AUA Working Paper Series No. 2010-??
September 2010

Hybrid linear programming to estimate CAP impacts of flatter rates and environmental top-ups

The case of arable cropping in Kopais plain, Greece

Stelios Rozakis
Department of Agricultural Economics & Rural Development
Agricultural University of Athens
s.rozakis@aua.gr

A newer version of this paper has been published on

Agricultural Economics Review (2011), 12 (2), pp. 30-39

Hybrid linear programming to estimate CAP impacts of flatter rates and environmental top-ups

The case of arable cropping in Kopais plain, Greece

Stelios Rozakis

Agricultural Economics and Rural Development Department

Agricultural University of Athens

Iera Odos 75, 11855 Athens GR

Tel. : +30210 5294735, Fax : +30210 5294767

ABSTRACT

This paper examines evolutions of the Common Agricultural Policy (CAP) decoupling regime and their impacts on Greek arable agriculture. Policy analysis is performed by using mathematical programming tools. Taking into account increasing uncertainty, we assume that farmers perceive gross margin in intervals rather than as expected crisp values. A bottom-up hybrid model accommodates both profit maximizing and risk prudent attitudes in order to accurately assess farmers' response. Marginal changes to crop plans are expected so that flatter single payment rates cause significant changes in incomes and subsidies. Nitrogen reduction incentives result in moderate changes putting their effectiveness in question.

Key-words: Interval Linear Programming, Min-Max Regret, Common Agricultural Policy, Arable cropping, Greece

JEL classification : C61, D81, Q12, Q18

Acknowledgments

The author would like to thank the "Laboratoire d'Analyse et Modélisation de Systèmes pour l'Aide à la Décision - LAMSADE" in University of Paris IX Dauphine for funding his sabbatical stay (April 2010) during which this research was undertaken.

Valuable remarks by George Vlahos, Stathis Klonaris and an anonymous referee as well as proofreading by John Stedman are appreciated.

Introduction

After several periods of implementation of CAP 2003 reform it is questionable if important objectives such as re-allocation of subsidies to the benefit of low-income farmers, enhancement of viable and diverse activities in rural areas, food security and environmental preservation are attained. Discussion on the CAP future beyond 2013 has started, mainly driven by budgetary restraint priorities. The cost of the CAP is subject to severe criticism, imposing strict accountability on social and environmental cost effectiveness. Nevertheless, various events such as significant decrease of farm incomes due to price decreases, the economic crisis and food shortages, arguments on the social role of agricultural activities and associated externalities have attenuated the risk of adoption of propositions for drastic decrease of resources earmarked to CAP.

However, even if the total amount of subsidies remain constant, a re-allocation among member countries and/or activities seems inevitable. As a matter of fact, there are significant deviations among EU members if payments reported on an area basis. Greece appears to receive from pillar I an average of €544 /ha when the mean payment in EU15 amounts at €295/ha with €185/ha for the 12 late member states.

For these reasons various studies have been undertaken to evaluate impacts of different policy measures to replace the current single farm payment regime. A comprehensive analysis in the context of the Health Check (EC, 2007) on behalf of the European Commission calculates impacts on allocation of the Net Value Added at the farm level in the EU25 for main products using Farm Accounting Data Network (FADN) data. Despite its broad scope and valuable results this study constitutes an accounting assessment without taking into consideration farmers' response to restructuring of the cropping plan for minimizing the negative impacts of policy measures on their welfare. In order to obtain reliable estimates useful for policy analysis, appropriate sector and regional models are required.

Classic analytical tools, such as crop supply and profit functions used for deriving conditional farm income estimates and factor demand functions, require considerable amounts of data to estimate all cross-price supply elasticities. Moreover econometric estimates are valid only for the observed range of variation of relative prices and other variables. Mathematical models may fill this gap and derive response functions for output, incomes, employment and other variables implicitly by means of parametric optimization (Kutcher and Norton, 1982). Especially in case of substantial policy changes such as the Common Agricultural Policy latest reform, with decoupling subsidies from production, mathematical programming models have been widely suggested to agricultural economists (Salvatici et al., 2000).

In Europe, such sector and regional models have been used to estimate impacts of CAP through subsequent policy changes in the last ten years (i.e. Ackril et al., 2001, Sourie et al., 2001, Wilson et al., 2003, Guindé et al., 2005). In Greece, examples include analyses focusing on the tobacco and cotton, staple crops that absorbed major alterations, following conventional linear programming (Mattas et al., 2006), multi-criteria methods (Manos et al. 2009) and also positive models incorporating downward sloping demand (Rozakis et al., 2008) or increasing cost functions (Positive Mathematical Programming (PMP), Petsakos and Rozakis, 2010) in the objective function. Multi-criteria methods with non-interactive elicitation of the utility function and PMP have dominated the recent literature concerning CAP analysis. These methods, broadening economic rationality, manage to transform the objective function so that optimal solutions include not only crop plans on the vertices of the feasible polyhedron but also points on hyper-plans enabling the model to approach observed levels of activities, thus outperforming its LP counterparts.

