

SOME CONCEPTUAL ISSUES CONCERNING THE WAY TO MODEL THE RELATIONS BETWEEN AGRICULTURE AND ENVIRONMENT

Guillermo Flichman (1), **Kamel Louhichi** (2), **Jean-Marie Boisson** (2)

(1) CIHEAM-IAMM; (2) INRA, économie publique; (3) Université de Montpellier I



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SOME CONCEPTUAL ISSUES CONCERNING THE WAY TO MODEL THE RELATIONS BETWEEN AGRICULTURE AND ENVIRONMENT USING BIO-ECONOMIC MATHEMATICAL PROGRAMMING MODELS

"Par ma foi ! il y a plus de quarante ans que je dis de la prose sans que j'en susse rien..."
M. Jourdain, "Le bourgeois gentilhomme", Molière
"Linear is beautiful", GF

Abstract

In the last years there has been a significant development of bio-economic models, especially those integrating biophysical models (called also agronomic or cropping system models) and economic mathematical programming models. This development was enhanced by the conjunction of several factors such as the multiplicity of objectives in new agricultural policies, the increase of demand for multi-disciplinary approaches for integrated assessment, the call for more dialogue and cooperation between scientists from diverse disciplines... An important number of bio-economic models was developed and tested on different farming systems and under various agro-ecological conditions (Janssen and van Ittersum, 2007). Nevertheless, this rich body of literature on empirical applications of bio-economic models was not followed by a conceptual development related to this type of models. Indeed, there is not enough literature regarding the relations between this models and the economic theory, their main interest compared to conventional economic approaches, their specifications and contributions in strengthening collaboration and improving integration between different disciplines...

The aim of this paper is to develop some conceptual and theoretical issues related to the bio-economic models (principally the farm models) and to present the suitable way to use this type of approach for modelling the relations between agriculture and environment and more largely for the integrated assessment.

A bio-economic model is known generally as a linkage between models from different disciplines to provide multi-disciplinary and multi-scales answers to a given problem. In reality, the philosophy behind this approach is more complicated. A bio-economic model should not be a simple link between models through an exchange of information but a real integration in both conceptual and technical terms. This has twofold implications: first, we are facing a new approach which should have a clear position in the economic and agronomic scientific corpus, and second, the construction of each model should take into account the specificity and the conceptual basis of the other. We try to better understand the economic theoretical issues behind the used mathematical programming models and also to present the main specifications that should have these economic models to ensure a consistent integration with the agronomic ones.

For analysing the relation between agriculture and environment, economic theory has summoned up several approaches: the application of the standard microeconomic analysis (i.e. "Environmental Economics"), the integration of original methods and tools based on the agent's revealed preferences into the conventional theoretical corpus (i.e. the so-called "London School"), or the exploration of new methodologies and knowledge stemming from other disciplines in particular from Natural Sciences (i.e. Constanza et al, 1987).

