Agricultural externalities and environmental regulation: The case od manure management and spreading land allocation

1 author:

Isabelle Piot-Lepetit
French National Institute for Agriculture, Food, and Environment (INRAE)

Chapter 5. Agricultural Externalities and Environmental Regulation: The Case of Manure Management and Spreading Land Allocation

Isabelle Piot-Lepetit
European Commission, Joint Research Centre (JRC)
Institute for Prospective Technological Studies (IPTS)[1,2]

Abstract: The aim of this paper is firstly to show how the measures introduced by the European regulation on manure management are incorporated into the theoretical analysis framework for studying the issue of nonpoint externality and especially, agricultural runoff. The model is extended because only some of the polluting emissions at the origin of diffuse pollution are regulated by the Nitrates Directive. More specifically, the model represents the standard that limits the spreading of organic manure to 170 kg/ha as a production right assigned to each farm. Secondly, this paper proposes an empirical model in which the theoretical assumption that productive abilities are fully exploited is relaxed. In order to describe the disparity that exists between individual situations, the empirical model represents the production technology by means of a directional distance function. Finally, the aggregation properties of the directional distance function are used to simulate the practice of looking for off-farm lands as a means of complying with the standard. We look at how land can be allocated among producers in such a way as to combine the disposal of manure in accordance with the limit of the Nitrates Directive with an improvement in the productive and environmental efficiency of all farms. Using a sample of French pig farms, results indicate only a low potential for a reduction in nitrogen pollution based on the reduction in productive inefficiencies and the allocation of spreading lands among farmers in a same area.

Introduction

In Europe, nitrogen pollution resulting from agricultural activities is a major threat to the quality of ground, surface and marine waters. Intensive livestock production is an important source of pollution, due to the insufficient area of land available to farmers for spreading manure. This is particularly relevant for pig production. The direct impact on the environment of pig production is really severe in some areas. Along with the expansion of production, there have also been significant structural changes in the pig sector. Pig farming has become more intensive and more regionally concentrated, with fewer farms producing a larger number of pigs often with very little land, and of a more specialized nature with feed obtained from off-farm sources. The disposal of pig manure tends to be driven more by the need to lower disposal costs than by the optimization of the nutrient needs of crops and grassland, at a detrimental cost to the environment. Because pig manure is a low-density nutrient fertilizer source and is more costly to transport over long distances than inorganic fertilizers are, areas of intensive pig production usually have a surplus of manure. This has led to an increase in residual pig manure in the environment in these areas, which can have an adverse effect on water quality and imposes environmental pollution costs on society as a whole.

Policy measures to deal with this problem are predominantly regulatory and are becoming increasingly severe and complex. Aid has been provided to offset the increased costs imposed by regulations, particularly to reduce the level of capital expenditure required to bring production facilities up to the regulatory standard. Regulations seek to influence producer behaviour in a direction that induces environmental benefits for society as a whole (OECD, 2003). In pig production, the main policy instrument introduced in Europe to combat pollution linked to nitrogen from agricultural sources is directive 91/676/CEE, known as the Nitrates Directive. The application of this directive in France got under way in 1994.

The actions to be undertaken were organized into a framework of two programs. These programs called *Programmes de Maîtrise des Pollutions d'Origine Agricole* (programs to control pollution of agricultural origin) or PMPOA were developed by the Ministries for Agriculture and the Environment

[1] Disclaimer: The views expressed are purely those of the author and may not in any circumstances be regarded as stating as official position of the European Commission.
[2] EC-JRC-IPTS, Edificio Expo, C/ Inca Garcilaso, 3, E-41092 Seville, Spain,
Email: isabelle.piot-lepetit@ec.europa.eu

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in consultation with agricultural organizations. The first program of action against nitrates (1994-2000) was aimed at rectifying the most polluting practices, targeting farms in decreasing order of size, while the second (2001-2003) was intendedto bring about changes in these practices so as to protect and even restore water quality. The main measures resulting from these programs were the implementation of more environmentally friendly agricultural practices with regard to soil management, the limitation of the spreading of livestock manure to 170kg of nitrogen per hectare per year and statutory storage durations for livestock effluent.

From the economic perspective, this environmental regulation amounts to granting each producer an individual production right, which is an expression of the 170kg of organic nitrogen per hectare spreading standard. Imposing this type of restriction on agricultural land is equivalent to annexing part of the producer's property rights and assumes that, in the original situation, the property rights were fully allocated to the farmers. Through government intervention in the use of private land, it implies a reallocation of a certain proportion of the set of property rights from producers to society. It thus implies that determining the most efficient scale of production is no longer an exclusively private decision and that it is now constrained by regulation. This restriction is viewed in this article as a restriction of the producer's property rights to influence his manure management through a subset of production possibilities compatible with the environmental regulation.

