CIHEAM
Options Méditerranéennes

Bio-economic models integrating agronomic, environmental and economic issues with agricultural use of water

Flichman G.

in

Dupuy B. (ed.).
Aspects économiques de la gestion de l'eau dans le bassin méditerranéen

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 31

1997
pages 327-336

Article available on line / Article disponible en ligne à l'adresse :

http://om.ciheam.org/article.php?IDPDF=CI971330

To cite this article / Pour citer cet article

Flichman G. **Bio-economic models integrating agronomic, environmental and economic issues with agricultural use of water.** In : Dupuy B. (ed.). *Aspects économiques de la gestion de l'eau dans le bassin méditerranéen* . Bari : CIHEAM, 1997. p. 327-336 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 31)

CIHEAM

http://www.ciheam.org/
http://om.ciheam.org/

CIHEAM - Options Mediterraneennes

Bio-economic models integrating agronomic, environmental and economic issues with agricultural use of water

G. Flichman
CIHEAM - Institut Agronomique Méditerranéen
Montpellier, France

SUMMARY - This paper presents a framework that permits an integrated analysis of a complex system in which intervene biophysical, socio-economic and policy components. A short introduction deals with the origin of this methodology, that implies a multidisciplinary approach, including soil science, agronomy, crop physiology and economics. A review of the different ways by which economists study the technical dimension of production is presented, making a comparison between the approach based on the use of econometric production functions and the engineering production functions approach. The advantages and limitations of both orientations will be briefly developed, in order to point the suitability of applying the engineering production function approach when analysing agricultural water use issues.
A schematic description of bio-economic models that integrate agronomic simulation models with mathematical programming models is presented. The specific case of POLEN project, realised in collaboration between IAM- Bari and IAM-Montpellier Institutes with a group of European research teams is showed as an application of this approach. New methodological developments, trying to ameliorate the performance of these models will be showed.

Key words: Simulation Models, mathematical programming, bio-economic modelling, production functions, irrigation.

RESUME: *Cette communication a pour objectif de présenter un cadre de travail qui permet l'analyse intégrée d'un système complexe où participent de composants biophysiques, socio-économiques et politiques. Dans l'introduction nous développons l'origine de cette méthodologie, qui implique une approche multidisciplinaire: pédologie, agronomie, physiologie de plantes et économie. Une révision de la manière dont les économistes saisissent la dimension technique de la production est présentée en comparant les estimations économétriques de fonctions de production et l'approche de la fonction de production dite "d'ingénieur". Les avantages et les inconvénients de ces deux orientations sont développés, pour montrer comment l'approche qui utilise les fonctions de production "d'ingénieur" est la plus adaptée, concernant les aspects économiques de l'utilisation agricole de l'eau.*

CIHEAM - Options Mediterraneennes

Une description schématique des modèles bio-économiques qui peuvent se construire à travers l'intégration de modèles de simulation agronomique avec modèles de programmation mathématiques est présentée. Le cas spécifique du projet POLEN, développé en collaboration entre l'IAM-Bari et l'IAM-Montpellier, avec un groupe d'équipes de recherche européen est exposé comme exemple. Des nouvelles approches méthodologiques, qui tentent d'améliorer la performance de ces modèles seront aussi discutées.

Mots-clés: *modèles de simulation, programmation mathématique, modélisation bio-économique, fonctions de production, irrigation.*

INTRODUCTION

An economic approach to agricultural water use requires a proper way to analyse the different technical options from an economic perspective. In economics, these technical options are usually represented by what is called production functions. Production functions are supposed to be a statistical estimation of the input-output relationships representing the different possible combinations of production factors that can be used in order to obtain the output. Yield response of crops to water is a simple one-factor production function. It is clear that when we have to deal with many inputs and factors simultaneously, the analysis becomes much more complicated.

We deal with this problem using a multi-disciplinary approach. This type of exercise had only a methodological interest before the recent computer technology development. It is now possible to build models that incorporate bio-physical, socio-economic and policy components. In practice, the development of agronomic simulation models was the principal factor that made feasible bio-economic modelling. These integrated agronomic models already consider the interactions between crop growth with climate, soil and tillage practices (including irrigation). These models incorporate in a recursive way the effects on soil and water of agricultural practices. This research orientation was developed during the last decade in several countries (Nederlands, U.S.A. and Australia, principally). We have been working with EPIC model (Williams et al, 1985) since 1988 for integrating bio-physical information in economic analysis. EPIC is one of the most widely used of these models all over the world. It has been ameliorated in 1993 by the Department of Agronomy of INRA-Toulouse (Cabelguenne, 1993), in order to simulate more accurately irrigated agriculture.

