Optimal land use and manure management : an application to the French case

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Summary

The problem of pollution originating from intensive rearing is analysed through a general welfare economics model. The policy option chosen to avoid this situation relies chiefly on command and control measures, with a limited amount of livestock manure which can be applied to the land (170 kg of nitrogen in the 1991 EC directive). When the standards are defined, the producers will maximise their profit under this constraint. This leads to develop a market of manure spreading rights, between farmers having land available for spreading manure, and farmers having a high disposal rate per unit of land. An empirical illustration concerning Brittany is presented.

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1. INTRODUCTION

Northern European areas characterised by a high agricultural employment per sq km have known an intensive animal husbandry development. This development has been encouraged by the Mc Sharry reform of the Common Agricultural Policy. As a matter of fact the cut in price support for cereals led to lower feed costs. Consequently, prices of livestock products, mainly pork and poultrymeat have decreased. These commodities becoming more competitive, there is an expansion effect at the expense of beef. Using a simplified world trade model which allows the simulation of the consequences of the CAP reform, it has been demonstrated that pork and poultrymeat would increase in France by 8.5 per cent from 1993 to 1995 (Léon and Quinqu, 1994). The figures confirm the results of the model since, during this period, the price decrease of feed compounds reached 8.7 per cent, whilst the production of pork and poultry meat increased by 9.3 per cent.

Simultaneously in these regions arable and permanent cropland has increased at the expense of permanent grassland, leading to a more important use of fertilizers. Consequently, not only manure and mineral surpluses appear to be causing nitrate deterioration of drinking water, but they are also the cause of the disruption of ecosystems due to eutrophication, and the emission of ammonia into the atmosphere. The presence of pathogens in slurry is another source of contamination of water facilities.

Controlling increasing pollution from agriculture becomes a major challenge for water protection and also for the protection of ecosystems. But, the management of manure represents a specific problem in intensive rearing regions since the volume of this by-product is increasing and many farmers want to dispose of their larger quantities as cheaply as possible, i.e. waste application on their land, or in the

close vicinity. Their motivation is not the effective use of the nutrients, according to the uptake by crops, but the disposal of manure within the limits of crop tolerance. Subsidiarily, the high level of tolerance of the maize explains the development of this crop.

In countries where this problem is acute, such as The Netherlands, researches have been conducted to determine the costs of reducing emissions from pig farming according to the situation of the farms and the type of measures (Leneman and al., 1993). The impact of environmental regulations on dairy farms has been carried out in the UK (Rigby and Young, 1996 ; Rigby, 1997). These studies are useful since they permit a better targeting of environmental policies, but they only concern the relationship between policy makers and producers. If we intend to define a Pareto optimum, we have to take into account explicitly the consumer with his level of utility determined by his set of preference orderings.

The second section of the paper proposes a model of public economy where consumers' preferences are represented by a collective utility function ; farmers produce jointly animal and plant outputs along with organic nitrogen. This nitrogen contributes, on the one hand, to soil fertilisation; on the other hand, it contributes to a pollution which is proportional to the spreading intensity per hectare. After characterising the Pareto optimum of this economy, we remind that a « laissez-faire » situation inevitably strays from it. The proposed internalisation solution considers the creation of two markets: one between consumers and producers; the other between producers who, depending on the level of animal wastes, trade amounts of organic nitrogen or spreading rights. We then evaluate to what extent French regulations are inspired from this normative solution.

The third section develops this model by formalising a market of manure spreading rights. A first empirical illustration is also provided, revealing the implicit overvalue related to the land because of the slow and progressive implementation of the nitrate regulation. The fourth section is the conclusion.

2. SOCIAL OPTIMUM : FROM THEORY TO POLICY IMPLEMENTATION

In a first sub-section, we present a model where effluents are produced by farmers and where consumers bear the negative externalities originating from intensive rearing. The co-production of organic nitrogen leads at the same time to a negative externality towards consumers and to an externality which is mutually positive among producers. Therefore, the internalisation solution requires the creation of two markets. The second sub-section analyses the extent to which current policies of nitrate surplus management follow the recommendations of this model.

2.1. The microeconomic model

Simplistically, a basic geographical unit is considered, such as a watershed where there are problems related to slurry excess. The economy is made of farmers specialized in animal production and of consumers who have to put up with agricultural externalities. The consumers' preferences are represented by an aggregated utility function $U(x_a, x_v, e)$ where x_a represents the consumption of animal products, x_v represents the consumption of plant products while e represents the pollution related to animal production. The latter is ensured by J producers, $j = 1,\ldots J$, who can use a given technology submitted to certain constraints. This is formalised by: $f_j\left(y_{ja}, y_{jv}, n_{z_j}, z_j, k_j\right) = 0$, $j = 1,\ldots J$; y_{ja} and y_{jv} represent animal and plant output levels and z_j is the acreage of farm j; thinking here in terms of partial equilibrium, the other inputs (capital, intermediate consumptions, ...) are gathered into the k_j vector[2]. Finally, n_{z_j} is the amount of organic nitrogen spread over this area. More generally, n_{z_j}, the amount spread, includes:

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[2] It will be defined more precisely in the econometric illustration (section 3).

i) partially or totally the amount of organic nitrogen produced by the rearing activity, i.e. $c_j y_{ja}$, where c_j is a technical coefficient which is a function of the rearing, food habits, ...

ii) possible external supplies, marked as $n_{j'j}$ $j' = 1,\ldots J$, i.e. amounts produced by farm j' and spread on area z_j.