When these programs were drawn up in France, the various courses of action producers were to take to dispose of their livestock effluent were set out in order of priority, to guide them in their decision-making processes. Spreading, using the land's purging capacity to full advantage, is the first course of action required. Then, in descending order of priority come the reduction of effluent at its source through changes in the animal's diet and improved control over the use of inorganic fertilizers, the treatment of manure, and as a final resort, a reduction in the total number of livestock on the farm. At the current time, only the first two courses of action have actually been put into practice. The third, which deals with the treatment of manure and its export to areas far away from the production centres, is being introduced. Thus, the most widespread practice currently used to deal with livestock effluent is spreading. Given the target of 170kg of nitrogen of animal origin per hectare set by the Nitrates Directive, a large number of farmers located in intensive production areas find themselves in a position where they do not have enough areas of available spreading land to dispose of all their effluent, and so have to resort to borrowing land. The practice of lending land allows producers to continue their production activities and, at the same time, to comply with current regulations on spreading. It is a low-cost solution since it does not involve any significant changes to the original production structure.

The aim of this paper is firstly to show how the measures introduced by the European regulation on manure management are incorporated into the theoretical analysis framework proposed by Griffin and Bromley (1982) for studying the issue of nonpoint externality and, in particular, agricultural runoff. The model is extended in the sense that only some of the polluting emissions at the origin of diffuse pollution are regulated by the Nitrates Directive. Secondly, this paper proposes an empirical model in which Griffin and Bromley's assumption that productive abilities are fully exploited (1982) is relaxed. In order to describe the disparity that exists between individual situations, the empirical model represents the production technology by means of a directional distance function (Chung et al. 1997; Chambers et al. 1996, 1998). As noticed by Chavas and Cox (1999), this function allows for the rescaling of inputs and outputs in a more flexible way than in Shephard's distance function. Furthermore, the directional distance function easily represents the jointness of production between the intended output and polluting emissions (Färe and Grosskopf, 2004). This function is used to assess the increase in productive efficiency that each farm can achieve when it seeks to increase its production - and thereby its income – while at the same time decreasing its production of nitrogen surplus, which is a source of environmental pollution, by improving its management and technical abilities. Finally, we simulate the management of the individual spreading constraint applicable to each farm, and look at how land can be allocated among producers in such a way as to combine the disposal of manure in accordance with the limit of the Nitrates Directive together with an improvement in the productive and environmental efficiency of all farms, using a sample of French pig farms.

Previous papers in the literature have already studied manure management in the pig sector by using the non parametric approach called Data Envelopment Analysis (DEA) for measuring productive and environmental performance of pig farms. Piot-Lepetit and Vermersch (1998) implicitly introduced the environmental regulation on organic manure in a DEA framework. By using a radial distance function, they estimated a price for organic manure disposal. A directional distance function is used by Piot-Lepetit and Le Moing (2007a) for measuring productivity of pig farms and decomposing it between two components, namely, efficiency and technical progress and by Piot-Lepetit (2010b) for providing efficiency measurements by farming system and at the sector level as a whole. In these papers, the environmental regulation is also implicitly modelled. The first introduction of an explicit design of the standard on organic manure within a DEA framework can be found in Piot-Lepetit and Le Moing (2007b). This development has been recently extended by Piot-Lepetit (2010a) for analyzing policy issues linked to the management of organic manure in the pig sector based on command and control and economic measures. However, none of them papers clearly describes the standard on the spreading of organic manure as a productive right allocated to each producer.

The current chapter adds to this literature by proposing a way to link the theoretical model on non point externality proposed by Griffin and Bromley (1982) with the specific case of manure management under the regulation of the Nitrates Directive. Furthermore, this chapter shows how the use of a directional distance function and a DEA approach allows for weakening the assumption of efficiency on which the theoretical model is based.

Nonpoint externality theoretical model

To analyze the economic problem posed by nitrate pollution and the regulatory choices introduced by the European Commission, we place ourselves in the theoretical framework proposed by for studying the nonpoint externality and, more specifically, agricultural runoff.

Considering a single-period model, we assume that a limit on emissions has been politically decided. The objective of the environmental regulation is to achieve this limit at minimal cost in a given geographical area. We assume that there are *J* firms (*j=1,…,J*) in the region. Let y_j be the output vector of firm *j* with y_{jm} being the *m*th element of that vector and x_j the input vector with x_{jn} being the *n*th element of that vector. We assume that there are *M* marketable goods that can be sold on markets at the price $p \in R_+^M$ and *N* marketable factors that can be purchased on markets at the price $w \in R_+^N$. At the same time, these farms produce pollutant emissions that are denoted b_j for farm *j* with b_{js} being the *s*th element of that vector. As we are concerned with nonpoint externality, the emission levels can be linked directly to output or input quantities. Assume that there exists a function h_j such that $f_j[y_j, x_j, h_j(y_j, x_j)] = 0$ for all *j*. Thus, nonpoint externality production can be expressed as a continuously differentiable function of inputs and outputs used in the production process. Following Griffin and Bromley, we assume that the nonpoint production function $h_j(y_j, x_j)$ does not differ among farms. This allows us to drop the underscript on this function without implying that all farms have the same soil types or slopes since these variables are arguments of the *h* function.