Alternatively, risk incorporation into the model may also yield optimal plans beside feasible polygon vertices. A review of methods introducing risk in mathematical programming can be found in Hardaker et al (2004). One could mention the E-V model as well as its linear versions such as MOTAD and target-MOTAD and also models based on game theory reasoning such as maximin, minmax, safety-first and other models that seek efficient diversification among activities as a means of hedging against risk (for early applications in the Greek context see Manos and Kitsopanidis, 2006, 2008). For all these models in order to introduce non-linear risk-related terms in the objective function, availability of covariance matrices – that require gross margins of individual crops related to different states of nature or years- is fundamental. Consequently, it is extremely difficult to apply these methods to sector or regional models containing numerous farms, thus relevant publications while theoretically appealing are applied to only a limited number of representative farms (Petsakos et al., 2008) or to limited activities or products (Katranidis & Kotakou, 2008).

In this exercise we opted for a sufficiently detailed techno-economic representation at the farm level containing a priori information on technology, fixed production factors, resource and agronomic constraints, production quotas and set aside as well as environmental regulations, along with explicit expression of physical linkages between activities. A bottom-up approach is adopted to reflect the diversity of arable agriculture, articulating numerous farm sub-models in a block angular form (Williams, 1999), that have neither the same productivity nor the same economic efficiency so that the production costs are variable. Thus, ex-post aggregation helps to relax the *proportionality hypothesis* of LP (concerning the Leontief technology) and to avoid problems such as discontinuous response and overspecialization arising in single representative farm models.

Moreover, we attempted to relax the *certainty assumption* incorporating risk considerations of the decision makers, in this case farmers, for two important reasons. Firstly, under decoupling reform much more than before, price and yield variations influence gross margins, as no crop specific subsidies exist anymore. Secondly, and more importantly, the radical increase of cereal prices of 2007 followed by their collapse in 2008 boosted price volatility. This situation obliges modelers to pay special attention to uncertainty of prices, which combined with the vagaries of nature and the new institutional environment, make farmers very cautious. As our intention is to use large samples of farms, we selected a novel method that is not data greedy, namely interval LP. The uncertainty element in the objective function is brought about via the introduction of intervals in the gross margin coefficients in the objective function. To specify intervals the sole requirement is an idea of gross margin variation range.

It is proved that interval linear programming (ILP) models are equivalent to a specific class of multi-objective (MO) models with objectives generated by the extreme interval values. Consequently, there is a need to select an appropriate criterion to resolve the MO problem and obtain a compromise solution. By means of experiments, an attempt was successively made to all elementary farm models to check whether it is reasonable to represent farmers' behavior using the min-max regret criterion. This criterion suggests that the decision-maker regrets after all about the costs of missing opportunities resulted by final decision compared with alternative actions that could be chosen. For farm sub-models whose observed behavior is explained better when uncertainty is taken into account in the form of ILP then minimizing maximum regret (optimal plan approaches closer to the base year crop mix that the optimal plan resulted by its LP counterpart), we adopt hereafter the ILP specification. When the gross margin maximization rule reproduces satisfactorily reality, it is retained as a decision rule and the corresponding farm models remain LP specified. Thus, a hybrid block angular arable sector model is formed with an improved predictive ability than the initial LP. The main drawback is the exponential increase of computing time lapse to solve the ILP as for *n* interval coefficients the min-max optimization of the ILP requires the solution of 2(*n*-1) LP and 0-1 models. In this study specified for the Kopais region however, farm models contain one-digit objective function terms keeping the model size manageable. Results indicate changes in crop mix for scenarios examined including counter-intuitive findings in the case of environmental top-ups that lead to less area cultivated applying reduced nitrogen less than expected mainly due to the specific consideration of uncertainty in the model and the significant number of farmers that adopt min-max regret behavior in the hybrid model.

The paper is organized as follows: A concise presentation of the mathematical structure of the LP model is given in the next section. Formal aspects of the "Interval Linear Programming (ILP)" approach are presented in section 3. The use of the min-max regret criterion within the ILP framework is explained in section 4. The case study and the results thereof are the focus points of section 5. Finally, conclusions and remarks for further research complete the article.

