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Modelling agricultural and environmental policy using a bio-economic approach

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Abstract

Environmental problems created through the intensive use of fertilisers and pesticides are very serious all over the world. From the technical perspective solutions exist, but without specific policies it is difficult to imagine that farmers will adopt them, since those solutions usually imply higher costs of production. The economic and environmental consequences of alternative agri-environmental policies will be presented here using a farm-level model.

The first part of the paper presents the concept of environmental risk and the theoretical difficulties of treating this problem. While concentrating on the different techniques used, it is argued that an econometric approach is too far from the biological specificity to be used to evaluate different policies. A bio-economic model is therefore needed to understand more clearly the biological aspects of water pollution.

An example will then illustrate the treament of groundwater nitrate pollution in Europe. The results obtained from a research project, named POLEN, that was supported by the European Community will be used. This research is based on the joint application of a bio-physical model and a mathematical programming model. Two alternative policies designed to reduce nitrate pollution are tested. The first one is a contractual approach: production plans using environment-friendly techniques are proposed to farmers, offering them compensation for income losses. The alternative is to place a tax on the input. We used the POLEN model with data from the "Vallées et Terrasses" (South-West France) region.

1. Introduction

Environmental policies first concentrated on point-source industrial pollution. Attention later shifted to non-point source surface and groundwater pollution where the agricultural sector was pinpointed as the main polluter of water supply. Hence, governments are required to counter ecological damage caused by agricultural practices, and the question immediately arises on the type of policies to be implemented. Agriculture has its own specificity implying an important influence on the type of policies to be implemented.

The agricultural sector often receives price support and direct subsidies (the Common Agricultural Policy in Europe is an example) that has reinforced the intensification of production. It is difficult to suggest a tax on agricultural products, subsidised otherwise, without having contradictory effects.

Land is a fixed input, and price subsidies create a spiral in distortions: high product prices induce intensification, intensification induces a higher price for land (rent), and high use of chemical inputs creates negative externalities.

However, pollution created by chemicals inputs cannot be linked in a linear way to the level of intensification. The relationship between agricultural practices and pollution is extremely complex: The types of rotations, and the type of crops, have crossed effects on the level of nitrate pollution. Even more, what is really important is not the average pollution level, but the pollution level that exceeds accepted standards, on some climatic conditions. As pollution is a stochastic phenomena, it is necessary to treat it taking into account the existence of different states of nature. That is why coupling a biophysical model with a mathematical programming one, and introducing environmental risk, appears to be an appropriate way to deal with this question.

In this paper we use the results obtained from a research project, named POLEN, that was supported by the European Community[1]. This research is based on the joint application of a biophysical and a mathematical programming model. Two alternative policies designed to reduce nitrate pollution are tested. The first one implies a contractual approach: production plans using environment-friendly techniques are proposed to farmers offering them compensation for income losses.

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[1] "Impact Analysis of Different Policies in Several European Regions". A European project dealing with the socio-economic and environmental impacts of Common Agricultural Policy Reform. The Project was realised between 1991 to 1995.

The alternative is to tax on the input. We used the POLEN model with data from the "Vallées et Terrasses" (South-West France) region.

2. Environmental risk

2.1. Scale of the study

Assessment on the effects of agricultural and environmental policies requires an understanding of the relationship between production, agricultural techniques, income and pollution.

We study these relations in a small agricultural region, in Southwest France, “Vallées et Terrasses”, represented by a farm model built upon the characteristics of the modal farm of the region.

2.2. Deterministic vs stochastic approach of environmental issues

At least two approaches are possible when environmental issues are considered. The first often used approach considers the average environmental damage over a large number of years. The effects of different policies are then tested on this index. One of these policies can be the establishment of a maximum limit in the chemical loading of groundwater due to agricultural practices. Some recent research, (Teague *et al.*,1995) showed that a deterministic solution, constraining the expected value of the chemical loading below the given target level, leaves a large place to specific climatic situations in which chemical loading exceeds this target.