Economic models that integrate information coming from biophysical models are currently called "bio-economic models". Usually, they are mathematical programming models (MPM). The way of representing technology in an economic model can be ameliorated in a very substantial way by the use of simulated data obtained from a biophysical model results. It is also possible to integrate in bioeconomic models environmental parameters associated with different agricultural techniques, such as soil erosion or water pollution of different sources (nitrates or chemical pesticides).

THE ENGINEERING PRODUCTION FUNCTION APPROACH USING AGRONOMIC SIMULATION MODELS

As we have mentioned, if we are dealing with the economic dimension of agricultural water use, it is necessary to get a detailed representation of the available set of techniques. In other words, to have

CIHEAM - Options Mediterraneennes

a good knowledge of the production functions; these functions are commonly estimated by econometric procedures. Usual econometric methods are based on statistical inference as information source. This approach presents different type of problems:

- **A limited number of observations** may prevent the estimation of the function's parameters (the number of observations has to be higher than the number of parameters).

- It is difficult to guarantee the **aleatory character of samples** used (Boussemart et al, 1994).

- If cross-section data are used, the individual techniques that proportionate the basic data for the estimations of the production functions are influenced by **the present structure of relative prices**. Very frequently, the variation among different farms in respect of the proportions of factors that are used for a certain crop at a certain moment is quite low.

- If time series are used, the problem of **technological progress measurement** appears. Even the most elegant procedures trying to deal with this question are not very convincing (Boussard, 1988).

In other terms, if we estimate production functions using statistical data from the past (time series), or from the present, through cross-data analysis, it will be very difficult to represent properly the technical universe. That is why we consider that the engineering production function approach is a more appropriate procedure when we deal with technico-economic issues, as the economic aspects of the agricultural water use.

For building engineering production functions, we should obtain technical coefficients of production from results obtained by agronomic experimentation and survey data and not from statistical data adjusted to "a priori" defined mathematical functions. A practical problem arises: it is almost impossible to obtain all the necessary information using these sources. Usually, agronomic research is not done in order to obtain appropriate input data for economic models. It is difficult, for example, to analyse separately the influence on production coming from fertilisation, from irrigation, from weather, from soil quality, from the influence of previous crop in the rotation and from other factors, as the variety used. This is the case, even in the countries where very old experimental agricultural stations exist. We have been able to solve partially these problems using an agronomic simulation model. As we already stated, the model we have used is EPIC (we are aware of its limits -Steduto et al, 1985-, but it is still a very powerful tool that performs quite well for our purposes, if properly used).

This procedure allows new ways of implementing the engineering production function approach. It becomes possible to simulate production outcomes concerning almost any type of agricultural technical schedule. We may represent the effects on yields coming from changes in the quantities of fertiliser, the levels of irrigation, the types of equipment, the characteristics of alternative cultivars, and rotation schemes. The model allows the analysis of weather variability on production as well as on environmental parameters (pollution, soil erosion), related with different type of agricultural techniques. EPIC can be considered as a kind of very sophisticated comprehensive agricultural production function. We have used it as a data generator for economic models since 1988 (Jaquet et Flichman, 1988, Flichman, 1990, Deybe et al 1990. Deybe and Flichman, 1992., Flichman 1993). The interest of this type of model and other similar characteristics ones, as CropSyst, Stockle, 1992, consists in implying a systemic approach of agronomic relationships. Interactions between irrigation, weather, fertilisation, type of varieties and tillage systems, are taken into account. Even if for specific scientific or technical objectives many other partial agronomic simulation models, that consider in a more efficient and detailed manner particular aspects of crops' growth, may be better than EPIC or CropSyst, for generating data to be used in economic analysis, a systemic, comprehensive agronomic simulator is the most suitable tool.

For economic analysis of agricultural water use, the possibility of simulating water response functions considering the interactions of irrigation with the rest of agronomic management is very advantageous.

A BIO-ECONOMIC POSITIVE APPROACH

We may contend that our representation of technology in economic models comes both from survey information and agronomic experimentation - following the "engineering production function approach". It is complemented with simulated data, for the techniques that are not actually used or ex

CIHEAM - Options Mediterraneennes

perimented and for the estimation of erosion and pollution levels.