The fertilizing value of animal rejections and the assimilative capacity of the soil are thus taken into account. The polluting emission e integrates the spreading load per hectare and per farm j :

$$e = \frac{1}{J}\sum_{j=1}^{J}\frac{n_{z_j}}{z_j} \qquad [1]$$

According to this formula, the contribution of each farm j to the overall pollution only depends on the amounts spread per hectare. The model can include, without any additional effort, a more accurate weighting function where the a_j parameter would depend on the farm technology, on other inputs k_j, on the location in the watershed,... At first sight, equation [1] only represents some kind of smoothing of organic nitrogen among farms, smoothing that could reduce the level of pollution felt by consumers.

The $U(.)$ utility function is supposed to be differentiable, strictly quasi-concave, increasing in x_a, x_v and decreasing in e. Similarly, $f_j\left(y_{ja}, y_{jv}, n_{z_j}, z_j, k_j\right) = 0$, $j = 1,\ldots J$ is differentiable and concave. Land allocations z_j being assumed to be quasi-fixed, the Pareto optimum of this economy results from the following program:

$$
\begin{aligned}
&Max\ U\left(x_a, x_v, e\right) \\
&s.t \\
&\quad f_j\left(y_{ja}, y_{jv}, n_{z_j}, z_j, k_j\right) \le 0 \quad j = 1,\ldots J \quad (\alpha) \\
&\quad e = \frac{1}{J}\sum_{j=1}^{J}\frac{n_{z_j}}{z_j} \\
&c_j y_{ja} = \sum_{j'=1}^{J} n_{jj'}\ ; n_{z_j} = \sum_{j'=1}^{J} n_{j'j} \quad j = 1,\ldots J \\
&\quad x_a \le \sum_{j=1}^{J} y_{ja}\ ; x_v \le \sum_{j=1}^{J} y_{jv} \quad (\beta)
\end{aligned}
\qquad [2]
$$

At the optimum, technological (α) and resources (β) constraints are saturated, which leads to the following Lagrangian :

$$
\begin{aligned}
L(.) = {} & U\left(x_a, x_v, e\right) + \sum_j \alpha_j f_j\left(y_{ja}, y_{jv}, n_{z_j}, z_j, k_j\right) + \\
& \sum_j \beta_j\left(c_j y_{ja} - \sum_{j'} n_{jj'}\right) + \sum_j \gamma_j\left(n_{z_j} - \sum_{j'} n_{j'j}\right) + \\
& + \left(e - \frac{1}{J}\sum_j \frac{n_{z_j}}{z_j}\right) + \delta\left(x_a - \sum_j y_{ja}\right) + \mu\left(x_v - \sum_j y_{jv}\right)
\end{aligned}
\qquad [3]
$$

From this expression, we can derive the first order necessary conditions that allow to characterise the Pareto optimum in the following way:

$$
\frac{U_a}{U_v} = \frac{f_{ja}}{f_{jv}} + c_j\left[\frac{f_{j'n}}{f_{j'v}} - \frac{1}{Jz_{j'}}\frac{U_e}{U_v}\right] \quad \forall\ j, j' = 1,\ldots J \qquad [4]
$$

with : $U_a = \dfrac{\partial U}{\partial x_a}$, $f_{ja} = \dfrac{\partial f_j}{\partial y_{ja}}$, ...

In other terms, the classical equality of substitution marginal rates between consumers and producers is corrected here because of the externality provided by the co-production of organic nitrogen. The latter leads to two contradictory effects:

i) a positive effect: the supply of organic nitrogen by farm j contributes to the fertilisation of plant productions of farm j'.

ii) a negative effect: it affects the consumer's utility.

The resolution if this system of equations provides, theoretically, the optimal pollution level e^*. Classically, in the absence of public intervention, the competitive equilibrium of this economy with an external effect is not Pareto-optimal (Baumol et Oates, 1988). In fact, it is clear that the various producers do not take into account, in their optimisation process, the effects of the amounts spread on the consumer's utility. But these externalities can be seen as resulting from a lack of property rights concerning the environment. When a system of strict liability exists and under which a source is financially responsible for damages, then the paretian efficiency can be restored.

Dales (1968) initially proposed the set up of a market of polluting rights in order to restore social efficiency. In our case, the externality is revealed through the relation between two factors: land and organic nitrogen. It has two effects: a negative effect on the consumer; a mutually positive effect among producers; some of them must get rid of a slurry excess, while the others benefit from fertilising elements. This leads to the creation of two different markets: one market between producers and consumers that contributes to the search for e^*; the other between producers who have or do not have an excess of slurry.