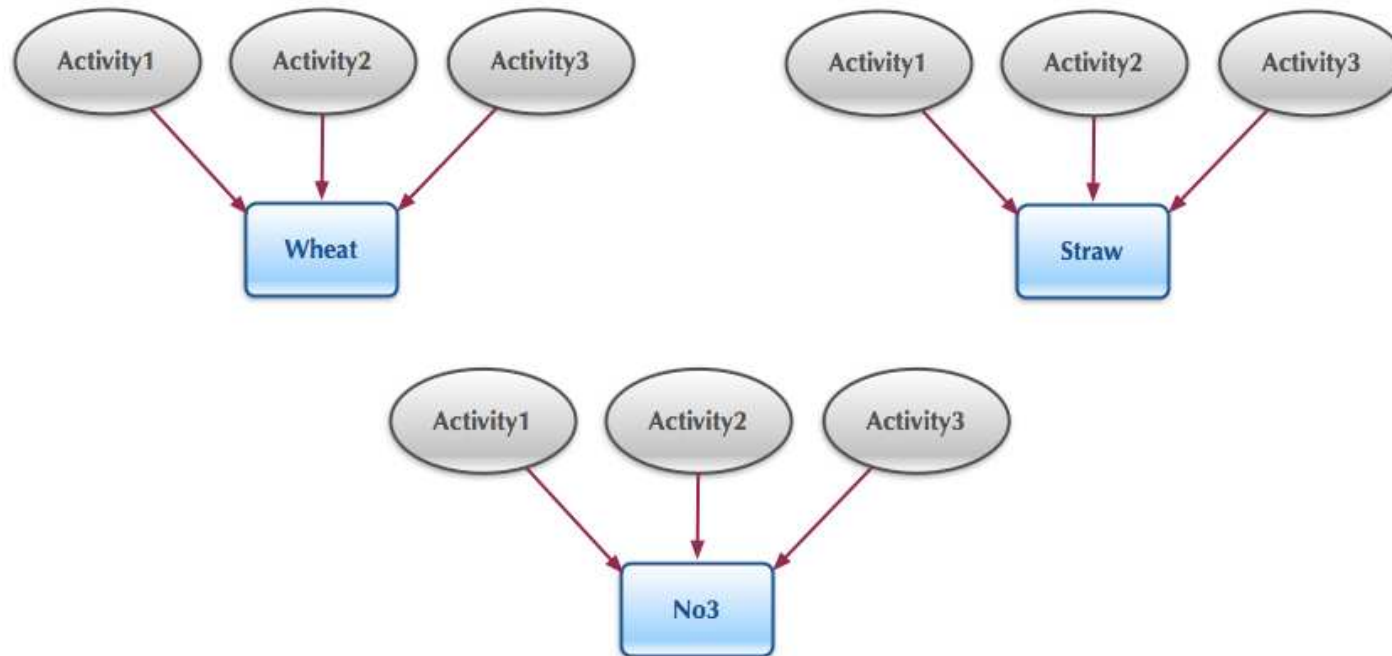
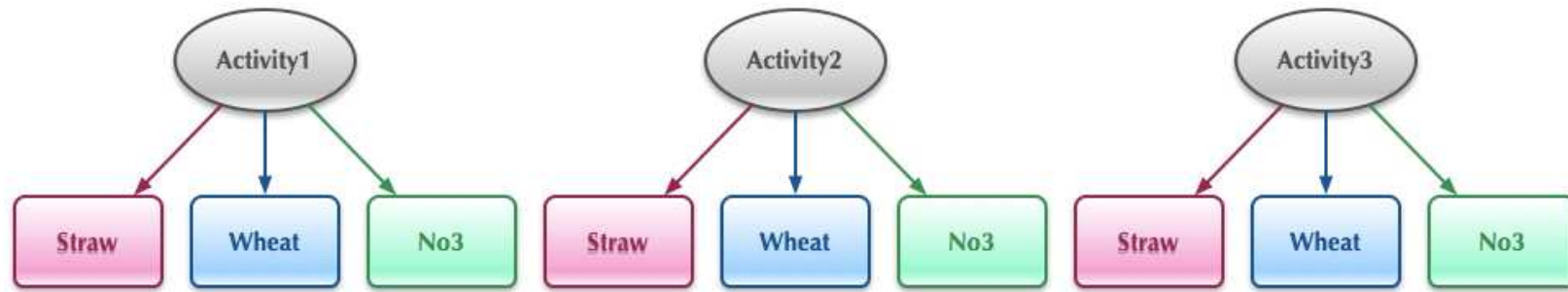
From this classification it appears at first sight that the bio-economic modelling method is a part of the *Ecological Economics* approach. However, as the bio-economic models are often based on optimisation models it could also be possible to situate this method under the conventional economic theory (i.e. “Environmental Economics”). This is a matter of discussion. What is important is to understand what we are doing and why.

Introduction

What are we doing when we build and apply a farm bio economic mathematical programming model?

A bio economic farm model normally should apply an engineering production function approach (Flichman G. et al 1998, Flichman & Jacquet, 2002, Janssen & Ittersum, 2007). The reasons justifying a primal representation of technology are very clear; with this models we have to deal simultaneously with bio-physic and economic systems, we need to quantify physical quantities, as well in the inputs of the model as in the outputs, such as level of pollution, erosion, etc. These models are activity based, what means that one product can be produced by several different activities. Each activity is defined by the technical coefficients that represent the use of inputs needed to produce one unit of output. In agricultural models, frequently these technical coefficients relate to one unit of the fixed factor (land) rather than to one unit of product. However, what is important for our purpose is to stress the fact that all the basic information concerning production is related with activities and not with products. One product can be produced by many activities. On the other side, one activity¹ produces also many products. When we build this type of model, we define, i.e. for wheat production, something that looks like this, in a very simplified case in which we consider 3 activities and 3 products:

¹ Activity, we mean the specific way of producing something, i.e. for producing wheat we can have several different activities that allow obtaining the same product (rainfed intensive, rainfed extensive, irrigated). **An activity is the representation of a production process.**



All this seems trivial and is indeed trivial, as trivial is the fact that we speak in prose, as M. Jourdain, but what is less trivial is the consequence in terms of the specification of production and cost functions in the mathematical programming models and in terms of analysing environmental externalities and natural resources related with agricultural production

The scheme presented below allows seeing the causal relationships that are implied in this type of model: what we call “products” are the outputs of a production process that is described by the activity: soil erosion i.e. is not provoked by wheat grain production, but by a specific way of producing wheat.