Modeling the Farmers' Behavior: The mathematical formulation

General architecture of the model

A cotton growing farm (f) is supposed to choose a cropping plan (x^f) and input use among technically feasible activity plans $A^f x^f \leq b^f$ so as to maximise gross margin gm^f. The optimisation problem for the farmer f appears as:

$$\begin{cases} \max\limits_{x^f} gm^f\left(x^f,\theta^f,\kappa\right) = g^f\left(\theta^f,\kappa\right)x^f \equiv \sum\limits_c \left[\left(p_c^f + s_c\right)y_c^f + sub_c - v_c^f\right]x_c^f \\ s.t.\_\_\ A^f\left(\theta^f,\kappa\right)x^f \leq b^f\left(\theta^f,\kappa\right)\_\_\_\ A \in \Re^{m\times n}\ \_(I) \\ x^f \geq 0\ \_\_\_\_\_\_\_\_\_\_\ \_\_\_\_\_\_\_\_\_\_\ \_\_\ x \in \Re^n\ \_\_(II) \end{cases} \quad (1)$$

The sector model contains f farm problems such as the one specified above. The basic farm problem is linear with respect to x^f, the primal n × 1-vector of the n cropping activities. The m × n-matrix A^f and the m × 1-vector b^f represent respectively the technical coefficients and the capacities of the m constraints on production. The vector of parameters θ^f characterizes the f^{th}

representative farm (y_c^f yields for crop c, v_c^f variable costs, p_c^f prices dependent on quality). κ stands for the vector of general economic parameters (p prices not dependent on farm, sub_c area subsidies and s_c on prices specific to crops).

The constraints can be distinguished as resource, agronomic, demand and policy factors. The model enables a comparative static analysis, but it does not allow for farm expansion, as it takes as given land resource endowments and land rent of the base year. Different sets of parameters are applied to denote the CAP 2000 and the current CAP (reform 2003). Specifically for the year 2008, a constant term denotes the decoupled subsidies enjoyed by the farm after the reform (this amount is fixed based on historical data on subsidies received by the farm during the 2000-2002 cultivation period) subject to additional constraints that modify feasible production plans:

I. Cross compliance[i] obligation in order to receive the single payment (crop – rotation with legumes in 20% of the eligible land).

II. Actual farm land must be greater than or equal to eligible land.

Uncertainty and Interval Programming

In mathematical programming models, the coefficient values are often considered known and fixed in a deterministic way. However, in practical situations, these values are frequently unknown or difficult to establish precisely. Interval Programming (IP) has been proposed as a means of avoiding the resulting modelling difficulties, by proceeding only with simple information on the variation range of the coefficients. Since decisions based on models that ignore variability in objective function coefficients can have devastating consequences, models that can deliver plans that will perform well regardless of future outcomes are appealing. More precisely, an ILP model consists of using parameters whose values can vary within some interval, instead of parameters with fixed values, as is the case in conventional mathematical programming.

Many techniques have been proposed to solve the resulting problem. Shaocheng studied the case where all the model parameters are represented by intervals and the decision variables are non negative. Later, Chinneck and Ramadan generalized their approach to the case where variables are without sign restriction. The case which is of greater interest for our purpose is the one where only the objective function coefficients are represented by intervals. This particular problem is the most frequently considered in ILP literature (Bitran, Inuiguchi and Sakawa, Ishibuchi and Tanaka, Mausser and Laguna (1998, 1999a, 1999b), Rommelfanger , Steuer). We now introduce some definitions and notations and briefly present the formal problem.

Interval Linear Programming Problem

Let us consider a Linear Programming (LP) model with *n* (real and positive) variables and *m* constraints. The objective function is to be maximized. Formally:

$$\max \{cx : c \in \Gamma, x \in S\} \qquad \text{(ILP)}$$

where

$$\Gamma = \{c \in \Re^n : c_i \in [l_i, u_i], \forall i = 1..n\}$$

$$S = \{x \in \Re^n : Ax \leq b, x \geq 0, A \in \Re^{m \times n}, b \in \Re^m\}$$

Let $\Pi = \{x \in S : x = \arg\max \{cy : y \in S, c \in \Gamma\}\}$ be the set of potentially optimal solutions. Let Y be the set of all the extreme objective functions: $Y = \{c \in \Gamma : c_i \in \{l_i, u_i\}, \forall i = 1..n\}$.To give insight into what the problem becomes when intervals are introduced, we recall the following theorem (Inuiguishi and Sakawa, Steuer):

Theorem

Let us consider the following multiobjective linear programming problem:

$$\upsilon\text{-}\max\{\mathbf{cx} : \mathbf{x} \in S; c \in Y\} \qquad \textit{(MOLP)}$$

where the υ-max notation stands for the vector maximization. Then, a solution is a potentially optimal solution to (ILP) problem if, and only if, it is weakly efficient to the (MOLP) problem.