Let's assume that the aggregated consumer can offer an amount of polluting rights e^s with a unit price of p_e and has an exogenous income R ; p_v is the price of crop output while $p_a = 1$ (the animal output is the numeraire). The consumer behaviour can be written as :

$$\begin{aligned} &Max\ U(x_a, x_v, e^s) \\ &\quad s.t \quad x_a + p_v x_v - p_e e^s = R \end{aligned} \qquad [5]$$

Noting λ the Lagrange multiplier related to the budget constraint we obtain the following first order conditions:

$$\begin{aligned} U_a &= \lambda \\ U_v &= \lambda p_v \\ U_e &= -\lambda p_e \end{aligned} \qquad [6]$$

Concerning producers, the spreading of organic nitrogen now depends on the purchase of spreading rights for a quantity e^d (with a weighting factor $\frac{1}{J}$), which leads them to buy or sell organic nitrogen at unit price w_n. The program of producer j can then be written as :

$$\begin{aligned} &Max\ y_{ja} + p_v y_{jv} - p_e e_j^d + w_n\left(c_j y_{ja} - n_{z_j}\right) \\ &s.t \quad f_j\left(y_{ja}, y_{jv}, n_{z_j}, z_j, k_j\right) = 0 \quad (\alpha) \\ &\qquad e_j^d = \frac{n_{z_j}}{J z_j} \quad (\beta) \end{aligned} \qquad [7]$$

where α and β are the Lagrange multipliers. Thus :

$$\begin{aligned} &1 + w_n c_j + \alpha f_{ja} = 0 \qquad p_v + \alpha f_{jv} = 0 \\ &-p_e + \beta = 0 \qquad\qquad -w_n + \alpha f_{jn} - \frac{\beta}{J z_j} = 0 \end{aligned} \qquad [8]$$

This new competitive equilibrium is also characterised by the equality between supply and demand on the various markets :

$$\begin{aligned} x_a &= \sum_j y_{ja} \qquad x_v = \sum_j y_{jv} \\ e^s &= \sum_j e_j^d \qquad \sum_j c_j y_{ja} = \sum_j n_{z_j} \end{aligned}$$

After removal of the multipliers, expressions [6] and [8] lead to:

$$\frac{U_a}{U_v} = \frac{f_{ja}}{f_{jv}} + c_j \left[\frac{f_{jn}}{f_{jv}} - \frac{1}{Jz_j} \frac{U_e}{U_v} \right] \quad \forall\ j = 1,\dots J$$

$$\left[\frac{f_{jn}}{f_{jv}} - \frac{1}{Jz_j} \frac{U_e}{U_v} \right] = -\frac{w_n}{p_v} \qquad \forall\ j = 1,\dots J \qquad [9]$$

which is equivalent to expression [4] that characterises the paretian optimality as soon as the corrective factor due to externality does not depend on j. On the other hand, [9] clearly shows that the equilibrium price, w_n, may be positive or negative depending on whether the fertilising contribution of organic nitrogen is more important than its harmful effects. Therefore, depending on the cases, the farmer offers either an amount of organic nitrogen or a spreading area. This latter case will be formalised in the following section by an illustration. Furthermore, there is no market where polluting emissions are traded between farmers and consumers. This market is implicit through the definition of standards concerning the disposal rate per unit of land. These standards are supposed to take into account the interests of the consumers as well as the interests of the producers. It is to this issue that we turn next.

2.2. Second best policy instruments : the French regulation system

The set up of the internalisation scheme previously described through the creation of a market of rights would come up, in practice, against many difficulties: non-convexity of agricultural technologies, non point characteristic of nitrogen pollution, ... Moreover, it is impossible to set up a market of pollution rights between consumers and producers who are more or less victims of, or responsible for the pollution harmful effects. In effect, and in a second order approach, the determination of an environmental policy is taken to be a two-step process : first, the policy maker sets standards in the form of maximum nitrogen units which can be spread per hectare ; otherwise a standard $\bar{e}$ that substitutes to the e^* which would result from the equilibrium set by the first market of rights. In a second stage, a

regulatory system is designed to achieve the standard. As mentioned by Cropper and Oates (1992, p.685) this is often the way environmental decision making proceeds ; it is the so-called « command and control approach ». However, this system may prove not to be neutral, as it is often the result of the state of the various existing forces and is in fact a compromise, which explains some perverse or non expected effects. The current French system of internalisation of animal related pollution highlights this situation.

The French system, a very complex one, combines regulation and economic tools. In terms of texts, the two most important ones are the law on classified facilities and the European Directive on nitrates originating from agriculture.

The 1976 law on « classified facilities » is a general framework for the integrated management of polluting installations, whatever their activity. However, for agriculture, only rearing is concerned. An activity coming under this Act has to be « classified », i.e listed in a nomenclature. This applies only to installations of a certain size for enumerated species. The law defines two types of installations: those which have a reduced impact on the environment, and for which a mere notification to the « Prefet » is enough, and those which have serious harmful effects or are dangerous, and which require the « Prefet »'s permission. For the latter, an environmental impact assessment is needed, to detail the impact that the project may have on the environment, whether it is neighbourhood unrest, effects on the landscape or on water quality. In order to protect the water, and especially groundwaters, the farmer must plan large enough slurry storage capacities and spreading areas.

The 1992 translation into French law of the Directive on nitrates originating from agriculture widens the field of application of the law on classifies facilities. For example, dairy cows, which were not concerned by the 1976 nomenclature, appeared in the 1992 version. Rearings of 40 to 80 cattle heads come under the simple declaration regime, while those of over 80 cattle heads are subject to the permission regime. Let's remind that the overall objective of this Directive is to « prevent and reduce the pollution by nitrates from agriculture source ». The

Directive addresses the earlier Directive on the quality of drinking water defining the Maximum Allowable Concentration of nitrates (50 mg per litre).