What is important is to realize that this type of representation has two "faces":

One activity (or production process) has several outputs – joint production

One product is produced by several activities (or production processes)

In other words, each agricultural activity i represents one production process, which produces several outputs and uses several inputs. Let $t \in \mathfrak{N}$, where \mathfrak{N} is the set of natural numbers, denote the number of year in a rotation. Denote $j = \{j_1, j_2, \dots\}$ the set of economic outputs produced by each agricultural activity, $\mathbf{O} = \{O_1, O_2, \dots\}$ the set of environmental (i.e. externalities) outputs produced by each agricultural activity, and $\mathbf{I} = \{I_1, I_2, \dots\}$ the set of inputs applied in production of agricultural activities. \mathbf{Y} , \mathbf{E} and $\mathbf{F} \in \mathbb{R}^{t \times m}$, where \mathbb{R} is the set of real numbers, represent, respectively, the matrix of economic outputs produced by each agricultural activity, the matrix of environmental outputs associated to each agricultural activity and the matrix of inputs used by each agricultural activity. To be more specific, Y_{ijt} denote the amount of the j^{th} economic output produced in the t^{th} year of the agricultural activity i , E_{iO_t} denote the amount of the O^{th} environmental output produced in the t^{th} year of the agricultural activity i and F_{iI_t} denote the amount of the I^{th} input used in the t^{th} year in production. To quantify the amount of inputs and outputs associated to each agricultural activity, we use a biophysical model and other sources (expert knowledge, surveys, etc.). The biophysical model consists on a multi-inputs and multi-outputs engineering production function in which:

- The relationships between inputs and outputs are expressed in transparent way.
- The inputs and the outputs (including externalities) are represented in discrete forms and expressed in physical terms (avoid monetary terms).
- The impact of each input can be assessed separately with respect to the others.
- The positive and the negative jointness in outputs (i.e. joint production) associated to the production process can be taken into account easily, as each agricultural activity i_1 can produce several outputs $j_1, j_2, O_1, O_2, \dots$ and each output j_1 can be produced by several agricultural activities i_1, i_2, \dots
- The complex problems related to non-linearity in the relation between agricultural production and environment can be expressed in an explicit way.

Cost specification

Let us begin by the first part of the problem: one product is (or can be) produced by several different production activities. Once this point is clear, let us look show how the costs of our models are defined. What is usually done is to define the costs out of engineering,

survey and/or statistical information and/or outputs of a biophysical model. We always need the physical quantities and the prices for correctly “feed” these models ². Costs are specified by **activity**, not by **product**. This extremely simple evidence has very important consequences. We are in the situation usually explained in the first pages of any good Microeconomic manual (i.e. Varian, 1992), where a set of activities (techniques or production processes) is used to build a continuous production function out of an original discrete function. Nevertheless, going on with basic microeconomics, when we arrive to the chapter discussing costs, we are no more in an “activity universe” but in a “product universe”, even if this is not very explicit in the manuals.

"This method, which precludes the separate measurement of alternative processes to produce the same commodity, or the recognition of joint production, can be and is being supplemented by the study of engineering information". ... (Koopmans, T. 1951)

If we deal with an activity-based model representing technology with a primal approach, the costs are considered per activity, not per product. If we have, as it is the case in modern detailed farm models, many activities for each product, **even if the costs of each activity are, by definition, linear (average cost = marginal cost) the costs per product are non linear and the marginal cost will normally increase if the level of production increases. The reason for this increase is the presence of a fixed factor; usually land, in agriculture production (in some cases it can be another natural limiting factor, as water)**

There are two options for representing these elements in a model:

