduction, the approach we take is based on the frontier framework. This approach explicitly recognizes that some farms are more efficient than others in production and allows for a representation of jointness in production between desirable outputs and pollution. Here, we denote inputs by $x=(x_1,...,x_N)\in R_+^N$, good or desirable outputs by $y=(y_1,...,y_M)\in R_+^M$, and undesirable or bad outputs by $b=(b_1,...,b_S)\in R_+^S$. The technology, expressed by the output sets, consists of all feasible input-output vectors as

$$P(x)=\{(y,b): x \text{ can produce } (y,b)\},\ x\in R_+^N \tag{2.1}$$

In order to adress the fact that the reduction of bad outputs is costly, we impose weak disposability of outputs, i.e.,

$$(y,b)\in P(x)\ \textit{then}\ (\theta y,\theta b)\in P(x)\ \textit{for}\ 0\le\theta\le 1 \tag{2.2}$$

Thus, a reduction of undesirable outputs can be attained by the reduction of goods given fixed input level. This assumption models the idea that diposing of the bads is not a free activity, but it requires giving up some of the good outputs or increasing some of the inputs. In addition to imposing weak disposability, we assume that the desirable outputs are freely disposable, i.e.,

$$(y,b)\in P(x)\ \textit{and}\ y'\le y\ \textit{imply}\ (y',b)\in P(x) \tag{2.3}$$

The production technology is assumed to produce both desirable and undesirable outputs and it is assumed that it cannot produce one without the other (joint-production of the output and the bads)

$$\textit{if}\ (y,b)\in P(x)\ \textit{and}\ b=0\ \textit{then}\ y=0 \tag{2.4}$$

The regulatory constraint facing the farms is quantitative in nature, i.e., organic manure is restricted in quantity. However, organic is not the undesirable output which in our case, is manure surplus. Thus, the quantitative constraint applies only to one component of the nutrient balance. Formally, the manure surplus is defined as:

$$b=b_{Norg}+b_{N\min}-b_{N\exp} \tag{2.5}$$

where b_{Norg} is the level nitrogen from organic manure, $b_{N\min}$ the level of nitrogen from mineral fertilizers and, $b_{N\exp}$ the level of nitrogen that are uptaken by crops on fields. The nitrate directive regulation concerning organic manure can be written as follows:

$$b_{Norg} \leq 170 * land \tag{2.6}$$

where *land* is the total area of the farm which can be used for disposal of manure. Thus, the following constraint have to be introduced in the representation of the production technology as defined by (2.1).

In order to assess farm's production efficiency, we use an output directional distance function:

$$D_o(y,b,g) = \sup\{\beta : ((y,b) + \beta.g \in P(x)\} \tag{2.7}$$

By construction, $D_o(y,b,g) \geq 1$ if and only if $(y,b) \in P(x)$. When $D_o(y,b,g) = 1$ the farm is on the boundary of the production set and thus, is employing to construct the frontier technology. The directional output distance takes *(y,b)* in the *g* direction and places it on the production frontier. In our case, the *g* vector is defined as (1,0). Thus, an increase in output is requied.

Futhermore, we assume that there are *k=1,..., K* observations of inputs and outputs and we model the reference technology by using a piece-wise linear programs:

$$\begin{aligned}
P(x) = \{(y,b) : & \sum_{k=1}^{K} z_k y_{km} \geq (1+\beta_{'}^{170}) y_m \quad m = 1,\dots,M \\
& \sum_{k=1}^{K} z_k b_{ks} = b_s \quad s = 1,\dots,S \\
& \sum_{k=1}^{K} z_k x_{kn} \leq x_n \quad n = 1,\dots,N_v \\
& \sum_{k=1}^{K} z_k x_{kn} \leq x_n \quad n = N_v + 1,\dots,N \\
& z_k \geq 0 \quad k = 1,\dots,K \\
& b_s = b_{Norg} + b_{N\min} - b_{N\exp} \\
& b_{Norg} \leq 170 * x_{land} \}
\end{aligned} \tag{2.8}$$

where N_v is the number of variables inputs. The *z*'s are intensity variables which serve to construct the reference technology as convex combinations of the observed data. The equality in the constraint on undesirable outputs in the above equation is based on the assumption that bad outputs are weakly disposable. The program defines the production frontier using the observed combinations of inputs and outputs *(x,y,b)* to evaluate inefficiency of individual farms. To formulate the farm *k'* specific efficiency measurement problem, we calculate for each *k'=1,...,K* the following linear programming problem:

$\min \beta_{k'}^{170}$

s.c.

$$\begin{aligned}
&\sum_{k=1}^{K} z_k y_{km} \geq (1+\beta_{k'}^{170}) y_{m,k'} \quad m = 1,\ldots,M \\
&\sum_{k=1}^{K} z_k b_{ks} = b_s \quad s = 1,\ldots,S \\
&\sum_{k=1}^{K} z_k x_{kn} \leq x_n \quad n = 1,\ldots,N_v \\
&\sum_{k=1}^{K} z_k x_{kn} \leq x_{n,k'} \quad n = N_v + 1,\ldots,N \qquad (2.9) \\
&z_k \geq 0 \quad k = 1,\ldots,K \\
&b_s = b_{Norg} + b_{N\min,k'} - b_{N\exp,k'} \\
&b_{Norg} \leq 170 * x_{land,k'}
\end{aligned}$$

In the model, b_s and x_n are variable. b_s represents the level of the individual farm manure surplus that can be realized in the context of the nitrate regulation and x_n the level of variable inputs that can be adjusted.