Maximizing profits subject to this technological constraint for each farm can be written as follows:

$$\max_{y_j, x_j} \; py_j - w_j x_j$$

$$s.t. \quad f_j[y_j, x_j, h_j(y_j, x_j)] = 0 \quad \text{for all } j \tag{1}$$

Equation in (1) yields the following Lagrangian:

$$L_j = py_j - w_j x_j - \delta_j f_j[y_j, x_j, h(y_j, x_j)] \tag{2}$$

where δ_j is the Lagrangian multiplier for farm *j*. The following optimality conditions are then derived:

$$\begin{aligned} & p_m - \delta_j(f_{jm} + f_{jb}h_m) = 0 \qquad \text{for all } m, j \\ & w_n - \delta_j(f_{jn} + f_{jb}h_n) = 0 \qquad \text{for all } n, j \end{aligned} \tag{3}$$

In our case, the nonpoint function $b_j = h(y_j, x_j)$ represents the farm's production of nitrogen surplus. This surplus is determined for each farm on the basis not only of its production of organic nitrogen from livestock farming and the use of chemical fertilizers for crops, but also on the characteristics of the land and choice of crops grown, which have an effect on the potential discharge of nutrients into the environment. To change the manure spreading behaviour of producers, the Nitrates Directive imposes an individual standard set at 170kg of organic nitrogen per hectare. We consider that this individual limit is a production right allocated by society to each producer and which depends directly on the area of land the farm has available for manure spreading and on the European standard. It has an effect on each individual farm's level of production. Assume that the production of organic manure is denoted $e_j = e(y_j)$ for all *j*. The restriction imposed by society on this by-product of animals can be expressed in the following way $e(y_j) \le \bar{e}_j$, where $\bar{e}_j$ is the value of the production right allocated to each farm by society. With this constraint, maximizing profits for each farm yields to the following model:

$$\begin{aligned} & \max_{y_j, x_j} \; py_j - w_j x_j \\ & s.t. \quad f_j[y_j, x_j, h_j(y_j, x_j)] = 0 \quad \text{for all } j \\ & \qquad e(y_j) \le \bar{e}_j \quad \text{for all } j \end{aligned} \tag{4}$$

The corresponding Lagrangian can be written as:

$$L_j = py_j - w_j - \delta_j f_j[y_j, x_j, h(y_j, x_j)] - \eta_j[\bar{e}_j - e(y_j)] \tag{5}$$

where δ_j and η_j are the Lagrangian multipliers for farm *j*. The derived optimality conditions are then:

$$\begin{aligned} & p_m - \delta_j(f_{jm} + f_{jb}h_m) - \eta_j e_{jm} = 0 \qquad \text{for all } m, j \\ & w_n - \delta_j(f_{jn} + f_{jb}h_n) = 0 \qquad \text{for all } n, j \end{aligned} \tag{6}$$

For certain producers, this production right $\bar{e}_j$ may be very limiting. If they wish to go on producing, they are forced to look for off-farm spreading land, i.e. to obtain production rights not used by other producers. This situation can be represented by the following model:

$$\begin{aligned} & \max_{y_j, x_j} \sum_{j=1}^{J} py_j - \sum_{j=1}^{J} w_j x_j \\ & s.t. \quad \sum_{j=1}^{J} f_j[y_j, x_j, h_j(y_j, x_j)] = 0 \\ & \qquad \sum_{j=1}^{J} e(y_j) \le \bar{E} \end{aligned} \tag{7}$$

The corresponding Lagrangian can be written as:

$$L = \sum_{j=1}^{J} py_j - \sum_{j=1}^{J} wy_j - \sum_{j=1}^{J} \alpha_j f_j[y_j, x_j, h(y_j, x_j)] - \mu[\sum_{j=1}^{J} e(y_j) - \bar{E}] \tag{8}$$

where $\bar{E} = \sum_{j=1}^{J} \bar{e}_j$ and α_j (*j=1,…J*) and μ are Lagrangian multipliers. The new optimality conditions are:

$$p_m - \alpha_j(f_{jm} + f_{jb}h_m) - \mu e_m = 0 \qquad \text{for all } m, j$$
$$w_n - \alpha_j(f_{jm} + f_{jb}h_n) = 0 \qquad \text{for all } n, j \tag{9}$$

This model enables producers to continue their activity and maximize profit, while at the same time taking into account the environmental impact of their production choices and complying with the spreading constraint imposed by the Nitrates Directive. Such compliance is achieved through exchanges of production rights between producers while keeping within the overall constraint imposed on the geographical area under consideration.