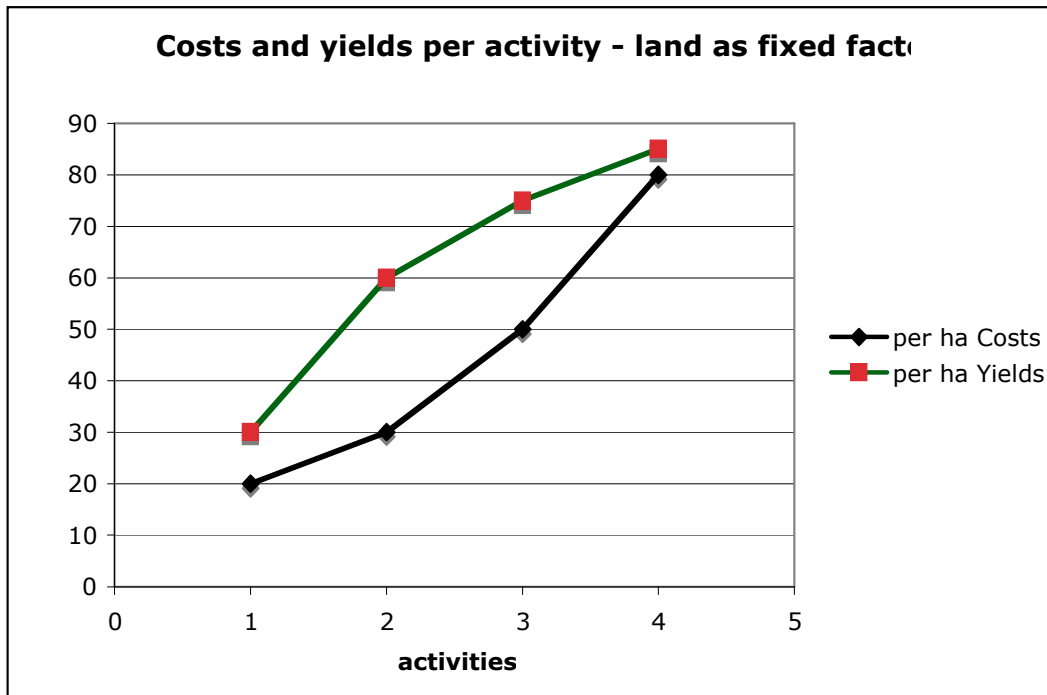
1. Keep a linear structure of multiple activities for each product
2. Estimate a non linear specification for each product, using the information obtained at an activity level

There are several important reasons advocating to keep a linear structure of multiple activities per product.

- The represented activities correspond directly to engineer or biophysical model base information. Interpretation of results are straightforward
- The "joint products" are related to activities, and in the case of some important agricultural externalities, they are usually proportional to the activity, not to the product

Let us see through a simple numerical example,

² There is frequently difficult to find information on costs per activity. At a global European level, the information is available only for costs at a farm level (Farm Accounting Data Network) in monetary units. This is a real difficult problem to apply these models in Europe. We need detailed technical information, available only at regional level and in some countries at national level.



In Graph 1 we present the relation between activities, costs and production of **one product**. The only difference with the usual presentation in microeconomic manuals is that we are taking into account a fixed factor and that production is represented together with costs (both per activity). It is easy to realise that when we move towards an analysis **per product, and not per activity** things will change. We can estimate a non-linear cost function, adopting a quadratic function without any problem.

$$ac = 3x^2 + 3.8x + 12.5 \text{ (average cost)}$$

$$R^2 = 0.9946$$

and the marginal cost will be

$$mc = 6x + 3.8$$

But it is absolutely necessary to question this procedure. Are we sure that the intermediate activities that may exist between the four ones for which we have information can be interpolated in a legitimate manner by a continuous function? This is not sure at all, and we will show why presenting two examples, one related with soil erosion and the other with nitrate pollution

Let us look at the relation between erosion and yield (Louhichi, K 2001). Taking an example of Northern Africa, wheat production in a semi arid region. A usual rotation, wheat-fallow, rain fed, produces a lower yield than a continuous wheat rotation, and erosion is higher, because the soil is not occupied by vegetation half of the time. But if you move to a third technique, with deeper tillage and continuous wheat, yield will increase and also erosion. A fourth technique, with irrigation, will make erosion lower and increase yield. Many examples like this one can be found, what gives realism to our argument.