In order to enforce the « Directive nitrates », France has defined vulnerable areas where agriculture contributes to the degradation of water quality and to the eutrophication of groundwaters. In these areas, which make up 46% of the used agricultural acreage (« Echo des Nitrates », 1997 n°113), the amount of animal effluents spread must not contain more than 170 kg of nitrogen par hectare, starting in 1999. France has not used the possible derogation that allows to go up to 210 kg per hectare between 1996 and 1999.

The enforcement of these obligations is insured by the law, but also by using the Polluter-Payer Principle (PPP), together with an aid system. Originally, agriculture was one of the activities likely to pay taxes, however it was not until 1992 that an official agreement was reached between the ministries of agriculture and environment on the one hand, and professionals on the other hand. In exchange for their entry into the PPP system, farmers obtained a financial aid that allowed them to regularise their obligations with respect to the « classified facilities » law and the « nitrates » Directive. This system constitutes the « Agricultural pollution Control Program » (APCP). This only concerns intensive rearing, arable crops and mineral fertilisers are therefore excluded.

A November 1993 decision defines the technical and financial decisions that allow to set up the APCP. For eligible farms, an environmental audit allows to determine the work required for rearing buildings and effluent storage capacities to comply to the various norms. This audit is completely paid for by the government and the water agencies. A contract is then passed with the farmer to take charge of the work deemed necessary to comply with the various norms, given the fact that only one third of the financial amount is under the farmer's responsibility. A progressive integration of eligible farms, according to their size, has been selected, knowing that there are about 70,000 such farms.

For farms which are part of the APCP, the polluting tax is estimated in a two-step process. The first step corresponds to the estimation of the gross tax. The latter depends on the dumping of suspended matter, organic matter, reduced nitrogen and phosphorus. However, since farmers have agreed to invest in order to pollute less, even if they already enjoy public aids, their gross tax benefits from an allowance under the form of a purification premium. The amount of the latter is such that the amount of the net tax becomes very small. This premium represents a very strong incentive to use spreading rather than slurry treatment, all the more since the latter is still today two to three times more costly.

To summarise, the French system of internalisation of animal related pollution shows a number of deficiencies for the consumer as well as for the producer. At the consumption level, this system negotiated between the government and farmers integrates very poorly the utility function of consumers who must pay more for their drinking water. This system is not efficient, since well-known polluters are rarely prosecuted. The limited number of people sued for damaging the environment shows that the liability principle is not strictly enforced, and therefore that this principle does not allow to internalise damages to the environment due to agriculture. At the production level, in order to prompt farmers to go by the rules, economic incentives are used under the form of aids with the APCP and, for farmers not complying with the standards the incentives are in the form of polluting charges (Doussan, 1997). The latter are only used to compensate for the lack of efficiency of regulation and police measures. Resorting to a single standard of 170 kg of nitrogen per hectare does not allow to take into account local conditions and is another cause of inefficiency. The stress put on spreading, and the indirect incentive to produce caused by financial aids granted to comply to the various standards, put even more pressure on the land market. Under such conditions, it is only logical to see the emergence of an implicit market of spreading rights.

3. THE DESIGN AND IMPLEMENTATION OF TRADABLE MANURE SPREADING RIGHTS

Instead of the previous « charges and standards » approach, the marketable permit system can be more consistent in the policy arena. Indeed, setting standards in the form of maximum nitrogen units per hectare is similar to a grandfathering system where the government can, based on historical levels of emission, distribute tradable emission rights to polluters without charging them. Each polluter thus receives a marketable asset which he can then use either to validate his own emissions or sell to someone else whose marginal benefit of pollution is higher than his on a market of permits (Cropper and Oates, 1992 ; Schöb, 1996).

Subsequently, targets and standards for environmental quality being defined, farmers will manage their manure surpluses according to their local situation. When a part of their surplus can be applied on deficit farms in the neighbourhood, we are facing a market of spreading rights. Therefore the first sub-section extends the previous microeconomic model whilst the second sub-section illustrates the potential equilibrium of such a market using the case of the Brittany region.

3.1. Modelling the tradable manure spreading rights

In order to implement the previous theoretical considerations (sub-section 2.1) and using the same notations, we now define more precisely the technology. Each farmer presents a production plan defined by a set of vectors (x_j, y_j, z_j) i.e, the input vector k_j includes x_j which indicates the factors which can be freely adjusted ; and a part of z_j the quasi-fixed inputs as land and labour. Each of these factors is used to produce the output vector y_j. T is the set of all the feasible production plans ; it is assumed to be regular and strictly convex[3] whereas inputs and outputs are strongly

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[3] T is closed, non-empty, if $y_j \neq 0$ then $(x_j, z_j) \neq 0$, if $x_j < \infty$ and $z_j < \infty$ then $y_j < \infty$.

disposable. These assumptions ensure the existence of the production function describing the technically efficient production plans.