Now in a second step, we want to simulate a collective management of the Nitrate directive. The constraint of 170 kg/ha is not applied at an individual level but at an aggregate one. We assume that the fulfillement of the constraint is achieved by a group of farms from a same region or production area. This allows us to calculate the socially optimal allocation of productive rights among the farms of the group. We have to solve the following linear programming problem where the objective is to optimize the average efficiency of the group of farms:

$$\begin{aligned}
&\min \beta^{170} = \sum_{k'=1}^{K} \beta_{k'}^{170} \\
&\text{s.c.} \\
&\mathit{Pour}\ k' = 1 \\
&\sum_{k=1}^{K} z_k^1 y_{km} \geq (1+\beta_{k'}^{170}) y_{1m} \quad m = 1,\ldots,M \\
&\sum_{k=1}^{K} z_k^1 b_{ks} = b_s^1 \quad s = 1,\ldots,S \\
&\sum_{k=1}^{K} z_k^1 x_{kn} \leq x_n^1 \quad n = 1,\ldots,N_v \qquad (2.10) \\
&\sum_{k=1}^{K} z_k^1 x_{kn} \leq x_{1n} \quad n = N_v + 1,\ldots,N \\
&z_k^1 \geq 0 \quad k = 1,\ldots,K \\
&b_s^1 = b_{Norg}^1 + b_{1,N\min} - b_{1,N\exp} \\
&\vdots
\end{aligned}$$

$$Pour\ k' = K$$

$$\sum_{k=1}^{K} z_k^K y_{km} \geq (1+\beta_{k'}^{170}) y_{Km} \quad m = 1,...,M$$

$$\sum_{k=1}^{K} z_k^K b_{ks} = b_s^K \quad s = 1,...,S$$

$$\sum_{k=1}^{K} z_k^K x_{kn} \leq x_n^K \quad n = 1,...,N_v$$

$$\sum_{k=1}^{K} z_k^K x_{kn} \leq x_{kn} \quad n = N_v + 1,...,N$$

$$z_k^K \geq 0 \quad k = 1,...,K$$

$$b_s^K = b_{Norg}^K + b_{K,N\min} - b_{K,N\exp}$$

$$\sum_{k'=1}^{K} b_{Norg}^{k'} = 170 * \sum_{k'=1}^{K} x_{land,k'}$$

In the above model, the b_s are variable. They represent the allocation of the individual farm manure surplus among the farms in the group when a collective management of manure is possible.

3. Data and results

Data for conducting this research are drawn from the Farm Accountancy Data Network (FADN) data set. The sample consists of farms with a pig farming activity in 1996 located in Brittany, a part of France which produces most of the French pig production. To implement this appraoch, a frontier technology is built with one desirable output (gross output), one bad output (manure surplus) and four inputs (land, livestock, labour and variable inputs). Summary staitistics for those variables are reported in Table 1.

Table 1. Summary statistics for inputs and outputs

	Mean	St. Dev.	Minimum	Maximum
Good output (€)	259 841.96	168 156.88	24 644.15	893 510.40
Bad output (kg)	5 196.37	4 791.32	-14 370.66	20 240.81
Land (ka)	45.90	2 0.95	5.61	115.42
Livestock (Lu)	24 403.15	18 826.54	2 577.80	108 433.00
Labour (Awu)	185.45	74.62	81.82	418.18
Variable inputs (€)	161 417.64	110 292.35	15 874.52	606 868.59
Organic manure(kg)	7 526.56	4 073.98	882.18	27 093.22
Mineral manure (kg)	6 083.39	4 255.88	0.00	20 747.25
Exportation (kg)	8 413.59	4 635.10	1 012.50	25 615.00
Manure surplus (kg)	5 196.37	4 791.32	-14 370.66	20 240.81

In the sample, 125 farms (60 %) are offers of spreading areas for an amount of 6 621 ha because they do not bind the individual constraint of 170 kg of organic manure per hectare while 83 of them are demanders of spreading areas (40 %) for an amount of 2 928 ha.

The results from applying the individual and the collective models are displayed in table 2. We note that there is a clear improvement in productive efficiency between the individual regulatory regime and the simulated collective one. The difference between these two measurements can be interpreted as the cost of using an inefficient regulatory scheme or as the cost of a more stringent environmental policy (the individual regulation).

Table 2. Productive efficiency of farms under an individual and a collective management of the European Nitrate directive

	Mean	St. Dev.	Minimum	Maximum
Individual management of the constraint				
Efficiency	0.713	0.719	0.000	2.414
Collective management of the constraint				
Efficiency	0.271	0.534	0.000	2.322

4. Conclusions

In this paper, we have developed a framework for calculating the potential gains of a collective management of the European Nitrate directive rather than an individual management, i.e., a system of fixed individual farm regulation. For an illustrative purpose, this framework is applied to a sample of French pig farms located in Brittany. Results highlight an improvement of productive efficiency when we simulate a less stringent regulation which allows for the collective management of pollution rights, i.e., an exchange of spreading areas between producer of the group of farms. The following step of this work will an evaluation of the economic and environmental impact of this change of regulatory.

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