Models may be built for different purposes. It is important to make at least one important distinction between what is usually called positive, analytical or descriptive models from normative models. In applied economics, it is frequent to identify econometric models - based on statistical inference, without optimisation procedures - as positive models and MPMs - based on the use of optimisation procedures - as normative models.

We will not discuss the fact that econometric models are positive models. But it is important to reaffirm that mathematical programming ones may also be positive models (Boussard, 1987). If we are able to reproduce in an adequate manner the technical and the economic universe in which the agricultural producers work - model specification - and if we assume a reasonably good utility function to be maximised (or minimised), we may build a model in order to reproduce a real situation, and not to advice an agent on the best way to use its resources (normative approach). In other words, a mathematical programming model can be built in order to make previsions, not to directly advise some "decision centre". The predictive use of a model implies the need of getting this model calibrated and validated. That means, the model should be able to reproduce the behaviour of a real system in order to allow us to change some parameters of that system (usually policy parameters, as prices, taxes or tariffs) and make forecasting analysis about the impact of these changes on the system. At its origin, mathematical programming was principally used to directly optimise decision making procedures (the first practical use of linear programming was ameliorating aviation performance during World War II). This fact induced the idea upon which these models are essentially normative. We consider a MPM model as positive, if it is built with the purpose of reproducing a real situation to be able to predict, out of different scenarios, future events. Anyway, a positive model of this type can be used to help decision making in an indirect way: if we can predict the evolution of water demand determined by a change in agricultural prices, we willbe able to adapt irrigation projects to these demand previsions.

The essential specificities of bio-economic positive models may be synthesised as follows :

- **High level of technical specification.** Characteristics of weather, soil, crops, technical schedules are very detailed.

- Part of the data used in the model are obtained from **simulation results of bio-physical models.**

- It is possible to calculate **negative externalities** associated to each solution of the MPM, both temporal and spatial. An example of temporal externalities is the level of soil erosion. This means that it is possible to analyse, for example, the interrelationships between different irrigation practices, tillage systems and long term consequences on soil erosion. The same is applied to nitrate or pesticide pollution, that can be considered spatial negative externalities.

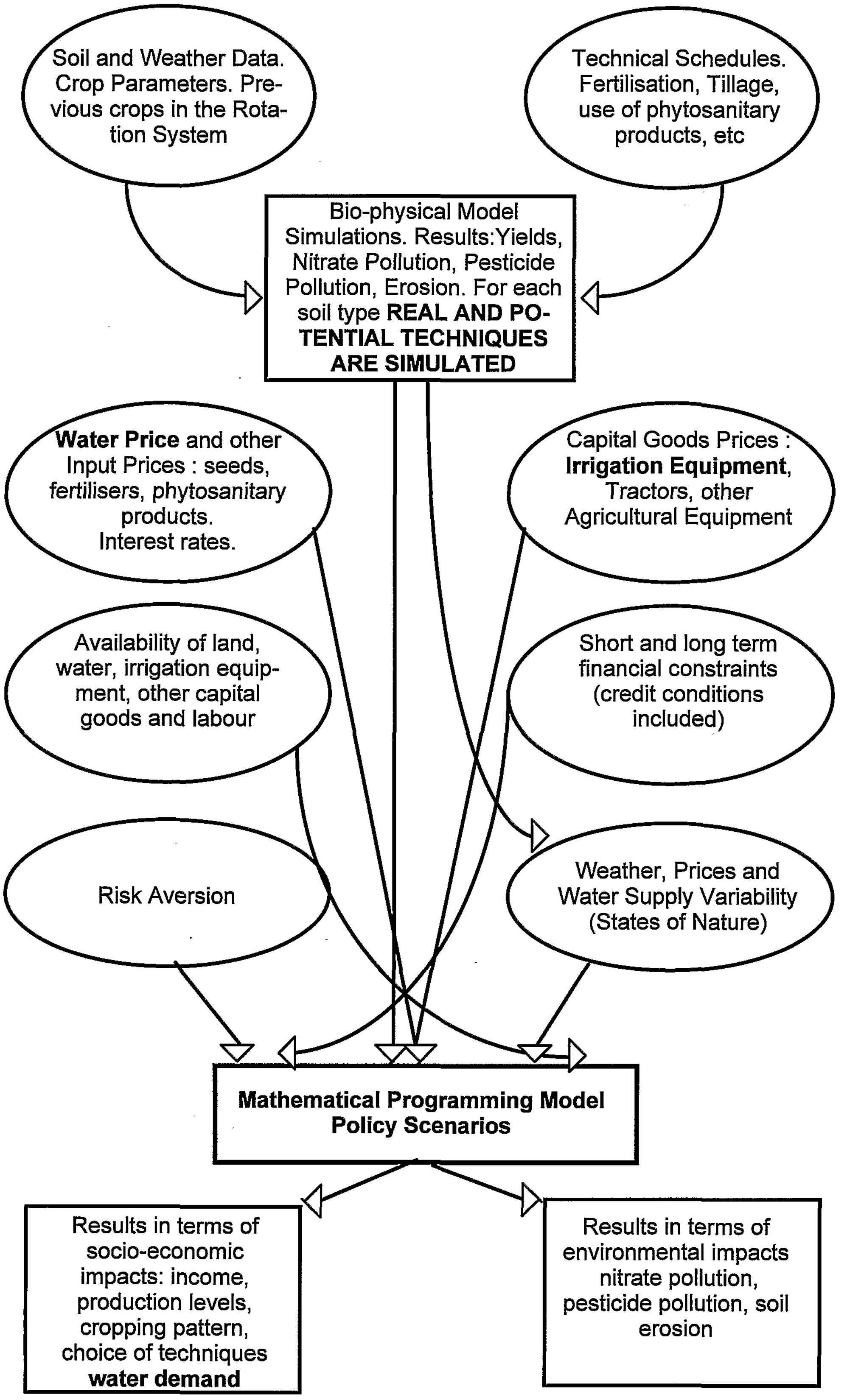
- The **high detail of technical specification characterising** these models determines the aggregation level. In principle they can be applied at farm or small regional level. It is more difficult to use them dealing with big regions or national levels. Of course this is just a matter of acceptable error and complexity in data manipulation.