Nonpoint externality empirical model

In the theoretical model, the production technology is described by a function of production based on the assumption that all producers are efficient, in other words, that they exploit their productive abilities to the full. The use of the directional distance function analysis framework (Chung et al., 1997; Chambers et al., 1996, 1998) allows a representation of the multi-product, multi-factor technology and takes into account the joint production of undesirable goods while at the same time weakening the assumption that producers fully exploit their productive abilities. Only those observations that are on the production possibility frontier are considered to be efficient. Farms that lie inside the set of production possibilities show a productive or environmental inefficiency. We then use this framework analysis to represent the individual behaviour model (1) and measure changes in practices in terms of each farm's productive and environmental efficiency subsequent to the introduction of a restrictive regulation on the disposal of jointly-produced goods at the origin of diffuse pollution. We then use the aggregation properties of directional distance functions (Färe and Grosskopf, 2004) to simulate the allocation of production rights as described by the model (7).

By using the same notations as in the previous section, the production technology can be expressed as an output set defined on all feasible input-output vectors as:

$$P(x_j) = \{(y_j, b_j) : x_j \text{ can produce } (y_j, b_j)\} \quad x_j \in R_+^N \tag{10}$$

The output set $P(x_j)$ is assumed to produce both desirable and undesirable outputs from the input allocation x_j. It is assumed that it cannot produce one without the other. Non-marketable and undesirable outputs are produced jointly with the desirable marketable goods. In order to address the fact that bad outputs are costly to reduce, we impose weak disposability on bad outputs, i.e. a reduction in undesirable outputs can be achieved by reducing good outputs given fixed input levels. This assumption models the idea that disposing of the bad outputs is not a free activity, but that it requires foregoing some of the good outputs or increasing some of the inputs. In addition to imposing weak disposability, we also assume that the desirable outputs are freely disposable, i.e. it is possible to dispose of goods without additional production costs (Färe *et al.*, 1994). Using this set of assumptions, the production technology can be represented with the help of a directional distance function.

Let $g = (g_y, g_b)$ be an output directional vector with $g \in R^M \times R^S$.

$$\vec{D}_o(y,b;g) = \max\{\beta : ((y,b) + \beta.g \in P(x)\} \tag{11}$$

where β is the measure of productive and environmental efficiency. By construction, $\vec{D}_o(y,b;g) \geq 0$ if and only if $(y,b) \in P(x)$. When $\vec{D}_o(y,b;g) = 0$, the farm is on the boundary of the production set. Otherwise, the output directional distance takes *(y,b)* in the *g* direction and places it on the production frontier. $\vec{D}_o(y,b;g) > 0$ means that the farm is located inside the production possibilities set. It reflects inefficiency in that the farm is not on the best practice frontier. Following Chung et al., 1997, we assume that the *g* vector is defined as $(y,-b)$. Thus, the output directional distance function seeks the simultaneous maximum expansion in good outputs and reduction in bad outputs. The output directional distance function is a generalization of the Shephard output distance function that allows some outputs to be expanded while others are contracted. This property is particularly attractive in our case as we study polluting outputs.

To characterize the first model, we consider a single time period and we assume that there are $j=1,..., J$ observations of inputs and outputs. We model the reference technology by using a DEA (Data Envelopment Analysis) approach.

To measure the farm j' specific output distance function, we calculate for each $j'=1,...,J$ the following linear programming problem:

$$\vec{D}_o^{j'}(y_{j'}, b_{j'}; g) = \max \beta_{j'} \tag{12}$$

s.t.

$$\sum_{j=1}^{J} z_j y_{jm} \geq (1+\beta_{j'}) y_{j'm} \quad m=1,...,M$$

$$\sum_{j=1}^{J} z_j b_{js} = (1-\beta_{j'}) b_{j's} \quad s=1,...,S$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{j'n} \quad n=1,...,N \tag{13}$$

$$\sum_{j=1}^{J} z_j = 1$$

$$z_j \geq 0 \quad j=1,...,J$$

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). The model is a single period model. The level of polluting emissions b_j is determined according to the practices observed over the period.

The model defined by (12) and (13) allows us to assess the productive and environmental efficiency of each farm together with the modelling of the polluting output that we seek to decrease so as to limit the environmental impact of this production activity. When $\beta_j = 0$, the observation is efficient. It lies on the production possibility frontier. When $\beta_j > 0$, the observation can improve its productive and environmental efficiency in the direction of the vector g by increasing its production of desirable goods and decreasing its polluting emissions of β_j. However, the model provides no information about the compatibility of the optimal solution obtained with the environmental regulation in place.