Therefore there is a need to develop a stochastic approach for the study of agri-environmental issues.

Target MOTAD was introduced (Tauer, 1983) to better represent the attitude of "safety first" towards risk. The decision-maker fixes an objective to be attained, but allows some negative deviations below this objective. This idea is similar to a goal programming approach.

Environmental risk can be studied as economic risk, with the advantage of having clear information on the target . In this article we use a target MOTAD approach to analyse the risk of pollution by agri-chemicals (Flichman,1995; Jourdain,1995; Teague, *et al.*,1995)

An important difference concerning environmental risk, compared with economic risk, is that it has a more "objective" and general meaning than economic risk. More objective, because the limit we place on an environmental variable is obtained from some criteria, related to a standard. This can also be done in economic models, when they are strictly normative. But in models built to make policy analysis, risk is usually used as a mean of calibration of the model (nobody really knows the risk aversion of farmers, and even if you know it, there is always the problem of aggregation). Methods of limited risk, such as Target MOTAD, appear very suitable for analysing environmental risk, and the interpretation of what we are limiting and why is, in this case, quite clear.

3. Mathematical programming

Mathematical programming models have a long tradition in the analysis of agricultural production systems, because they show explicitly how resources are used and the effects of policy constraints. An additional component including environmental parameters and constraints can easily be added. Besides information on cropping pattern, cultivation method, labour supply and needs, environmental criteria for each activity is included in the model. Different constraints on the environmental effects of agricultural practices can then be added.

3.1. POLEN model

The POLEN model is a farm linear programming model, with special characteristics:

- It uses simulated data obtained with the agronomic model, EPIC. Part of the technical coefficients used have been obtained through simulations done with the EPIC model. These coefficients are crop yields and pollution indicators. The pollution index used is the summation of all nitrate losses (leaching, sub-surface flow and run-off).
- POLEN is a recursive model. Optimisation is annual, and the results of each year have an influence on the following year, as well in terms of yields associated with different rotation schemes as in relation with the availability of capital goods, financial flows, etc.

- Risk is treated in the model using a method that combines Freund's approach with the Target MOTAD method (Tauer, 1983). We consider different "states of nature" : (a) those determined by climatic conditions that will affect yields and nitrate pollution; (b) those determined by future price variations; and (c) those determined by future expectations on subsidies variation. The complete set that defines the states of nature is built upon a series of climatic inputs obtained using historical long-term climatic data and their influence on yields. In addition, future variations of prices and subsidies are built according to common sense criteria, the results of farmer's and policy makers' expectations. A gradual reduction in prices is foreseen both by farmers and policy analysts after the CAP-reform but the level of subsidies paid cannot be considered as a sure event. Thus, in our model we attach different subjective probabilities to expected subsidies based on the current year's level (years 3 to 5 in the recursivity).

The POLEN Model permits an analysis of the technical, socio-economic and environmental aspects of the problem within a unified framework. The integrated use of a very comprehensive agronomic simulation calculator with a mathematical programming model, make it possible to associate the techniques chosen for production with yields and potential levels of pollution. All this is done in relation with each specific soil and weather situation. The same level of irrigation and fertilisation may have quite different effects in terms of nitrate pollution according to weather and soil conditions. EPIC makes the calculation per hectare, for all of the simulated techniques and this information enters the linear programming model. When we obtain the optimal solutions from the economic point of view (concerning different scenarios), it is possible to observe the associated results in terms of potential pollution. In another way, we can run the model with the aim of evaluating the "cost" in terms of farmers' revenue losses caused by an imposed reduction on the pollution level and also calculate the results concerning production level and land use pattern.