As long as the Nitrate Directive is not enforced, the farmer is close to maximising the profit given the quasi-fixed inputs level $\bar{z}_j$:

$$\underset{x_j, y_j}{Max}\left[p'.y_j - q'.x_j \; ; \; f_j\left(x_j, y_j, \bar{z}_j\right) = 0\right] = \Pi R_j\left(p, q, \bar{z}_j\right) \qquad [10]$$

where p and q indicate the respective price vectors for y_j and x_j. The previous assumptions related to T ensure a solution for program [10] and the existence of the restricted profit function $\Pi R_j\left(p, q, \bar{z}_j\right)$. In a partial equilibrium framework the term "restricted" recalls that the optimisation has been only operated upon a subset of T; it concerns other dual expressions of the technology such as the cost function $CR_j\left(y, q, \bar{z}_j\right)$ intermediary of [10] in a step-by-step optimisation and that we shall use subsequently:

$$CR_j\left(y_j, q, \bar{z}_j\right) = \underset{x_j}{Min}\left[q'.x_j \; ; \; f_j\left(x_j, y_j, \bar{z}_j\right) = 0\right] \qquad [11]$$

The enforcement of the Nitrate Directive can be formalised as a new constraint for the technological choices of the farmer and corresponds in a second-best approach to the potential attainment of the optimal level of pollution e^* defined by equation [4] :

$$\frac{c_j y_{ja}}{\bar{z}_j} \leq \bar{e} \qquad [12]$$

$\bar{e}$ is the guideline regulating the quantity of nitrogen from animal waste that may be spread per hectare of farmland (170 kg per hectare). As previously y_{ja} represents the quantity of animal products whereas $c_j y_{ja}$ indicates the organic nitrogen by-product issued from animal breeding. The scalar $\bar{z}_j$ is the acreage of the farm which is available for spreading. Linked with the land constraint $z_j = \bar{z}_j$, expression [12] can

be or not saturated at the optimum according to the livestock size and the total acreage of the farm. However, it can be more easily relaxed than $z_j = \bar{z}_j$ since the farmers are able to lease spare land in the neighbourhood in order to spread their surplus of animal waste. In other words, the land input provides two services : one for farming and the other one for spreading. Furthermore, they can be linked insofar as some crops allow more or less organic nitrogen. In the hypothetic market for manure spreading services, the producers will be buyers or sellers depending on whether expression [12] is initially saturated or not.

Let us note z_{je} the net demand of manure spreading services for the farm j. In the present instance, manure spreading services are costless or the above limit $\bar{e}$ is not respected and that would imply a positive latent demand $z_{je} > 0$. Hence, the program for the producer can be written as :

$$\begin{aligned} &\underset{y_j}{Max}\ p'.y_j - CR_j\left(y_j, q, \bar{z}_j\right) \\ &s.t \quad 0 \le \frac{c_j y_{ja}}{z_{je} + \bar{z}_j} \le \bar{e} \end{aligned} \qquad [13]$$

whereas the possibility of a manure spreading market with a unit price w_e leads to the following behaviour :

$$\begin{aligned} &\underset{y_j, z_{je}}{Max}\ p'.y_j - CR_j\left(y_j, q, \bar{z}_j\right) - w_e.z_{je} \\ &s.t \quad 0 \le \frac{c_j y_{ja}}{z_{je} + \bar{z}_j} \le \bar{e} \end{aligned} \qquad [14]$$

The prescribed constraint applies on the overall agricultural surfaces, i.e : $\frac{n_{\bar{z}_j}}{\bar{z}_j} \le \bar{e} \quad j = 1,\ldots J$ However it remains a potential moral hazard : overspreading, multiple spreading supply of the same area,... Let us now consider the positivity constraint $0 \le \frac{c_j y_{ja}}{z_{je} + \bar{z}_j}$. It is saturated for a zero livestock production : $y_{ja} = 0$. In that

case, the farmer potentially supplies the whole surface for a manure spreading service. Furthermore some crops such as vegetables do not tolerate manure which involves : $z_{je} > -\bar{z}_j$. This last inequality is also true in the case where the positivity constraint is not saturated at the optimum. Then we may deduce the expression of the lagrangian related to [14] :

$$L\left(p,q,w_e,\lambda,\bar{z}_j,c_j,\bar{e}\right) = p'.y_j - CR_j\left(y_j,q,\bar{z}_j\right) - w_e.z_{je} - \lambda.\left[\frac{c_j y_{ja}}{z_{je}+\bar{z}_j} - \bar{e}\right] \qquad [15]$$

with the following first-order conditions :

$$\begin{aligned} & p_a - \frac{\partial CR_j}{\partial y_{ja}} - \lambda \frac{c_j}{z_{je}+\bar{z}_j} = 0 \\ & p_m - \frac{\partial CR_j}{\partial y_{jm}} = 0 \quad \forall m \neq a \\ & -w_e + \lambda \frac{c_j y_{ja}}{\left(z_{je}+\bar{z}_j\right)^2} = 0 \end{aligned} \qquad [16]$$

Eliminating the multiplier λ we obtain the total demand of manure spreading service for the farm j :

$$z^*_{je} + \bar{z}_j = \frac{y^*_{ja}}{w_e}\left[p_a - \left.\frac{\partial CR_j}{\partial y_{ja}}\right|_{y^*_{ja}}\right] \qquad [17]$$