- Bio-economic models need an **interdisciplinary approach**. This is perhaps the most difficult problem to overcome. What we usually call "data" we introduce in a model, is already a complex product that has its origin in another discipline. This means that interdisciplinary work requires a minimum understanding of the basic approaches followed by the different disciplines taking part in the research. We met this problem when we wanted to define intensity levels of agricultural techniques: the implicit criteria used by agronomists are different from those employed by economists. If an economist just take information provided by agronomists without understanding thoroughly how these data had been generated, the errors may be important.

We present a simplified scheme of a bio-economic model, in order to clarify the essential relationships present in this approach.

CIHEAM - Options Mediterraneennes

Scheme of a positive bio-economic model



CIHEAM - Options Mediterraneennes

POLEN MODEL

POLEN model was developed in order to analyse the impacts of the Common Agricultural Policy Reform in several European Regions. The same basic methodology was employed in all the case studies. The objective of this Research was the impact analysis of agricultural policy programs on the pattern of technological choice, the level of input use, the crop pattern as well as some indirect environmental impacts (nitrate pollution). The regions are the plains of south-eastern England, La Beauce in France, the Po Valley in Italy, South-western France, Andalucía in Spain and Alentejo in Portugal. Some of them have irrigated agriculture. The impact of the CAP Reform on irrigation was analysed in the case of Andalucía and South-western France. For each region, representative farms have been modelled for studying the effects of the policy reform.

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 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 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 information obtained using historical long term climatic data and simulating with EPIC their influence on yields and pollution. In addition, future variations of prices and subsidies are built according to common sense criteria, results of a 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).

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 MPM, make it possible to associate the techniques chosen for production with yields and potential levels of pollution. All this, 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 the simulated techniques. These information enter 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 in 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.

Definition of the crop production activities

The MPM 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 coherent with the information provided by EPIC. The name of a crop corresponds to the name of one of the crops defined in EPIC cropfile, that is the first dimension. The second is the technique, related 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.

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

CIHEAM - Options Mediterraneennes

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

- yields
- 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.
- tillage, fertiliser, irrigation, pesticide application, supervision, seeding and any other operations taking part in the technical schedule
- quantities of fertiliser and water applied

This data are obtained out of simulations of five typical climatic years, that are a representative sample of a long period climatic series (25 years)

Principal Equations of 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.

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

where $U(.)$ is the utility level; Xt the set of farming decisions in period t, including allocated allocated surface to crops, techniques, use of inputs, and so on; Yt represents the set of financial variables, 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 coefficient; and $\lambda(Xt, Y_t)$ is the sum of negative deviations of from $E[NETINCOME\ (Xt, Yt)]$,
for the different "states of nature", as expressed in equation 6.
One element of the farming variables X_t appears like this:
WHEAT.T1.S2.SUNFLOWER.YES, meaning 1 hectare of wheat grown with technique 1, on soil 2, with sunflower as the previous crop, and under the CAP-reform regulations (denoted by YES).