Of course, this example represents the situation for a time horizon that is not very long. That is why effects of erosion on production are not considered. These effects need quite long periods to appear. The same reasoning can be done concerning soil degradation by salinity (Belhouchette et al, 2004). This long time lag explains why in the utility function

of the farmer usually this negative effect in terms of natural resources is not taken into account. It is possible to analyse erosion as a joint product of the agricultural activity, without giving a monetary value to it. From the point of view of sustainability, it is relatively easy to define a physical threshold that can be considered adequate in order to ensure sustainability. That is the way it works in the real world, as well for erosion, for soil salinity or for chemical pollution (nitrates, pesticides). When there are effects in the very long term or when the external costs of agricultural joint products are not easy to measure (or any measurement is subject to a high level of subjectivism and can always be discussed), a physical measurement, related with preservation of the environment, or human health seems more appropriate (and that is how policy standards are expressed usually).

In different applied research work concerning agricultural joint products their relation with the level of **production** is rarely smooth, as well in the case of Nitrate pollution, soil erosion or soil salinisation, but it is proportional always to the **activity**. A linear representation, based on the activity, is simple and precise.

Activities can be defined in terms of agricultural rotations, procedure that allows to take into account the dynamic effects of a succession of crops, as well on the soil quality as on the external effects, such as pollution, soil erosion, amount of organic matter, etc. But the representation of these dynamic effects do not always require to specify a dynamic mathematical programming model (MPM), it is enough in many cases to adopt a comparative static approach, using the results of a dynamic biophysical model (BM) as inputs of the MPM model. This is the approach followed in the FSSIM model³

Of course it can be argued that at an aggregate level it may be acceptable to adopt a continuous functional form ... but what is the advantage? Getting more easily accepted a paper in a journal? Having a more elegant formulation? These advantages, we recognise, are legitimate. **But in that case the continuous function for environmental joint products will be in many cases a non-convex one – it will not be "well behaved"**.

On the other side, if we try to build models useful to analyse and formulate policies in the real world, we need to study the relations between the way we represent activities in our models and the policy instruments that can be used or proposed in order to develop a sustainable agriculture. Cross compliance instruments are more and more applied and usually with certain success. These instruments need to define precisely agricultural practices exactly in the way we define activities. This is the way in which one of the oldest policies to control soil erosion is applied in the USA (USDA, 2002). And to model these erosion impacts, the USDA developed a specific biophysical model already many years ago (Williams et al. 1990)

Environmental externalities as joint products

In our view, each production activity has several outputs. In the simple example presented in the introduction, these products are grain, pollution and straw. All these **products** emerge from one **production activity**. **They are joint products** (Pasinetti, L, 1980, Baumgartner, S. 2001). The relation between a production activity, the principal product (from the point of view of the firm) and the joint(s) product(s) is a fatal relation. It is

³ Farming System Simulation Model, developed in SEAMLESS integrated project, EU 6th Framework Programme, contract no. 010036-2 . http://www.seamless-ip.org/Reports/Report_04_PD3.3.2.1.pdf

impossible to produce grain without polluting or producing straw. And these relations (production activity \rightarrow products) are linear ones.

Adopting this vision, we should not approach the external effect (cost or benefit for other economic agent) as a direct consequence, i.e., of wheat production; we have to relate the production of what will generate this cost to other agents (nitrate pollution) in physical quantities. Doing this, we consider pollution, as a product of the activity that has both **wheat and pollution as outputs**. This means that for calculating the externality as a cost, we need first to have some knowledge about it as a physical product, and we need to measure it in physical terms (tons of soil erosion, kg of NO₃ pollution, etc.). We have the chance, since about 20 years ago, to have at our disposal dynamic biophysical models that simulate the different products related with an agricultural activity (in our case, grain, straw, pollution) within an integrated framework.