$z^*_{je}\left(p,q,w_e,\bar{z}_j,c_j,\bar{e}\right)$ and $y^*_{ja}\left(p,q,w_e,\bar{z}_j,c_j,\bar{e}\right)$ being the solutions of [14]. Resolving this program also allows us to define the restricted profit function :

$$\Pi R_j\left(p,q,w_e,\bar{z}_j,c_j,\bar{e}\right) = \underset{y_j,z_{je}}{Max}\left[p'.y_j - CR_j\left(y_j,q,\bar{z}_j\right) - w_e.z_{je} \,;\, 0 \leq \frac{c_j y_{ja}}{z_{je}+\bar{z}_j} \leq \bar{e}\right]$$

The competitive market equilibrium for manure spreading rights is characterised by a rental price w^*_e, solution of the following equation :

$$\sum_{j=1}^{J} z_{je}^{*}\left(p,q,w_e,\bar{z}_j,c_j,\bar{e}\right)=0 \qquad [18]$$

3.2. A first empirical illustration

The previous model has been the object of an application using the results obtained through a direct survey in Brittany. This region has experienced a large growth in livestock farming in the last three decades. In particular, the number of pigs and poultry has strongly increased, representing respectively 55 per cent and 45 per cent of the total French production (SCEES, 1996). Moreover, Brittany is the first region for milk production. As a result, it has the highest disposal rate per unit of land relative to other French regions. Because of its geological features, Brittany has 80 per cent of total disposable water coming from water streams and reservoirs. In consequence, the region is vulnerable to nitrate and phosphate pollution and 60 per cent of water resources are threatened in the near future (SRAEP, 1996). In some places, the use of aquifers had to be abandoned and water treatment supplemented with denitrification. Nowadays, about 60 000 persons are fed with a drinking water exceeding the maximum allowable concentration whereas 850 000 people are occasionally exposed to drinking water with concentrations over 50 mg/l.

The overall results of Brittany farms that depend on the APCP allow to characterise the farms which need large spreading areas and, on the contrary, those which are likely to receive animal effluents. This highlights the fact that intensive farms with rearing installations specialised mainly in pig production or in pig and bovine production need between 10 and 40 hectares of spreading land outside the farm. On the contrary, less intensive farms with rearing installations specialised in bovine production have 5 to 15 hectares of unused spreading capacities.

The previous model has been applied to two samples of French intensive livestock farms located in Brittany and whose rearing installations are specialised

mainly in pig production and in pig and bovine production. Table 1 provides some statistics about them.

Table 1 : Main characteristics of the two samples

	Pig farms	mixed farms (pig and bovine rearing)
Structure of the total output		
animal output % total	92.8	90.7
crops output % total	5.5	5.6
subsidies % total	1.7	3.7
Total output (10^3 FF)	2324.8	1733.2
Total of variable costs (10^3 FF)	469.8	454.3
Useful agricultural area (ha)	50.1	68.1
Total Nitrogen Livestock Units	176	168
Units of family labour	2.3	2.6
Units of paid labour	0.6	0.1

The various outputs (vegetables and livestock) are indexed by $m, m = 1,...M$ with $y_j = \left(y_{j1},...y_{jm},...y_{jM}\right)$. The objective function that we intend to maximise expresses the producer's rationale behaviour. Given the availability of data this function is defined from the gross margins per activity GM_{jm} which can be written as :

$$GM_{jm} = p_m y_{jm} - CR_{jm}\left(y_{jm}, q, \bar{z}_j\right) \qquad [19]$$

where p_m and q represent output and input prices, y_{jm} the output quantities and $\bar{z}_j$ the quasi-fixed factors. We calculate the total gross margin as the sum of the margins per activity[4] :

$$GM_j\left(p, y_j, q, \bar{z}_j\right) = \sum_m GM_{jm} = \sum_m p_m y_{jm} - CR_{jm}\left(y_{jm}, q, \bar{z}_j\right) \qquad [20]$$

whose maximisation corresponds to the restricted profit function defined by [10] :

$$\underset{y_j}{Max}\, GM_j\left(p, y_j, q, \bar{z}_j\right) = \Pi R_j\left(p, q, \bar{z}_j\right) \qquad [21]$$

In fact this optimisation is constrained by some quasi-fixities on inputs and outputs. They can be expressed as linear constraints related to land availability[5], family labour, milk quotas, cultural rotations, size of rearing installations...

The resolution of [21] is obtained using S.A.S./O.R procedures which provides : ΠR_j (value of the objective function for each farm), $\dot{y}_{jm}$ (optimal quantities per activity) and $\frac{\partial \Pi R_j}{\partial \bar{z}_{jk}}$. This last term represents the marginal increase of the restricted profit provided by a marginal increase of the quantity $\bar{z}_{jk}$. It is still defined as the shadow price $\bar{w}_{jk}$ related to $\bar{z}_{jk}$ which is equal to the unit price w_k of the input z_k where the maximisation states upon the whole input space.

The prescribed constraint linked to the Nitrate Directive can be considered also as a quasi-fixity. It first leads to define the shadow price $\bar{w}_{je}$ issued from the restricted profit function $\Pi R_j\left(p, q, z_{je}, \bar{z}_j, c_j, \bar{e}\right)$ such as :

$$\bar{w}_{je}\left(p, q, z_{je}, \bar{z}_j, c_j, \bar{e}\right) = \frac{\partial \Pi R_j}{\partial z_{je}} \qquad [22]$$

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[4] That implies the non jointness of the technology : this assumption is questionable but imposed by data.