Theoretically, this result enables us to mobilize all the tools and concepts of multi-objective linear programming literature, especially to choose/propose suitable solution concepts for (ILP) problem. In the literature, two distinct attitudes can be observed. The first attitude consists of finding all potentially optimal solutions that the model can return in order to examine the possible evolutions of the system that the model is representing. The methods proposed by Steuer as well as Bitran follow this type of logic. The second attitude consists of adopting a specific criterion (such as the Hurwicz's criterion, the maxmin gain of Falk, the minmax regret of Savage, etc.) to select a solution among the potentially optimal solutions. Rommelfanger, Ishibuchi and Tanaka, Inuiguchi and Sakawa and also Mausser and Laguna proposed different methods with this second perspective. Following this perspective, the next section introduces the approach that we have selected, namely the minimization of the maximum regret approach, and the procedure we adopted for its implementation.

Minimizing the Maximum Regret

Minimizing the maximum regret consists of finding a solution which will give the decision maker a satisfaction level as close as possible to the optimal situation (which can only be known as a *posteriori*), whatever situation occurs in the future. The farmers are faced with a highly unstable economic situation and know that their decisions will result in uncertain gains. It seems reasonable to suppose that they will decide on their surface allocations *prudently* in order to go through this time of economic instability with minimum loss, while trying to obtain a satisfying profit level. This is precisely the logic underlying the minmax regret criterion; i.e. selection of a *robust* solution that will give a high satisfaction level whatever happens in the future and that will not cause regret (Loomes and Sugden, 1982). Therefore, we make the hypothesis that the farmers of the considered region adopt the min-max regret criterion to make their surface allocation decisions. The mathematical translation of this hypothesis for the arable sector supply model was to implement the minmax regret solution procedure proposed in the literature (Inuiguchi and Sakawa, Mausser and Laguna, 1998, 1999a, 1999b). The presentation of the formal problem and the algorithm of minmax regret are presented in the following paragraphs.

The MinMax Regret (MMR) Problem

Suppose that a solution $x \in S$ is selected for a given $c \in \Gamma$. The regret is then:

$$R(c, x) = \max_{y \in S} (cy) - cx$$

The maximum regret is:

$$\max_{c \in \Gamma} R(c, x)$$

The *minmax* regret solution $\hat{x}$ is then such that $R_{\max}(\hat{x}) \leq R_{\max}(x)$ for all $x \in S$. The corresponding problem to be solved is:

$$\min_{x \in S} \left\{ \max_{c \in \Gamma} \left\{ \max_{y \in S} \{cy\} - cx \right\} \right\} \qquad (MMR)$$

The main difficulty in solving *MMR* lies into the infinity of objective functions to be considered. Shimizu and Aiyoshi proposed a relaxation procedure to handle this problem. Instead of considering all possible objective functions, they consider only a limited number among them and solve a relaxed problem (hereafter called *MMR'*) to obtain a candidate regret solution. A second problem (called hereafter *CMR*) is then solved to test the global optimality of the generated solution. If the solution is globally optimal, the algorithm terminates. Otherwise, *CMR* generates a constraint which is then integrated into the constraint system of *MMR'* to solve it again for a new candidate solution. This process continues in this manner until a globally optimal solution is obtained. The relaxed *MMR'* problem is:

$$\min_{x \in S} \left\{ \max_{c \in C} \left\{ \max_{y \in S} \{cy\} - cx \right\} \right\} \qquad (MMR')$$

where $C = \{c^1, c^2, \ldots, c^p\} \subset \Gamma$. This problem is equivalent to:

$$\min r \qquad (MMR')$$

s.t. $r + c^k x \geq c^k x_{c^k}$, $\quad k = 1, \ldots, p$

$r \geq 0,\ x \in S,\ c^k \in C$

where x_{c^k} is the optimal solution of $\max_{y \in S} \{c^k y\}$. A constraint of type $r + c^k x \geq c^k x_{c^k}$ is called a regret cut. Let us denote $\bar{x}$ the optimal solution of *MMR'* and $\bar{r}$ the corresponding regret. Since all possible objective functions are not considered in *MMR'* we cannot be sure that there is no *c* belonging to $\Gamma \setminus C$ which can cause a greater regret by its realization in the future. Hence, we use the following CMR problem to test the global optimality of $\bar{x}$:

$$\max_{c \in \Gamma} \left\{ \max_{y \in S} \{cy\} - c\bar{x} \right\} \qquad (CMR)$$