This type of representation intends to provide a mechanistic, cause-effect explanation of what is usually called externality. Very frequently we find empirical approaches, trying to find statistical relations between some crop production (considered as THE product) and some externality, as soil erosion. By construction, even if sometimes it is possible to find beautiful functional forms that allow wonderful fits, **these relationships will always be limited to the specific case from where they have been calculated they are purely empirical**, because there is a complete lack of analysis of the processes that connect, for example, grain production with soil erosion. What produces erosion is not the wheat production, is the way it is produced, what type of tillage is used, in what period, in connection with the weather, with the type of soil, the precedent crop and many other technical issues. In other words it is the process of production, represented by a specific activity. A certain amount of nitrate leaching is not provoked by maize production, but by a certain production activity of which maize grain is one of the outputs (i.e. a wheat-maize rotation with a specific input combination). The relation between a maize non-linear production function and the level of nitrate pollution can be extremely complicated to establish and, if established, it will not be in a chain of cause-effect relationships (because there is not a direct relation between these two variables), **the empirically obtained function will be applicable only to the specific situation where it was estimated**. Each agricultural technique represented by each production activity is related, in a defined environment (soil-weather) with one value of pollution or erosion, and **there is not any functional form that can be "a priori" applied to represent the relations between two of the joint products, as they are an outcome of extremely complex processes that can be properly represented by fixed technical coefficients relating activities and products**. Of course, it can be possible, out of an optimisation exercise at the farm level, to estimate non-linear relationships between different outputs of the model, using parametric procedures. But no functional form should be introduced "a priori" in the optimisation model. The results of simulations done using a biophysical model (BM) can be synthesized in an appropriate way and introduced as linear technical coefficients in the MPM. And this procedure can be applied as well in a dynamic MPM or in a static one. We have experimented both, and found that the complications of a dynamic model (particularly if it is a stochastic one) are not always justified. But the know-how to build such a model is available (Blanco, M., Flichman, G. 2002) and was tested successfully (Belhouchette et al. 2004).

There is a problem, anyway, concerning the issue from the point of view of natural resources, or natural capital. Let us take the example of soil. The qualities of soil, in terms of its production capacities, change related with the type of use of the land. This implies that, by essence, this issue should be analysed using a dynamic approach. That is why the

biophysical models are perfectly appropriate for doing this. But it is possible to incorporate the long term results as indicators in a static comparative model, and these indicators can be used in conditional statements in the model, to represent cross-compliance policies, as we do in the FSSIM model.

There is a situation in terms of "state of the arts" that allows enormous progress in this field. But it is difficult to work on pluridisciplinary issues and to be accepted inside the different disciplines as legitimate...

Modelling the relations between agriculture, natural resources and environment needs to mobilise different type of models and of knowledge. It is difficult to do so and it is even more difficult to expose it.

An empirical example of joint production using a biophysical model

In order to provide a very simple empirical example, we performed a simulation using a biophysical model (CropSyst, Stockle et al 2003) for a biannual rotation of wheat and sunflower, applying different amounts of nitrogen and testing the introduction of a catch crop to reduce nitrate pollution. Applying the concepts defined before, we simulate here an important number of production activities, i.e. each rotation with a specific management is one production activity. All the activities produce wheat, sunflower and nitrate pollution (products) and each product can be produced by all the activities. We will observe only partial results of these activities, the yields of wheat and the nitrate pollution (in physical units) mapped with the total costs of production.

It is possible to define an efficiency frontier in terms of yields and a different one in terms of nitrate pollution. In a discrete function like the one we use, the conditions for a certain activity to be efficient concerning yields are:

- $y_{ci} > y_{ci-1}$; if the cost increases, the yield also increases
 - o y = yields, c = costs
- $(y_{ci} - y_{ci-1}) > (y_{ci+1} - y_{ci})$; yield increases when cost increases but at a decreasing rate.

Of course, this is equivalent to the situation of continuous functions, with a first derivative positive and a second negative. **The difference, and it is an important one, is that discrete functions like these do not have intermediate points, only linear combinations of two points that correspond to specific production activities.**

The efficiency in terms of yields is the one that will be taken into account for defining the choice of the producer. The environmental efficiency may be a policy objective, not a producer objective. And we try to develop a positive approach, useful to define policies in order to ameliorate the environmental situation, in this case reduce the pollution levels.

The efficiency frontier in terms of pollution is the following:

- $p_{ci} > p_{ci-1}$; if the cost increases, the pollution also increases
 - o p = pollution, c = costs
- $(y_{ci} - y_{ci-1}) > (y_{ci+1} - y_{ci})$; pollution increases when cost increases at an increasing rate

It is possible to define a frontier taking into account only the activities that are efficient both from the yield and the environmental point of view, but it would be a normative approach, realistic only in a well managed "sovkhoz".

But it is still necessary to give an explanation concerning the pollution discrete function, as we gave for the case of soil erosion. There are management techniques that may allow increases in production and costs with decreases in pollution. When we introduce catch crops that use the Nitrogen surplus, reducing pollution, they imply an increase of costs but also a higher yield (more organic matter in the soil, better soil structure). Agronomists understand this immediately. A bit more difficult for economists sometimes ... We are always in a situation in which a product can be an output of many different activities, this basic issue explains the apparent mystery.