[5] Quasi-fixed factors as land or family labour can be allocatable according to the different activities : $\bar{z}_{jk} = \sum_m \bar{z}_{jkm}$

The farmer compares this last value with w_e^* solution of [18]. As an illustration, if $\overline{w}_{je} > w_e^*$ there is a marginal gain to rent land for spreading. Following Färe and Primont (1995 p.56) the estimated values $\overline{w}_{je}$ have been calibrated by w_i which is the average price for hired land. For w_i = FF 1,000 (corresponding to the observed price of the rent in Brittany), resolution of [21] and [22] leads to higher shadow prices for spreading services from FF 1,170 to FF 1,300 in the case of pig farms.

Moreover, the resolution in z_{je} of:

$$\overline{w}_{je}\left(p,q,z_{je},\overline{z}_j,c_j,\overline{e}\right) = w_e \quad j = 1,\ldots J \qquad [23]$$

provides $z_{je}^*\left(p,q,w_e,\overline{z}_j,c_j,\overline{e}\right)$ the net demand of manure spreading services for the farm j. In fact, equation [23] is just another way of writing one of the first order necessary conditions of the program [14]. According to the two studied samples, these values are represented in figures 1 and 2 which also indicate the equilibrium price w_e^*, solution in w_e of [18].

Figure one : Market equilibrium for intensive pig rearings

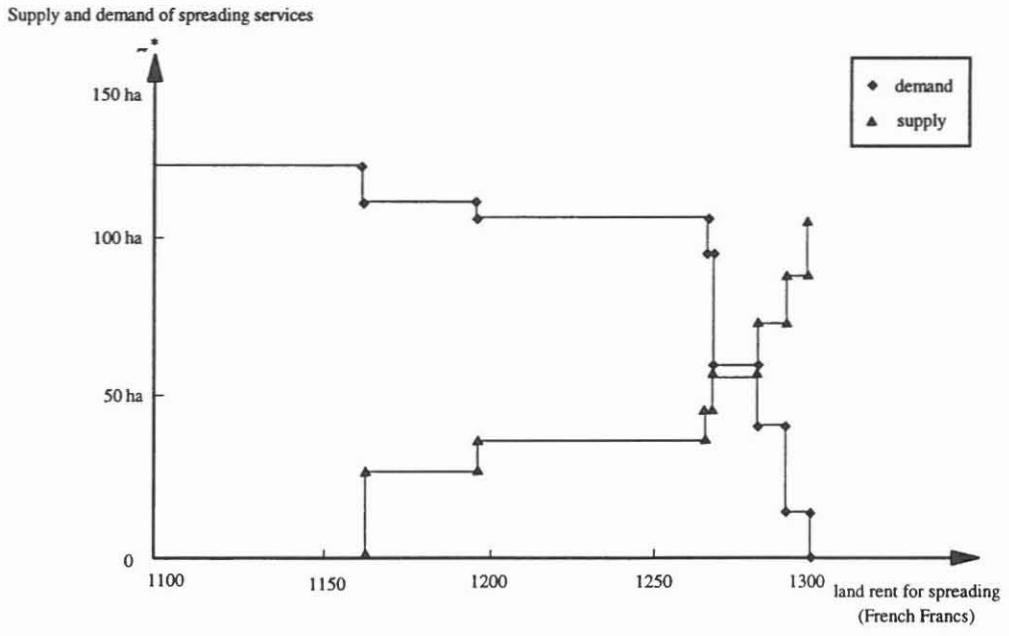
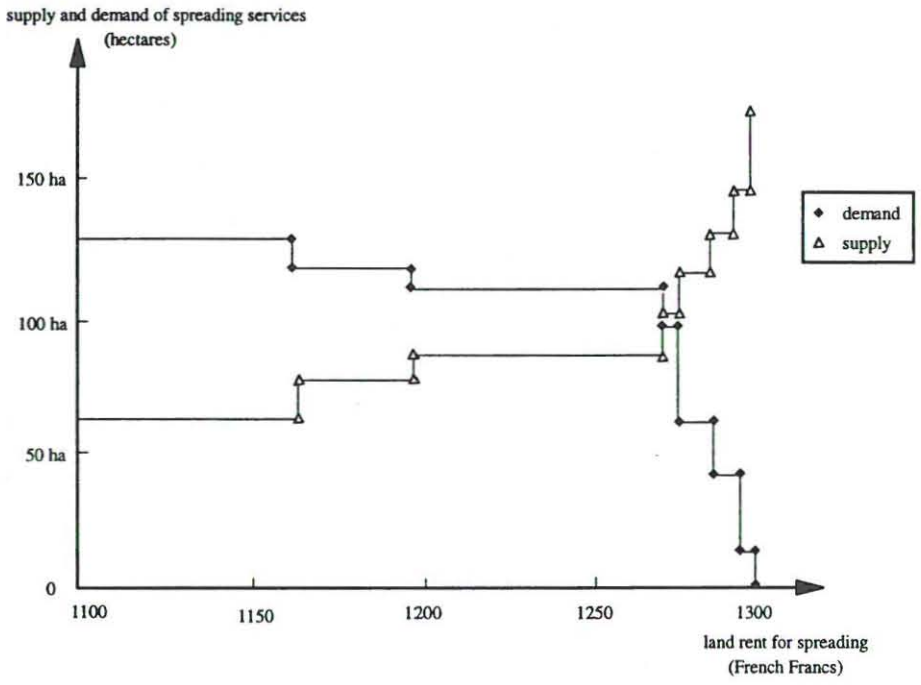


Figure two : Market equilibrium for mixed breedings economy



One could expect to obtain a more important equilibrium price w_e^* in the case of farms specialized in pig production because of a lesser average land availability (cf table 1). However, in the two study cases, the equilibrium price is similar and varies between FF 1250 and FF 1300. That can be explained by the Act on classified facilities : the application was stricter for land-independent husbandry, especially for storage capacities. Thus, cattle breeders are penalised through lack of storage capacities and require subsequently more acreage for spreading.