Observe that the objective function value of CMR represents the maximum regret for $\bar{x}$ over Γ, denoted by $R_{\max}(\bar{x})$. If the optimal solution $x_{c^{p+1}} \in S, c^{p+1} \in \Gamma$ of CMR gives $R_{\max}(\bar{x}) > \bar{r}$, it means that c^{p+1} can cause a greater regret than $\bar{r}$ by its realization in the future and that it has to be considered also in C while solving *MMR'*. So, the regret cut $r + c^{p+1} x \geq c^{p+1} x_{c^{p+1}}$ is added to the previous constraint set of the *MMR'* to solve it again and obtain a new candidate. The process is iterated until the generated candidate regret solution is found to be optimal by CMR. This solution procedure idea is summarized by the following algorithm:

The MinMax Regret Algorithm

Step 0: $r^{\circ} \leftarrow 0, k \leftarrow 0,$ choose an initial candidate $\bar{x}$. For the initial regret candidates to start the algorithm, the LP optimal solutions may be used.

Step 1: $k \leftarrow k+1,$ Solve CMR to find c^k and $R_{\max}(\bar{x})$:

If $R_{\max}(\bar{x}) = r^{\circ}$ then END. $\bar{x}$ minimizes the maximum regret.

Step 2: Add the regret cut $r + c^k x \geq c^k x_{c^k}$ to the constraint set of *MMR'*

Step 3: Solve (*MMR'*) to obtain a new candidate $\bar{x}$ and $\bar{r}$. $r^{\circ} \leftarrow \bar{r}$. Go to Step 1.

The difficulty in this resolution process lies in the quadratic nature of the CMR problem. Inuiguchi and Sakawa investigated the properties of the minmax regret solution to find a more suitable way to solve CRM. Mausser and Laguna (1998) used their results to formulate a mixed integer linear program equivalent to CMR which is less complex to solve. As Mausser and Laguna (1999a) noticed that the complexity of that mixed integer program severely limits the size of problems to be addressed, therefore they suggested to use heuristics. In the problem studied here, uncertain objective function coefficients are in no farm decision making unit more than five. Thus, in our experiments we used this equivalent problem mixed-integer formulation[ii].

Let us consider the following ILP model solved in the two dimensional variable space to illustrate how the algorithm works and its underlying logic.

max $c_1x_1+c_2x_2$

subject to

$x_1 + x_2 \leq 60$ *land availability*

$70\,x_1 + 25\,x_2 \leq 2000$ *own labour availability*

$12\,x_1 + 2.5\,x_2 \leq 300$ *working capital*

and $x_1, x_2 \geq 0$ where $c_1 \in [7.2, 10.4]$ and $c_2 \in [3, 5.5]$.

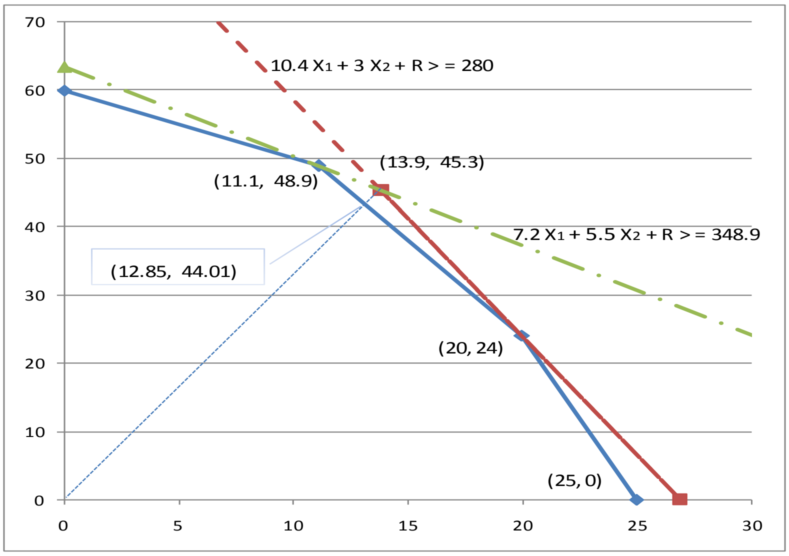

Figure 1. Variable Space in the Example and Regret Cuts.