To obtain a representation of the model introducing the production rights $\bar{e}_j$ allocated to each producer defined in (7), we use a property of the directional distance function, namely that "when a common directional vector is chosen for all firms in an industry, the sum of the directional distance functions for the firms equals industry directional function" (Färe and Grosskopf, 2004). In other words, we have:

$$\vec{D}_o^{coll}\left(\sum_{j=1}^{J} y_j, \sum_{j=1}^{J} b_j; g\right) = \sum_{j=1}^{J} \vec{D}_o^{j}(y_j, b_j; g) \tag{14}$$

In the modelling of production rights management, the polluting emissions are always weakly disposable because of the set of regulatory measures that exist to restrict spreading possibilities. These measures concern storage durations and storage capacities, the periods when it is possible to spread manure, and specific restrictions depending on the nature of the soil. If we denote $\bar{e}_j$ as the level of spreading the individual j can carry out on his farm, we could define his productive right as follows:

$$\bar{e}_j = 170 * land_j \quad j=1,...,J \tag{15}$$

where $land_j$ is the area available for spreading and 170kg/ha is the standard resulting from the European regulation on manure management.

Over the region under study, the total level of production rights for these farms is defined by:

$$\overline{E} = \sum_{j=1}^{J} \overline{e}_j \tag{16}$$

The introduction of this last constraint results in the production technology being represented by the directional distance function as the following aggregate output:

$$\begin{aligned}\vec{D}_o^{coll}\left(\sum_{j=1}^{J} y_j, \sum_{j=1}^{J} b_j, \overline{E}; g\right) &= \sum_{j=1}^{J} \vec{D}_o^{j}(y_j, b_j, e_j; g)\\ &= \max\left\{\sum_{j=1}^{J} \beta_j^{coll} : ((y_j, b_j, e_j) + \beta_j^{coll} g) \in P(x_j), \quad \sum_{j=1}^{J} e_j \le \overline{E}\right\}\end{aligned} \tag{17}$$

The production rights management model is obtained from the set of J observations for the sample, allowing production rights to be allocated in such a way as to maximize the sum of their output directional distance functions or productive and environmental efficiencies.

This "collective" model can be expressed as follows:

$$\vec{D}_o^{coll}\left(\sum_{j=1}^{J} y_j, \sum_{j=1}^{J} b_j, \overline{E}; g\right) = \max \sum_{j'=1}^{J} \beta_{j'}^{coll} \tag{18}$$

s.t.

$$\begin{aligned}&For\ j'=1\\ &\sum_{j=1}^{J} z_j^1 y_{jm} \ge (1+\beta_1^{coll}) y_{1m} \quad m = 1,\ldots,M\\ &\sum_{j=1}^{J} z_j^1 b_{js} = (1-\beta_1^{coll}) b_{1s} \quad s = 1,\ldots,S\\ &\sum_{j=1}^{J} z_j^1 \overline{e}_j = e^1\\ &\sum_{j=1}^{J} z_j^1 x_{jn} \le x_{1n} \quad n = 1,\ldots,N\\ &\sum_{j=1}^{J} z_j^1 = 1\\ &z_j^1 \ge 0 \quad j = 1,\ldots,J\\ &\vdots\end{aligned} \tag{19}$$

$$\begin{aligned}
&For\ j' = J \\
&\sum_{j=1}^{J} z_j^J y_{jm} \geq (1+\beta_J^{coll}) y_{Jm} \quad m = 1,\ldots,M \\
&\sum_{j=1}^{J} z_j^J b_{js} = (1-\beta_J^{coll}) b_{Js} \quad s = 1,\ldots,S \\
&\sum_{j=1}^{J} z_j^J \bar{e}_j = e^J \qquad (20) \\
&\sum_{j=1}^{J} z_j^J x_{jn} \leq x_{Jn} \quad n = 1,\ldots,N \\
&\sum_{j=1}^{J} z_j^J = 1 \\
&z_j^J \geq 0 \quad j = 1,\ldots,J
\end{aligned}$$

$$\sum_{j=1}^{J} e^j \leq \sum_{j=1}^{J} \bar{e}_j = \bar{E} \qquad (21)$$

where z^j, e^j and β_j^{coll} $(j = 1,\ldots,J)$ are the variables of this linear program. Other variables are observed data from the sample data set.

A number of comments are required with regard to the applicability of such modelling. First of all, the model assumes that livestock effluent from farms that do not comply with the standard will be fully accepted by those that do. This is a valid assumption if we consider a set of farms all located within a zone where compliance with the Nitrates Directive is mandatory. Brittany, a region located within a "*zone d'excédent structurel*" (area with a structural surplus of nitrogen), falls into this category. Secondly, the model does not incorporate the cost of transporting the effluent. As a general rule, areas of land that are lent are located close to the farms that require the extra land. The sample therefore has to be restricted to an area in which the geographical proximity of the farms concerned allows such lending to be simulated without the need for transport cost data. Finally, the production right is defined *a priori* without allowing for any changes in the nitrogen balance leading to an increase in this right. This assumption, albeit admittedly restrictive, is not inconsistent with the observed reality, since the amount of nitrogen that may be accepted by each farm is set out in an agreement between the two partners, and is therefore known in advance. Land loan agreements refer to the number of tons of organic nitrogen to be accepted by the farm lending the land, and define the parcels of land on which the manure will be spread, and the approximate date on which it will be offloaded. The requesting farm is responsible for carrying out the spreading. However, the impact of a change in the nitrogen balance on the spreading potential will need to be taken into account if several years are considered, rather than the single year looked at in the modelling presented here.