2.1.1. Definition of the crop production activities

The economic model is built out partially from simulated data obtained using the agronomic model EPIC. We defined the dimensions of the crop production activities in order to be consistent with the information provided by EPIC. The name of a crop corresponds to the name of one of the crops defined in the EPIC cropfile, that is the first dimension. The second dimension is the technique, associated with each technical schedule applied to that crop. The soil is the third dimension and the last one is the previous crop in the rotation.

a large number of technical coefficients are associated with each crop activity, defined in this way. These are all defined "ex-ante" and incorporated principally in auxiliary external files to make the core of the model as "clean" as possible.

Some of these technical coefficients come from input and output EPIC files. They are:

1 - yields;

2 - environmental results (nitrate leaching, run-off and sub-surface flow). The addition of these results is referred in the text as nitrate loss, or potential nitrate pollution;

3 - tillage, fertilizer, irrigation, pesticide application, supervision, seeding and any other operations taking part in the technical schedule;

4 - quantities of inputs applied.

Coefficients mentioned in points 1 and 2 come from the EPIC output. This data are obtained from simulations of five typical climatic years, that are a representative sample of a 25- year period.

3.1.2. Principal equations of the POLEN model

• *The objective function*: Farm Net Revenue is maximised. Yields considered for the calculation are the average of the five years' simulations. The optimisation process is annual. Capital goods (irrigation equipment, tillage equipment) may be increased on an annual rental basis.

$$MAX\ U(X_t, Y_t) = E[NETINCOME(X_t, Y_t)] - \varphi .\ \lambda(X_t, Y_t) \qquad (1)$$

where $U(.)$ is the utility level; X_t the set of farming decisions in period t, including the allocated surface to crops, techniques, use of inputs, and so on; Y_t represents the set of financial variables, such as monthly cash-flow, interest payments and investment level; $E[.]$ is the expected value operator; NETINCOME, fully described in equation 2, is net income; φ is the risk-aversion coeffient; $\lambda(X_t, Y_t)$ and is the sum of negative deviations of what from $E[NETINCOME(X_t, Y_t)]$, as expressed in equation 6. An element of the farming variables X_t may, for example be expressed as: WHEAT. T1. S2. SUNFLOWER. YES. This shoul be interpreted to mean 1 hectare of wheat (WHEAT) grown with technique 1 (T1), on soil 2 (S2), with sunflower as the previous crop, under the CAP-reform regulations (denoted by YES).

$NETINCOME\ (.)$ is composed of the following elements:

$$NETINCOME(X_t, Y_t) = REVENUE(X_t;P_t) + SUBSIDY(X_t) - VARCOST(X_t) \\ - FINANCOST(Y_t, Y_{t-1}) - FIXEDCOSTS \qquad (2)$$

where P_t is the vector of prices for year t; $REVENUE(X_t;P_t)$ represents the crop revenues resulting from the multiplication of yields (EPIC output) with crop prices and hectares allocated to each crop; $SUBSIDY(X_t)$ is the sum of all collected subsidies under the CAP-reform; $VARCOST(X_t)$ is the sum of all variable costs; $FINANCOST(Y_t, Y_{t-1})$, are the net financial costs dependent on financial decisions in years t and $t-1$.

The maximisation problem is subject to the following constraints:

- *Rotational constraints* : Equation 3 expresses the rotational constraints. It simply means two things: all land available is subject to the set aside provisions of the CAP-reform, and land allocated to a particular crop i over crop j in year t, has to be less than the surface of crop j grown in year $t-1$; its purpose is to model rotational constraints.

$$\Sigma X_t \leq \Sigma X_{t-1} - SETASIDE(X_t) \qquad (3)$$

- *Labour constraints* : This is the simplest farm labour balance equation used in the project. It says that the sum of all labor requirements is less than the amount of permanent labor available in the farm (*FARMLAB*), plus the amount of hired seasonal labour *SEASON(t)*. *FARMLAB* is an exogenous parameter. According to the characteristics of the labour markets in the different regions, labour constraints have been expressed differently[2].

$$\Sigma(X_t{*}LABOR(X_t)) \leq FARMLAB + SEASON(t) \qquad (4)$$

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[2] This is very important in the Spanish region. See G.Flichman, A.Garrido, C.Varela. "Agricultural policy and technological choice: a regional analysis of income variation, soil use and environmental effects uncertainty and market imperfections". AEEA-CIHEAM Seminary, Zaragoza, February 1994.