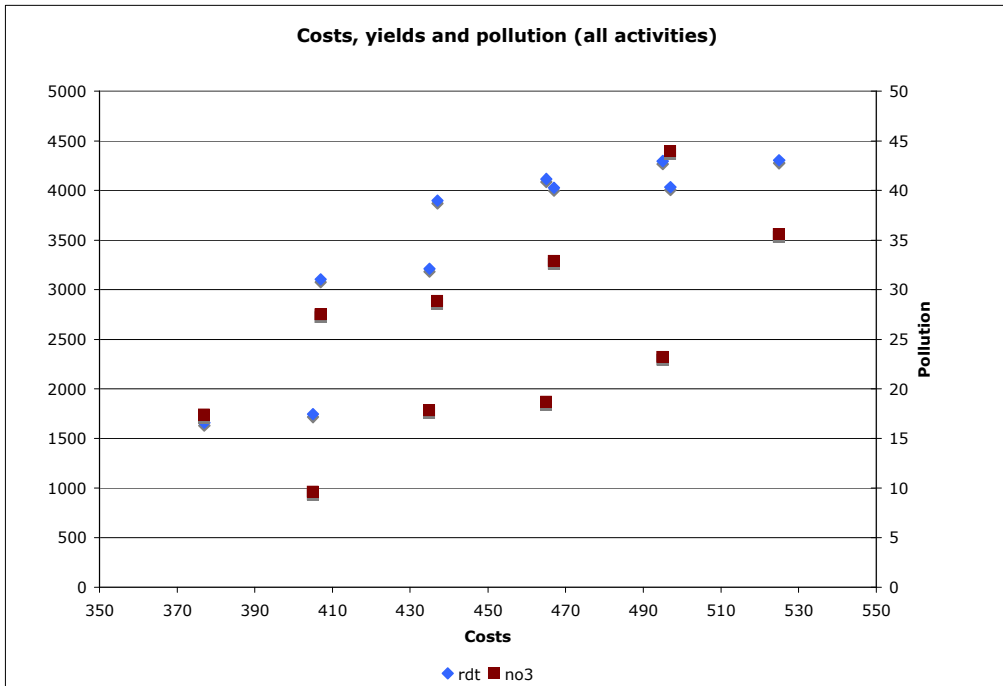
We can see in this example that there are activities on the yield frontier – potentially candidates to be chosen by the farmers – that are inefficient from the environmental point of view. That is why it appears usually necessary to use cross-compliance policies to achieve good results. Taxes or subsidies related directly to production levels or even to polluting inputs may give very bad results.

These are the findings when we look at a field level. If we move to the farm level, these "bad behaved" relations appear even in a more clear way, because there is a mix of activities defining the global result of the farm. It is possible to show how in certain circumstances, a tax on the amount of nitrogen fertilisation may produce an increase in pollution (Flichman et al 2003)

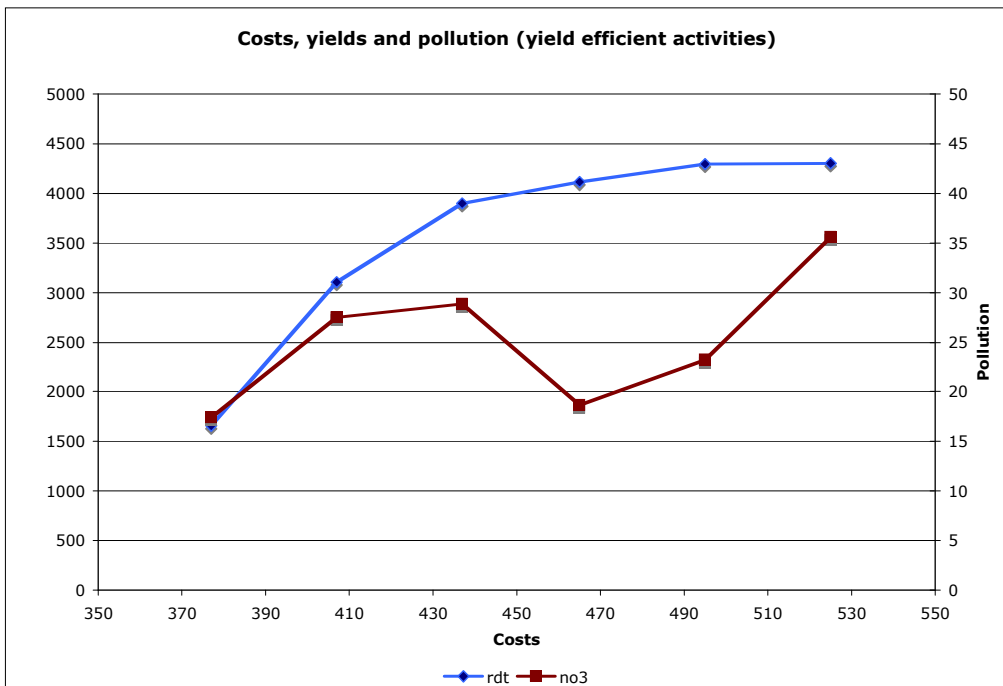
Using BEM based on production activities allows calculating cost-efficiency indicators of different policies that intend to induce farmers to adopt a more environmental friendly way of production; policies based on environmental targets fixed using physical thresholds. And this is the way policies are beginning to be established in the real world.