NETINCOME (.) is composed of the following elements:

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

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; $FINANCOST(Y_t, Y_t\text{-}1)$, are the net financial costs dependent on financial decisions in years t and $t\text{-}1$.

The maximization 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 $t\text{-}1$; its purpose is to modelise rotational constraints.

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

- ***Water constraint:*** Equation 4 define the water constraint. It means that the total of the water used per period us subject to water availability in each period

$$\Sigma(X_t{*}WATER(X_t)) \leq WATAVAIL(t) \qquad (4)$$

CIHEAM - Options Mediterraneennes

In the case of the Spanish Model (Region of Andalucía), different water availability scenarios have been built, in order to analyse the relations with alternative policy scenarios.

- ***Labour constraints*** : This is the simplest farm labor 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 labor *SEASON(t)*. *FARMLAB* is an exogenous parameter. According to the caracteristics of the labour markets in the different regions, labour constraints have been expressed differently (FLICHMAN et al, 1995).

$$\Sigma(X_t{*}LABOR(X_t)) \leq FARMLAB + SEASON(t) \quad (5)$$

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

$$NETINCOME(X_t, Y_t; e,q,n) + DEV(e,q,n) = E[NETINCOME(X_t, Y_t)] \quad (6)$$

Equation 6 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 by parameter *q*, which in turn can take 5 values, one for each year of the five years considered in the EPIC model simulations ([1]) (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 of "states of nature".

$$\Sigma_e \Sigma_t \Sigma_n DEV(e,t,n) \leq \lambda(X_t, Y_t) \quad (7)$$

Equation 7, sums up all the negative deviations and makes them less than or equal than $\lambda(X_t, Y_t)$. The right-hand side of this equation, multiplied by the risk aversion coefficient, appears in the objective function (equation 1) with a negative sign.

Other equations, not written here, deal with other specific constraints, technical and economical, applicable to each region.

Nitrate 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.

The use of this methodology for building models in different European regions, allowed us to arrive to comparable results for all the cases. It was also possible to analyse the relative importance that different factors have in producing the observed changes after the CAP Policy Reform was implemented. In other words, this model allows to make counter-experimentation. We used it particularly in the cases where different policies of heterogeneous level are operating simultaneously (that is the case of devaluation, that affected strongly the situation in some of the case-studies).

([1]) 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)

CIHEAM - Options Mediterraneennes

Effects of the CAP Reform as predicted by Polen Model

PRINCIPAL RESULTS OF THE MODIFICATIONS INTRODUCED BY THE CAP REFORM SCENARIO RESPECT THE NON CAP REFORM SCENARIO

REGIONS	CROP PATTERN	FARM INCOME	NITRATE POLL	IRRIGATION
S-W FRANCE (HAUTE GARONNE)	++OILSEEDS --CEREALS	ABSOLUTE AND RELATIVE INCREASE	--DECREASES	INCREASE SURFACE, CONSTANT WATER USE
LA BEAUCE	++CEREALS --OILSEEDS	ABSOLUTE AND RELATIVE DECREASE	--DECREASES	DECREASES
S-E ENGLAND (KENT)	+OILSEEDS --CEREALS	ABSOLUTE INCREASE RELATIVE DECREASE	-DECREASES	NON EXISTING
EMILIA-ROMAGNA	++OILSEEDS -- CEREALS	ABSOLUTE INCREASE RELATIVE DECREASE	--DECREASES	NEUTRAL
ANDALUSIA	REFORM NEUTRAL	ABSOLUTE AND RELATIVE INCREASE	-DECREASES	NEUTRAL, DEPENDING ON CLIMATE
ALENTEJO		ABSOLUTE AND RELATIVE DECREASE	-DECREASES	NON EXISTING

These results are close to what is really going on in the studied regions after CAP Reform implementation.

It appeared interesting to compare the impact of the CAP Reform on irrigated agriculture in two Southern European Regions: south-west France and Andalucía (Flichman et al, 1995). In the French case, the scenario assuming the application of the Reform, shows an important augmentation in the irrigated surface, while the total water demand increases slightly. In Andalucía, the Reform doesn't seem to influence very much the importance of irrigation, both in terms of surface and water demand. On the other side, it reduces strongly the negative impact of bad climatic years on farmers' income. Using a bio-economic model as POLEN, allows to understand the reason of these differences quite clearly and explicitly: Water restrictions play a much more important role in Andalucía than in SO France. That is why policy changes don't produce important modifications on the use of irrigation methods in the Spanish Region. In France, on the contrary, it is possible to use supplementary irrigation techniques with good economic results. As the new policy introduces important levels of subsidies to irrigated land, without taking into account the level of production, farmers irrigate more land, using less water per hectare.