- *Risk constraints* : Risk is considered according to the next two equations:

$$NETINCOME(X_i, Y_i; e,q,n) + DEV^{-}(e,q,n) \geq E[NETINCOME(X_i, Y_i)] \qquad (5)$$

Equation 5 computes for each combination of states of nature the negative deviations of actual net income from the expected value of net income. Parameters (e,q,n) represent three different sources of instability. Subsidies instability is represented by e, and can take three values for each crop within the CAP-reform (e_1, e_2, e_3). Yields instability is accounted for by the parameter q, which in turn can take 5 values, one for each year of the five years considered in the EPIC model simulations[3] (q is high in good years, and low in bad years). Lastly, price instability is reflected by the parameter n, which can take two values (n_1, n_2) one is optimistic and the other pessimistic. In sum, constraint 5 is represented by (3*5*2=30) equations, one for each combination "states of nature" situations.

$$\Sigma_e \Sigma_t \Sigma_n DEV^{-}(e,t,n) \leq \lambda(X_i, Y_i)*30 \qquad (6)$$

Equation 6, sums up all the negative deviations and makes them less than or equal to $\lambda(X_i, Y_i)*30$. It is multiplied by 30 because there are (3*5*2) combinations of states of nature. The right-hand side in this equation is multiplied by the risk aversion coefficient, and appears in the objective function (equation 1) with a negative sign.

Other equations, not writen here, deal with other specific constraints, technical and economical, applicable to each region. In the cases where irrigation activities are incorporated, additional constraints related with variable water availability are taken into account.

Pollution is estimated in terms of total nitrate losses in the farm. EPIC calculates the losses for each crop activity, and these values are incorporated as associated parameters of the production activities. It is then possible to "count" the potential nitrate pollution that is related with each specific optimal solution of the model.

4. Policy simulations

The POLEN Model allowed us to explore the possibilities of applying two types

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[3] These five years are a representative sample of the climatic conditions of the Regions, obtained from data of long period climatic data (between 25 and 35 years).

of policy in order to reduce nitrate pollution : 1. The adoption of production plans that limit potential pollution without affecting price structures and 2. The introduction of a tax on nitrogen fertiliser. We used the model built for the "Vallées et Terrasses" region to simulate the possible effect of these policies.

In the first case, the obtained results correspond to the best production plan in order to maximize the objective function and limiting pollution in two different ways : 1.1 imposing a limit to average pollution respect to climatic influence and 1.2. limiting the level of pollution for each type of climatic year, with three levels of tolerance for the non-respect of the imposed limit.[4]

$$NITLOSS(X_p,Y_p,n) - DEV^-(n)\_\leq\_BUT(X_p,Y_t)] \quad (7)$$

$$\Sigma_n DEV^-(n) \leq \lambda E(X_p,Y_t) \quad (8)$$

NITLOSS is the total loss of nitrates, as estimated by EPIC for each production activity. *BUT* is the limit to pollution, applied for each climatic situation and *lE* is the limit to the accumulation of deviations (Target MOTAD)[5]. It may be useful to remind that we considered five types of climatic years.

For the second case, we present the results of simulating a tax to nitrogen of 200% (necessary level to obtain a sensible reduction to pollution).