The use of land off the holding for waste spreading will be limited by the cost of transportation. For pig manure such cost reaches FF 0.77 per ton and per km (Poux and Barbut, 1997).

4. CONCLUSION

The model developed shows that the internalisation of animal related pollution requires the creation of two markets of rights to pollute. The first market between producers and consumers is impossible to install. The regulation means used instead are not very efficient, since these regulations are the result of a negotiation between the administration and the professionals. Consumers are not in any of the two parties' mind. The only progress is the unofficial set up of an exchange market dealing with rights to pollute between producers who, by exceeding the standard of 170 kg of nitrogen per hectare need additional spreading areas, and farmers who use less intensive production systems, and can, therefore, receive some slurry.

The way this market between producers operates is detailed in a generic model that takes into account the fertilising value of slurry. For the sake of simplification, this model does not integrate the cost of transport of slurry, which limits its practical use. However, a preliminary application shows shadow prices of spreading areas that are higher than the usual land rental cost. It is therefore obvious that the use of this parallel market of spreading rights is the answer of producers to regulations when they are located in areas with a high animal density. In the current price context, it is possible to extrapolate the effects of an increase of the production density on the shadow land prices. At a certain level, it is not in the producers' interest to look for new spreading areas. Rather than exporting their slurry at an increasing cost, either because lands are too expensive or because transport costs are too high, they must use other solutions.

The first solution is to use animal food which is less rich in proteins, which allows to decrease the nitrogen content of the effluents. At first, it is possible to decrease noticeably the nitrogen content, by about 25% for pigs (Dourmad *et al.*,1995). Above that value, the cost increases drastically and the rearing becomes much more difficult. It may then become more interesting to consider manure processing. There again regulations may play a role. In areas of structural excess, the limitation of spreading areas per producer would right away make the processes of slurry treatment more attractive.

As a last resort, when the marginal cost of the excess nitrogen unit becomes too high, the solution may be to decrease the production level. The only way to internalise pollution of farming origin is to play with this parameter.

REFERENCES

Baumol W.-J., Oates W.-E., (1988) : **The theory of environmental policy**. Cambridge University Press.

Cropper M.-L., Oates W.-E., (1992) : Environmental Economics : a Survey. **Journal of Economic Literature**, vol. XXX (June 1992), p. 675-740.

Dales J. H., (1968), Pollution, property and prices. Toronto, Ont. : U. of Toronto Press, 1968.

Doussan I., (1996), Production négociée du droit des pollutions agricoles. Colloque CREDECO, Nice, 30-31 octobre 1996 "Après la déréglementation, les nouvelles formes de régulation : premier bilan".

Dourmad J.Y., Le Mouël C., Rainelli P., (1995), Réduction des rejets azotés des porcs par la voie alimentaire : évaluation économique et influence des changements de la Politique Agricole Commune. **INRA Productions animales** (8) p. 135-144.

Färe R., Primont D., (1995), Multi-output production and duality : Theory and applications. Kluwer Academic Publishers.

Leneman H., Giesen G.-W.-J., Berentsen P.-B.-M., (1993), Costs of reducing nitrogen and phosphorus emissions on pig farms in The Netherlands. **Journal of Environmental Management** (39), p. 107-119.

Léon Y., Quinqu M., (1994), Réforme de la PAC : un faible impact sur la répartition régionale des valeurs ajoutées. **INRA Actes et Communications** (12), 119-146.

Official Journal of the European Communities, (1991), Council Directive concerning the protection of wtaers against pollution caused by nitrates from agricultural sources, 91/L375/EEC 01-07.

Poux X., Barbut L., (1997), Etude sur l'insertion optimale des procédés de traitement dans les cantons en excédebt structurel. Application des sciences de l'action. Agence de l'Eau Loire-Bretagne-Ministère de l'Environnement.

Rigby D., (1997), European Community guidelines to reduce water pollution by nitrates from agriculture : an analysis of their impact on UK dairy farms. **Journal of Agricultural Economics** 48 (1) p.71-82.

Rigby D., Young T., (1996), European environmental regulations to reduce wtaer pollution : an analysis of their impact on UK dairy farms. **European Review of Agricultural Economics** (23) p. 59-78.

Schöb R., (1996), Choosing the Right Instrument, The Rôle of Public Revenues for Environmental Policy. **Environmental and Resource Economics** 8, p. 399-416.

Shortle J. S., Dunn J.W., (1986), The relative efficiency of agricultural source water pollution control policies. American Journal of Agricultural Economics (68) p. 668-677.

SRAEP, (1996), Schéma régional d'alimentation en eau potable. Novembre 1996, Région Bretagne, 57p.