Data

The modelling has been applied for the sole purpose of illustrating the relevance of the models presented in the previous section. The results do not provide information about observed practices, but endeavour to come somewhere close. Real data about farms that have resorted to lending and borrowing land is actually hard to come by, mainly because information about these practices is not centralized in any way. Loans are often made within the framework of an agreement between two partners. The sample has been compiled on the basis of the most plausible possible criteria using a sample from the French FADN (Farm Accountancy Data Network) database.

We have chosen to look at a region in which livestock production is intensive. Brittany has to deal with nitrogen surpluses that need to be absorbed and uses the practice of lending land to dispose of livestock manure (produced by pig farms in particular). In most cases, land is lent by one farm raising livestock to another farm raising livestock, and, as a general rule, the type of land lent for the purposes of manure spreading is grassland. We have restricted our sample to farms mainly producing pigs, either as a specialist activity or in conjunction with other livestock such as cattle. The compiled sample enables us to illustrate the appropriateness of nonpoint externality empirical models from the previous section. Indeed, some of the farms comply with the standard imposed by the environmental regulation while others do not; a fact that will enable us to simulate the allocation of spreading land among the farms in the sample.

Our analysis is restricted to 1996. The year 1996 was selected firstly because it falls at the beginning of the period when the PMPOA was introduced – the largest farms were targeted by this program during the years 1994-1996. Secondly, the year 1996 came just before the 1997 and 1998 drop in production prices, in other words at a time when certain shock elements caused by the implementation of the regulation can be seen without too much interference from the economic upset of the following years.

Data on the nitrogen surplus and on the production right of each farm are calculated. The level of organic manure is based on the number of animals on the farm. We have applied the coefficients provided by the CORPEN[31], which provide an approximation of the level of organic manure produced by each type of animal. The level of manure surplus is derived from the individual nutrient balance of each farm. This balance is a tool used to provide estimates of flows of nitrogen across the farm boundary. Nutrient balances are defined as the difference between input and output flows, where input flows are nitrogen from inorganic fertilizers, nitrogen from organic manure, and nitrogen by deposition from the atmosphere, and where output flows include uptake by harvested crops and livestock sold (Meisinger and Randall, 1991). In view of the lack of any specific data on the area of spreading land, we have used a conventional, non-real approach to calculate each farm's production right. The area of spreading land is estimated on the basis of the farm's Utilised Agricultural Area (UAA). This estimation is approximate and leaves out agronomic constraints. Under these conditions, the theoretical estimated area available for receiving livestock effluent is over-estimated. In spite of this over-estimation, 80 farms in our sample do not have enough spreading land available to deal with all their effluents and therefore need extra land outside their own perimeter. The other 108 farms comply with the constraint.

In the sample, the average nitrogen surplus level (b) is 158.65kg/ha. However, this mean does not reflect the differences that exist between farms. 43% of the farms in the sample do not comply with the constraint imposed by the Nitrates Directive, which requires a level of organic manure spread per hectare (e) of less than 170kg/ha. These farms represent 319kg/ha of organic nitrogen, i.e. an average excess of almost 150kg/ha over the regulatory threshold, with an average nitrogen surplus of 250kg/ha. Conversely, farms complying with the spreading constraint have an average theoretical capacity to accept 53kg of effluent per hectare. Thus, when evaluating farms' performances relative to their productive and environmental efficiency, it seems important to integrate the standard derived from the EU regulation and to allow for the lending of spreading land by one producer to another.

We have implemented empirical models by specifying a set of inputs and outputs. The first model given in (12) and (13) corresponds to the conventional analysis framework. It simply considers the presence of an undesirable by-output. It measures the efficiency of farms in a direction which only allows an increase in production if the surplus can be reduced by the same proportion. In this context, the two desirable outputs are total gross output from pig production and from other types of production. The bad output is nitrogen surplus. Six inputs are used to describe farms' production activities (land, labour, pig livestock, other livestock, variable inputs for pig production and other variable inputs). For the second empirical model given in (18)-(21), we also consider the regulation on organic manure from the EU Nitrates Directive via the introduction of production rights, and the

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3 The CORPEN is an organization responsible for defining the Codes of Good Agricultural Practice relating to the management of nitrogen and phosphorus. It also provides information on the average level of nitrogen produced by different types of animal and taken up by crops.

possibility of lending and borrowing spreading land as a means of complying with those production rights. The same outputs and inputs are used to define the production technology. We merely define an additional variable that represents the production right of each farm, i.e. its on-farm spreading land possibilities. Summary statistics for these variables are reported in table 1.