Figures 1 and 2 show the effects created by imposing different level of restrictions to pollution, or applying a 200% tax to nitrate fertilisation. Each set of bars is composed of four elements: (average) nitrate pollution (kg/ha), nitrate pollution the climatic year when it is the highest, farm income level and irrigated surface. Income and irrigated surface are measured by an index. Set "no ref." reflects the scenario without applying the Common Agricultural Policy Reform prices and subsidies, and without any restriction to pollution. Set "avg." represents

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[4] We apply the Target MOTAD approach to pollution risk (Teague *et al.*, 1995). The levels of potential pollution correspond to an average of the farm. They may vary strongly, depending on soil type, crop and technique. The data base used for nitrate has approximately 5000 values per each region, obtained by means of EPIC simulations.

[5] In the original formulation of Target MOTAD, equation 8 appears as an equality.This formulation is also used by Hazell and Norton (1986), Teague et al. (1995), and many other authors. We think it is not correct. The deviations should not be obliged to be equal to a certain limit, but "equal or inferior". Introducing the equality, provokes also computational problems. It is usual to find infeaseable problems, that can be easily solved when we replace the sign of the equation.

the situation with a restriction to average pollution. In the sets "but 1", "but 2" and "but 3", a restriction is imposed for all the climatic years, with three different levels of *lE*.

In figure 2, the set "reform" shows the scenario with CAP Reform and without any restriction to nitrate pollution.

Figure 1

Income and Pollution - Non Reformed CAP

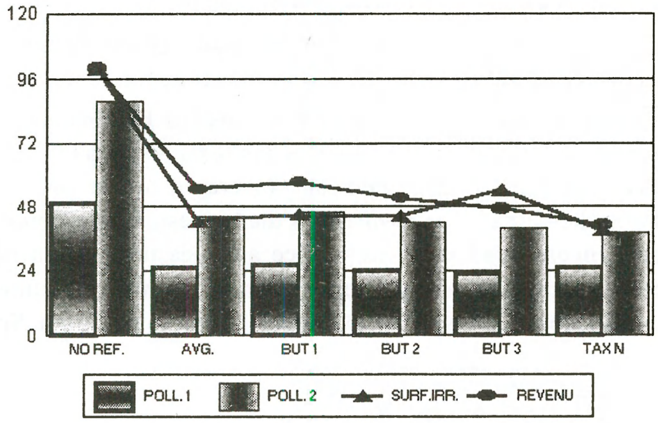
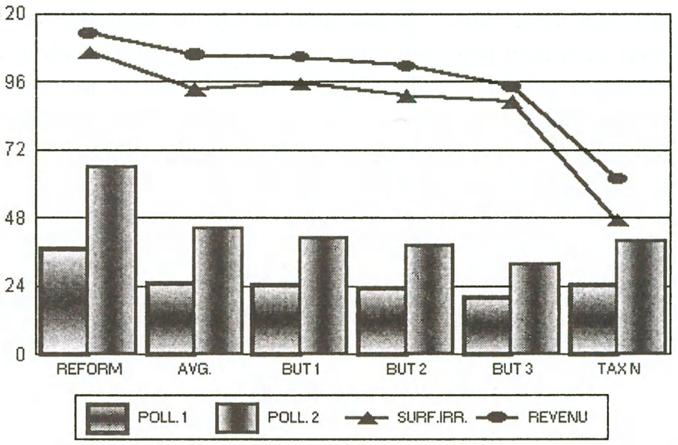


Figure 2

Income and Pollution - Reformed CAP



The results shown in the figures may appreciate the importance of CAP Reform concerning the relations between potential pollution levels and farmers' incomes. In the scenario without reform, if we impose constraints to pollution, income losses are much higher that in the "reform" scenario. It is possible to propose to farmers production plans allowing a sensible pollution reduction with very small losses in income. Under these conditions, after CAP Reform, implementing environmental protection policies becomes easier. Cost of imposing restrictions to pollution in terms of income losses will be lower in the post CAP Reform situation.