This problem has a feasible region delimited by the five vertices (Fig. 1). The set of all the extreme objective functions is Y=*{(7.2, 3) ;(7.2, 5.5) ;(10.4, 3) ;(10.4, 5.5)}*. The corresponding MOLP problem, by denoting S the feasible region defined by the constraints, is

$$\upsilon\text{-}max\{\ 7.2\ x_1 + 3\ x_2,\ 7.2\ x_1 + 5.5\ x_2,\ 10.4\ x_1 + 3\ x_2,\ 10.4\ x_1 + 5.5\ x_2 : (x_1, x_2) \in S\ \}$$

When considered, separately, to each of these objective functions corresponds a different optimal solution (respectively to Y, (11.1, 48.9) ; (11.1, 48.9); (20, 24) ; (11.1, 48.9)). Along with the vertices (25, 0) ; (60, 0), those solutions constitute basic efficient solutions for the MOLP. The set Π of potentially optimal solutions for the ILP (the efficient solutions for the MOLP) is given by convex linear combinations of every adjacent couple of these four solutions.

Let us apply the algorithm to this problem and discuss the results.

Initialisation Step 0 : $r^\circ \leftarrow 0$, $k = 0$, Let us choose (11.1, 48.9) as the initial candidate $\bar{x}$.

Iteration 1 Step 1 : $k \leftarrow 1$, Solving CMR leads to $R_{\max}(\bar{x})$ = 17.78 and c^1 is (10.4, 3) , $R_{\max}(\bar{x}) \geq r^\circ$.

Step 2 :The regret cut 10.4 x_1+ 3 x_2 + r ≥ (10.4*20+3*24) = 280 is then added to the constraint set of the MMR'. In this way, the program will return a new candidate which will try to minimize the potential regret (280 – 10.4 x_1 - 3 x_2)

that might occur if (20, 24) is not selected as a solution. Notice that this is logical considering since we have selected (11.1, 48.9) as the initial candidate solution. The algorithm detects that the objective function for which the other end of the efficient frontier, the point (20, 24), is optimal, may cause an important regret if this turns out to be the real objective function in the future.

Step 3 : (MMR') returns another candidate $\bar{x}$ = (20, 24) and $\bar{r}$ = 0. $r^{\circ} \leftarrow \bar{r}$. Obviously, this solution minimizes the potential regret (280 – 10.4 x_1 - 3 x_2) ! It will be tested next.

Iteration 2 *Step* 1 : $k \leftarrow 2$, Solving CMR leads to $R_{max}(\bar{x})$ = 72.89 and c^2 is (7.2, 5.5), $R_{max}(\bar{x}) \geq r^{\circ}$.

Step 2: Following the results of step 1, 7.2 x_1+ 5.5 x_2 + r ≥ (7.2*11.1+5.5*48.9) =348.9 is added as the new regret cut to constraint system of the MMR'. As before, the aim is to take into consideration the last regret possibility that CMR has returned. Now, MMR' will try to return a new candidate by considering both potential greatest regrets (280 – 10.4 x_1 - 3 x_2) and (348.9 – 7.2 x_1 – 5.5 x_2).

Step 3: Under these constraints, MMR' returns $\bar{x}$ = (12.85, 44.01) and $\bar{r}$ =14.29. $r^{\circ} \leftarrow \bar{r}$. This time the regret is positive and the corresponding solution is not a vertex (see in figure 1).

Itération 3 Step 1 : $k \leftarrow 3$, Testing the candidate by CMR leads to $R_{max}(\mathbf{x^*})$ = 14.29 = r° . END.

Thus, $\bar{x}$*****= (12.85, 44.01) minimizes the maximum possible regret by $\bar{r}$ = 14.29. Graphically this regret equals to the minimum distance between the intersection of regret cut lines (figure 1) and the feasible frontier. The ILP solution corresponds to the projection of the intersection point to the frontier direction towards point (0,0) in the variable space. It can also be noted that the min-max regret solution is a well balanced solution, an efficient solution of the MOLP, which has been obtained by taking into account extreme cases that might prove "fatal" for a decision maker.

Case study

Surveyed farms are located in Kopais plain (in Sterea Hellas, about 100 km north of Athens) of a total surface of 25 thousand ha. These farms are representative of arable agriculture (OTEX 'cotton' and OTEX 'other arable crops'). Farm data concerning production plans for years 2005 and 2006 were collected by personal interviews in the context of a doctoral dissertation (Lychnaras, 2008) aiming at evaluating perennial energy crop penetration in the area. For this reason questionnaires have elicited detailed information about the value and quantity of agricultural inputs (i.e. water, fertilizers and pesticides), yields and subsidies per crop, land ownership, entitlements for the single payment regime, farm machinery and buildings, as well as specific information about human and machinery labor used per hectare for each crop and field operation. A follow-up survey has been conducted in 2008 limiting the sample to 41 farms (out of 52 initially surveyed in 2006) with updated information on actual crop mix of the period 2007-08. It was the third cultivation period after the implementation of the CAP reform presumably revealing the farmers' responses to the adopted arrangements affecting relative crop profitability and imposing cross compliance rules (constraints materializing these rules in the region of study are detailed in the next sub-section).