LIMITATIONS OF POLEN MODEL AND NEW RESEARCH PERSPECTIVES

The experience gained developing this research is important. The principal limitations of the approach, open the way for new research perspectives, specifically related with economic aspects of agricultural water use can be synthetized as follows:

CIHEAM - Options Mediterraneennes

- Level of the analysis. The farm model level has limitations for policy analysis. It is necessary to develop models at regional levels what implies dealing with the traditional aggregation problems. The region may be defined as an irrigation area or a river basin.

- Temporal dimension. The recursivity, as specified in the POLEN Model, may create problems related with the short planning horizon that was defined. A dynamic-recursive approach could be a better solution.

- It will be necessary to integrate new disciplines in the modelling exercise. In POLEN, Economics and Agronomy where interacting. It is important as well to incorporate Hydraulic Engineering and Hydrology.

REFERENCES

- **Blaskovic, H.** *Une analyse du système de production agricole socialisé dans la région continentale de la Croatie et les possibilités de réorganisation - Tentative d'utilisation des modèles.* Centre International de Hautes Etudes Agronomiques Méditerranéennes, Institut de Montpellier. (Thèses et Masters). 1992, 129 p.
- **Boussard, J.M.** On Agricultural Production Functions. *Association of European Agricultural Economists Seminar,* Bonn, April 13-14, 1988
- **Boussard, J.M.** *Economie de l'Agriculture.* Economica, Paris 1988.
- **Boussemart, J.P. Flichman, G. Jacquet, F. Lefer, H.B..** L'évaluation micro-économique de la réforme de la PAC par un modèle bio-économique: une illustration sur la Beauce et la région de Toulouse. *Communication présentée dans les 11émes journées de Microéconomie Appliquée,* 2 et 3 juin 1994 à Marseille.
- **Cabelguenne, M. EPIC-PHASE,** Inra-Toulouse, 1994.
- **Deybe, D., Flichman, G., Vicien, C.** Is Cereal Extensive Production Possible?, in *AGRICULTURE. Methods and socio-economic criteria for the analysis and the prevision of land use and land evaluation.* Report EUR 12340 EN. Comission of the European Communities, Luxembourg, 1990. (p.49-61).
- **Deybe, D. and Flichman, G.** A Regional Agricultural Model Using a Plant Growth Simulation Program as Activities Generator",in *Agricultural Systems,* Edinbourgh, 1992.
- **Flichman, G.** Analyse des possibilités d'expansion de l'offre de céréales en Argentine. Convention d'étude CIHEAM-Ministère de l'Agriculture. Janvier 1993.
- **Flichman, G.** *International Comparisons of Efficiency in Agriculture.* OCDE Development Centre, Technical Paper No.21, 1990, Paris.
- **Flichman,G., Garrido, A., Varela Ortega, C.** Agricultural policy and technical choice : a regional analysis of income variation, soil use and environmental effects under uncertainty and market imperfections », (L) 15 p., in *Environmental and land use issues : an economic perpective.* Actes du 34ème séminaire de l'EAAE (European Association of Agricultural Economists), 7-9 février. 1994, Zaragoza (Esp.), Ed. Luis Miguel Albisu et Carlos Romero, Wissenschaftverlag Vauk Kiel KG, 1995, 380 p.
- **Jacquet, Flichman, G.** Intensification et efficacité en agriculture. *Economie Rurale,* Paris, Janvier-Février 1988.
- **Lamaddalena, N., G. Ciollaro, L. Santos Pereira** : "Effect of changing irrigation delivery schedules during periods of limited availability of water". To be published in Journal of Agricultural Engineering Research
- **Steduto, P., Pocuca, V., Caliandro, A. Debaeke, P.** An Evaluation of the crop-growth simulation submodel of EPIC for wheat grown in a Mediterranean climate with variable soil-water regimes. to be published in the European Journal of Agronomy. 1985.
- **Williams, J.R. Jones, C.A. and Dyke, P.T** (1984). A modelling approach to determine the relationships between erosion and soil productivity. Trans. ASAE, 27 129 N. 44.