Table 1: Summary Statistics for Inputs and Outputs.

	Mean	**St. Dev.**	**Minimum**	**Maximum**
Desirable outputs				
Pig total gross output (€)	192 689.13	169 910.95	136.59	827 605.16
Other products total gross output (€)	81 090.53	52 894.54	316.03	272 136.13
Undesirable outputs				
Nitrogen surplus (kg)	5 976.32	4 142.90	186.66	20 240.81
Inputs				
Land (ha)	45.32	19.77	5.61	104.00
Labour (Awu)	186.69	75.91	81.82	418.18
Pig livestock (Lu)	20 399.83	16 603.27	30.00	92 232.00
Other livestock (Lu)	4 797.37	9 688.47	0.00	89 614.94
Variable inputs for pigs (€)	112 184.41	97 350.47	64.79	489 811.68
Other variable inputs (€)	58 670.63	30 135.46	10 479.96	168 080.99
Environmental regulation				
Productive rights (kg)	7 704.76	3 360.36	953.70	17 680.00

Results

Table 2 presents the results obtained from the two nonpoint externality empirical models developed and implemented in this article. The 'individual' model repeats the conventional approach used in economic literature and only considers the presence of polluting emissions (nitrogen surplus), and gives only information on productive and environmental efficiency improvements of sample farms. The 'collective' model however introduces an individual productive right for each farm and a simulation of the allocation of production rights among the farms when measuring their productive and environmental efficiency.

When a farm is considered to be efficient, the value taken by the output directional function is zero, since there is no way of increasing production while at the same time jointly decreasing the production of the polluting output. When the value is greater than zero, then there are possibilities for modifying practices in order to improve the productive and environmental performance of these farms

Table 2: Economic and Environmental Efficiency of Farms.

	#	β^{ind}		**Efficient farms**		β^{coll}		**Efficient farms**	
		Mean	St-Dev	#	%	Mean	St-Dev	#	%
$e_j > 170$	80	0.0409	0.0682	49	61	0.0436	0.0695	46	57
$e_j < 170$	108	0.0312	0.0691	73	67	0.0330	0.0707	72	67
Total	188	0.0354	0.0687	122	65	0.0375	0.0702	118	63

On average across the sample, both models provide very similar measurements, and the same farms are considered to be efficient in both cases. The mean inefficiency measurement provided by the individual model is 3.54% with 65% of efficient farms. The mean measurement obtained from the collective model is 3.75% of inefficiency and 63% of efficient farms. Regardless of the model used, the possibilities for farm development are weak, but do exist. Farms above the 170kg/ha standard are on average less efficient than those below it. These results are in keeping with the recorded fact that controlling spreading alone has not led to a decrease in water pollution by nitrates. The potential for improving individual situations, on a like-for-like production structure basis, based solely on the practice of spreading with or without land loans, is relatively low.

The relevance of the collective model is that it represents behaviour in terms of the allocation of production rights or spreading land among the farms in the sample. The optimal distribution of spreading lands is described in table 3. Of the 188 farms in the sample, 57% are in a position to be potential suppliers of spreading land whenever the practices observed for these farms do not result in the complete saturation of the constraint resulting from the European standard. The other farms (43%) are in a demand position, and require spreading land. In the initial situation, none of the farms completely saturates the 170kg/ha organic nitrogen constraint imposed by the environmental regulation. The results obtained using the individual model leave this situation unchanged. However, the results provided by the collective model enable us to obtain the same level of decrease in inefficiency by distributing spreading land among supply and demand farms. After land reallocation, 84% of the farms in the sample saturate their productive right, which means they spread the full amount of organic nitrogen authorized by the regulation on their land.

Table 3: Distribution of Spreading Land.

	Observed situation		**Optimal situation**	
	#	**%**	**#**	**%**
Supply farms (<170)	108	57	30	16
Demand farms (>170)	80	43	0	0
Other (=170)	0		158	84
All farms	188	100	188	100

Table 4 compares the initial situation observed for each farm with the optimal situation obtained by means of the collective model. There are notable differences. Of the 158 farms that saturate the standard in the optimal situation, 53% initially stood as suppliers of spreading land and 47% as demand farms. Only 30 farms (16% of the total sample) still have any land potentially available to receive manure, 6 of which (3% of the total sample) used to be farms with a demand for spreading land in the observed situation. The status of these farms has thus changed during the allocation of land. Not a single farm is left in a demand situation.

Table 4: Changes in Farms between the Initial Situation and the Optimal Situation.