Two types of pollution restriction policies have been tested with the model:

In the "reform scenario", a policy for reducing nitrate pollution based upon a tax on nitrogen use, would cause a severe income diminution. The alternative, based on a contractual policy ("cahier de charges") would produce only a small reduction of farmers' income. The nitrogen tax would also produce a strong reduction in irrigation (see figure 2). In this region, well managed irrigation allows a better use of nitrogen by the crop, avoiding leaching provoked by rain that falls in the bad period. Pollution is not directly correlated with the quantity of nitrogen applied, that is the reason of the inefficiency of a tax to reduce pollution.

We have calculated the budgetary cost of these two policies (in the case of the reform scenario). Table 1 shows quite clearly that applying a contractual policy has a lower cost than applying a tax to nitrogen. Cost of each policy was calculated assuming a complete compensation for the loss of income determined by the reduction of pollution. In the case of the tax policy, the product of the tax is deduced from the cost. That means that the cost in Table 6 is the difference between income reduction and tax perception.

Table 1

CAP Reform Scenario

	BUDG.COST/ ha	POLL 1	POLL 2	IRRIG. SURF.
BUT 1	89	24.69	41.31	44.83
BUT 2	124	23.21	38.10	42.84
BUT 3	199	19.98	31.55	41.84
TAX	184	24.77	39.71	22.26

The advantage of a policy based upon contracts with farmers, compared to one applying a tax to nitrogen use, comes from the fact that a tax provokes the search for a production plan using less nitrogen. But pollution is not linearly determined by the quantities of nitrogen used. Rotations and type of technique used strongly influence pollution levels. An indirect way to reduce pollution using the price structure could be applied, but it would be necessary to modify more than one input price to obtain good results. A contractual policy creates the problem of additional costs for controlling the application of the established norms by farmers. This is an important problem in general terms, but in the case of the agriculture of the European Union, a minor one. Farmers have already to give an enormous amount of information, that is controlled, to get the subsidies per hectare payments. This type of contractual policy will imply a relatively low marginal control cost.

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Özet

Biyo-iktisadi bir yaklaşım kullanarak tarım ve çevre politikalarının modellenmesi

Gübre ve böcek ilacı kullanımında ortaya çıkan çevre problemleri dünyanın her köşesinde ciddi boyutlara ulaşmıştır. Teknik açıdan çözümler bulunsa da teşvik edici politikalar olmadan çiftçiler genelde daha yüksek üretim maliyetlerini beraberinde getiren bu çözümleri benimsemeyebilir. Çalışmada çiftlik bazında bir modelle, değişik tarım-çevre politikalarının ekonomik ve çevre etkilerine bakılmaktadır.

Makalenin ilk kısmında 'çevre riski' kavramı ve bu kavramın teorik güçlükleri özetlenmektedir. Değişik politikaları kıyaslayabilmek açısından ekonometrik bir yaklaşım kullanmak sakıncalıdır çünkü sorunun biyolojik özelliklerinden uzaklaşılmış olur. Bu yüzden su kirliliğinin biyolojik açılarını daha doğru bir şekilde algılayabilmek için bir biyo-iktisadi model kullanılması gerekir. Bu çalışmada, örnek olarak Avrupa'daki yeraltı sularının nitrit kirliliği alınmıştır. Bunun için de Avrupa Topluluğu tarafından desteklenen POLEN adlı araştırma projesinin neticeleri kullanılmıştır. Yapılan çalışma matematiksel programlama modeli ve biyo-fiziksel bir modelin ortak uygulanmasına dayalıdır. Nitrit kirliliğini azaltmayı amaçlayan iki farklı politika sınanmıştır. İlk yaklaşımda çiftçilere çevre-dostu üretim planları önerilir ve bu öneriyi kabul eden çiftçilerin gelir kayıpları tazminatla karşılanır. Diğer yaklaşımda ise kullanılan girdi üzerinden bir vergi alınır. Kullanılan POLEN modelindeki veriler 'Valleés et Terrasses' Güney-Batı Fransa bölgesinden alınmıştır.