The following graphs summarise the result of the numerical example. A Wheat-Sunflower rotation is simulated, with different levels of fertilisation, without irrigation and with and without a catch crop. We present here the wheat yields and the average nitrate pollution, for all the simulated activities in Graph 1 and for yield efficient activities in Graph 2

Graph 1



Graph 2



Looking at these graphs, it is possible to see that there are several points that correspond to both frontiers. If we were in a well managed sovkhov, it would be possible to choose between these points, but for a farmer, in a market economy, what counts is the yield frontier only. That is why policies tend to influence the production procedures directly, in order to obtain results acceptable in terms both of yield and environment (*code des bonnes*

pratiques agricoles) That is why policies affecting only prices, as well on products or on inputs do not appear to be efficient.

References

- Costanza, R. and H. E. Daly. 1987. Toward an ecological economics.148 *Ecological Modeling* 38:1-7.
- Flichman, G., Jourdain, D "Economic Policy and Water Pollution". in *Economics of Agro-Chemicals: An International Overview of Use Patterns, Technical and Institutional Determinants. Policies and Perspectives.* eds G.A.A. Wossink, G.C. van Kooten and G.H. Peters, 1998, 283-294. Aldershot, UK, Ashgate.
- Flichman G., Jacquet, F. "Le couplage des modèles agronomiques et économiques : intérêt pour l'analyse des politiques". *Cahiers d'économie et sociologie rurales*, n° 67 2003.
- Janssen, S.J.C.; Ittersum, M.K. van , *Assessing farm innovations and responses to policies: a review of bio-economic farm models*
Agricultural Systems 94 (3). 2007- p. 622 - 636.
- Varian, H., *Microeconomic Analysis*, New York: W.W. Norton, 1992
- Koopmans, T. *Activity Analysis of Production and Allocation*, Proceedings of a Conference, Cowles Commission, New York 1951.
<http://cowles.econ.yale.edu/P/cm/m13/index.htm>
- Louhichi, K. (2001). *Essai de modélisation bioéconomique de la relation agriculture environnement : le cas de l'érosion en Tunisie.* Thèse doctorat, Université Montpellier I : Faculté des sciences économiques, 250 p.
- Belhouchette, H., Blanco, M., Flichman, G. 2004 "Targeting sustainability of agricultural systems in the Cebalat watershed in Northern Tunisia: an economic perspective using a recursive stochastic model". *European Association of Environmental and Resource Economics. Thirteenth Annual Conference, Budapest. Hungary. June 25-28th, 2004.*
- National Resources conservation Service, USDA, *Farm Bill 2002, Highly Erodible Land and Wetland Conservation Compliance*, October 2002
- Williams, J.R., C.A. Jones, and P.T. Dyke. 1990. *The EPIC model documentation.* USDA-ARS. Technical Bulletin No. 1768. U.S. Department of Agriculture
- Pasinetti, L.(editor) *Essays on the Theory of Joint Production*, Columbia University Press 1980.
- Baumgärtner, S. et al, "The concept of joint production and ecological economics", *Ecological Economics* 36 (2001) 365-372.
- Blanco, M., Flichman, G., "Dynamic optimisation problems: different resolution methods regarding agriculture and natural resource economics". Working Paper, CIHEAM-IAMM, 2002. <http://www.iamm.fr/recherche/chercheurs/flichman/publications/index.html>
- Stöckle, C, Donatelli, M. Nelson, D., *CropSyst, a cropping systems simulation model - European Journal of Agronomy*, 2003 – Elsevier