Table 1. Cropping patterns and characteristics in the sample farms

crops	% of farms (2005-06)	Area (ha) (2005-06)	% of area (2005-06)	% of farms (2007-08)	Area (ha) (2007-08)	% of area (2007-08)
Set aside	2	3.3	0.2%	5	7.3	0.5%
Cotton	90	474.7	36%	80	416.4	30.7%
Cotton dry				2	0.3	0.0%
D. Wheat	20	23.5	2%	17	21.6	1.6%
d.wheat irrig	20	24.9	2%	32	43.9	3.2%
Maize	24	98	7%	27	97.9	7.2%
Maize fodder	20	139	10%	22	139.4	10.3%
Tomato	29	43.2	3%	22	40.5	3.0%
Alfalfa	51	520.6	39%	49	547.5	40.4%
Other arable crops*				9	38	2.9%
Olive trees				2	2.5	0.2%

*includes water melons, onions, oats, potatoes, dry tomatoes and witloof

Farming in Kopais involves mainly arable crops such as cotton, durum wheat, oats, alfalfa, tomatoes, maize for seed and fodder (Table 1). About 90% of farms cultivated cotton in 2005, which was the main crop in terms of land coverage (36% of total area), along with alfalfa (half of the farms with 39% of total area), 40% of durum wheat (irrigated and dry included), about 30% producing tomatoes and 24 and 20% of the farms cultivated maize for seed and fodder respectively and one farm had set aside land. As can be seen in Table 1, the CAP 2003 reform has not caused significant changes of activity levels in the sample. The only serious change one observe is a 15% reduction of cultivated area by cotton. About 10% of this area is replaced by alternative cultivations such as melons, onions, oats, potato, non-irrigated tomato and witloof as well as land set aside. Only a few hectares (0.5% of total) can be considered subject to permanent land use change (olive trees) whereas durum wheat, alfalfa, maize and set aside land increase compensate for the rest of cotton land decrease.

Variables and constraints

All crops cultivated in the region have been treated as alternative activities for every farm in the sample. In the 2006 scenario, observed crop yields and prices for the same year were used for each farm. For crops not present in a farm production plan, the corresponding sample averages from the observed data of the same year were used.

For the base year scenario a set of farm specific "policy constraints" was included for the analysis. More specifically, cotton areas for the previous CAP regime are constrained to the cultivated areas observed in the base year reflecting national policy to attenuate co-responsibility charges for exceeding a maximum guaranteed national quantity. These constraints were dropped for the simulation of the new CAP regime. It should be noted that although total decoupling was chosen for most agricultural crops in Greece, cotton remains partially coupled as a land subsidy of €546.5 /ha still applies[iii].

The total area utilized by each farm in 2005 was divided into eligible and non-eligible land. The single payment that corresponds to an eligible hectare for each farm was also added to the objective function as a constant term, so that the model calculates the total single payment per farm, bounded at a level dictated by the total eligible surface

For tomatoes (contracts with canning industry) and maize for fodder, a "market constraint" was imposed: These crops are considered only for the farms that cultivated these crops in the base year but with possibility of a 10% increase in cultivated area. This restriction, which is actually verified by the 2008 observations, is due to the estimate for weakness of disposal of additional production. We note that tomatoes and fodder maize are not considered as eligible crops in this exercise, since these crops were not included in the reform agenda at the time of data collection.

In order to satisfy cross-compliance obligation (new CAP), at least 20% of the eligible area is required to be cultivated with a leguminous crop. The only leguminous crops considered in this exercise are alfalfa and the common vetch intercropped activity[iv]. For all crops, except durum wheat, this cross-compliance requirement is fulfilled by either or both of the above legumes. Durum wheat coincides with vetch in the field for several months during every cultivating season thus the rotation is modeled only with alfalfa. The “idle land” activity was also added so that the model calculates at the optimum the farm land that is not cultivated but is maintained with the minimal required care in order to receive the decoupled payment[v]. Both activities were added as linear variables in the objective function, associated with a negative parameter that represents their estimated variable cost (€100 /ha for the “idle land” and €150 /ha for the vetch activity).