#	**Optimal situation**					
Observed situation	Supply farms		Others		All farms	
	#	%	#	%	#	%
Supply farms	24	80	84	53	108	57
Demand farms	6	20	74	47	80	43
All farms	30	100	158	100	188	100

In terms of the distribution of land for spreading among the farms, table 5 shows the estimates provided by the collective model and compares them to the situation observed in the sample. In the initial situation, the farms have 8,520 hectares of land available for a spreading requirement of 8,628 hectares. A simple mathematical sum shows us that this sample falls 107 hectares short of complying with the regulation. The supply farms have 5,656 hectares of land at their disposal and the demand farms have 2,864 hectares. Their own requirements are for 3,843 and 4,784 hectares respectively. The supply farms therefore have 1,813 hectares available while the demand farms need about 1,921 hectares of spreading land.

Table 5: Distribution among the Farms of Land available for Spreading (hectares).

(hectares)	Observed situation	Land requirement*		Optimal situation	
	∑	∑	Diff**	∑	Diff**
Supply farms	5656.64	3843.12	+1813.52	5429.11	+227.53
Demand farms	2863.92	4784.64	-1920.72	2836.61	+27.31
All farms	8520.56	8627.76	-107.20	8265.72	254.84

* land requirement: number of hectares needed to meet the European directive with regard to the maximum spreading threshold of 170kg/ha of organic nitrogen.
** diff: difference between the amount of land available on the farm and the amount of spreading land required to comply with the Nitrates Directive.

In the optimal collective model situation, the land areas of supply farms used to meet spreading requirements total 5,429 hectares, in other words, 1,586 hectares more are used than in the initial situation. The areas used by demand farms total 2,836 hectares, slightly less than their initial productive rights, which total 2,864 hectares. The 27-hectare positive balance for the latter farms can be explained by the change in the situation of 6 farms, which switched from being in a demand situation to a supply situation at the time of the reallocation. The scarce spreading land resource could therefore be allocated when optimizing the collective model. Over the sample used, some production rights even remain unused, for a total of 254 hectares. This distribution of land among the farms with a view to complying with the regulation is accompanied by an average 3.75% increase in production and decrease in the nitrogen surplus.

The results obtained are based on a simulation using theoretical data. They describe a situation in which there are no limits on exchanges of land between the participants. Nonetheless they do highlight the potential for pig farms to comply with the existing regulation through the practice of lending land, as well as the low impact of this type of action on reducing nitrogen pollution from pig farms.

Conclusion

This paper adapts the modelling approach proposed by Griffin and Bromley to represent nonpoint externality and, more specifically, agricultural run-off. It extends the said modelling in two ways. Firstly, the manure spreading standard introduced by the European regulation aimed at regulating nitrate pollution from agricultural activities is introduced into the models as a production right. Secondly, the assumption that productive abilities are fully exploited is weakened by using a directional distance function to represent the production technology.

At the empirical level, the models developed using the directional distance function can be used to measure the productive and environmental efficiency of farms, while at the same time taking into account the joint production of polluting emissions. The aggregation properties of the directional distance function allow us to develop a model that simulates exchanges of production rights between farms in the sample under consideration.

This analysis framework is applied to a sample of pig farms located in Brittany in 1996. The results highlight the fact that both analysis frameworks provide a very similar assessment of the efficiency of the farms. The simulation of the practice of lending spreading land demonstrates that it is possible for farms to collectively manage the constraint linked to the Nitrates Directive while at the same time improving their efficiency in a direction that enables them to increase production and decrease their nitrogen surplus that is a source of pollution. The results indicate the low potential for a reduction in nitrogen pollution on the basis of a reduction in the productive and environmental inefficiencies of farms and the practice of manure spreading alone, even when there is a standard to be complied with.

Despite the fact that the simulated results are not compared with any real data, the work carried out here is original in two ways. First of all, it expresses the European organic nitrogen spreading standard in the form of a production right assigned to each farm by the public decision maker. Unlike the approaches developed in Environmental Economics, the production right is not a license to emit pollutants. In the context of pig production, the emission of pollution comes from the nitrogen surplus whereas the standard is applicable to just one component of this surplus, organic nitrogen. Secondly, the developments made in this article enable us to consider not just the productive and marketable functions of land, but also its function in disposing of undesirable outputs, which by definition is a non-marketable function. The collective model is used to simulate the practice of lending spreading land among the farms in the sample. The aim is then to improve the productive and environmental efficiency of each farm, the sole constraint being to comply collectively and individually with the Nitrates Directive spreading standard. Thus defined, the model enables an exchange of production rights, or loans of spreading land by one farm to another, in an area subjected to a broader set of command-and-control measures that restrict producers' production possibilities. This system respects individual production rights and, at the same time, improves the efficiency of the farms under study. The model can then be used within the framework of a set of simulations to study the change in the production of livestock farms in a given area that is limited by the land factor and an environmental regulation.

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