The “resource constraints” used in both scenarios concern the availability of land and water. The constraint for total farm land was defined as an equation and not as a weak inequality, allowing the replacement of the constraint slackness with the “idle land” activity, in order to impose the cross compliance obligation of maintaining idle hectares in “good agricultural condition”. Water resources were modelled in terms of both irrigated area and total water quantity. For the former, a constraint bounding total irrigated land in each farm at the observed levels for the base year was used. For the latter, personal communication with experts provided information about average water requirements per hectare for each crop, which allowed the formulation of a constraint bounding the total water quantity in every farm to its 2005 estimated level.

Most farms in the sample are considered “large” farms by Greek standards, since the average land used is 32.4 hectares, while the national average is only 4.8 hectares per farm. The land entitlements for the new CAP regime amount at more than 67% of the total land used, while the single payment received in 2006 varies between €100 and €1200 per ha (average €370 /ha) , signifying the importance of the single payment for the survival of the farms in the sample.

Gross margin, hereafter net of subsidies, modifies the risk and return conditions within which arable farms operate. As a matter of fact, in the present context, with subsequent CAP reforms that downgrade subsidy stability factor in the formation of gross margin, the natural uncertainty about yields, combined with an increasing uncertainty about prices, enlarge the gross margin variation range. Table 2 illustrates variability of gross margins for crops observed in the sample in both policy contexts. For only 10% price variation, cereals suffer of a tenfold increase in gross margin relative importance while significant increases are observed for maize and cotton. Thus, we assume that unitary gross margins are perceived by farmers as imprecise numbers rather than crisp values of expected gross margins. Therefore, they will be represented in the model by intervals transforming the original LP to an interval linear programming problem. Intervals of ±25-50% have been used in the model for wheat, cotton and maize (products exposed in exogenous shocks) while for fodder maize, alfalfa, oats and tomatoes, expected gross margins are retained (prices clear in national markets) so that the number *s* of interval-valued coefficients are up to five.

Table 2. Gross margins and risk dependent on CAP (€/ha).

crops	Average Gross margin 2005	Coupled subsidies as % of gross margin 2005	±10% sales impact to gross margin 2005		Average Gross margin 2008	Coupled subsidies as % of gross margin 2008	% impact to gm 2008	
Maize-fod	39	0%	47%	570 , 200	390	0%	47%	570 , 200
Maize	560.5	80%	26%	700 , 410	140.5	21%	103%	280 , -10
Cotton	2013.7	107%	5%	2110 , 1910	413	133%	23%	500 , 310
Oats	458	66%	15%	520 , 380	298	47%	24%	360 , 220
Alfalfa	938.2	0%	20%	1120 , 750	938.2	0%	20%	1120 , 750
Wht-irr	298.6	134%	18%	350 , 240	38.6	0%	142%	90 , -20
Wht-dry	267.7	149%	16%	310 , 220	7.7	0%	555%	50 , -40
tomato	2726	0%	25%	3390 , 2050	2726	0%	25%	3390 , 2050

Model validation

The validity of the arable sector model has been checked by comparing optimal activity level outcomes of the LP model with the actual ones in the base year (2005). Then interval linear programming approach using the min-max regret criterion has been implemented to investigate if the model's validity can be improved. The CPLEX solver linear and mixed-integer algorithms have been used for this purpose[vi]. To evaluate the proximity of the optimal solution x_k^{opt} to the observed activity level x_k^{obs} for the crop *k*, several indicators are suggested in the literature such as the sum of absolute distances of individual crops in the plan, the mean absolute distance, the Theil index and others. In this exercise, we used the following distance (FK) measure that indicates the "similarity" of crop plan patterns proposed by Finger and Kreinin (1979):

$$S \quad x^{opt}, x^{obs} \quad = 100 \cdot \left\{ \sum_i \min\left[x_i^{opt}, x_i^{obs} \right] \right\} \qquad (2)$$

If cultivated area of crop *i* in the observed and the optimal set are identical ($X_i^{obs} = X_i^{opt}$ for each *i*) the index will take on a value of 100. If crop plan patterns are totally dissimilar (for each $X_i^{obs} > 0$, $X_i^{opt} = 0$ and vice versa) the index will take on a value f zero. As table 3 shows, both models satisfactorily "predict" base year that was rather expected since alternative crops are limited to those already cultivated in each farm in the observed crop plan. When LP and ILP models are updated according to the new institutional context, both specifications lose about 15 FK index units when predicting year 2008. Examining results at the farm level, one observes that in the 2005 period the ILP model has performed better only in 6 farms, whereas in 2007-08, the ILP model predicts more accurately in 29 farms.

Table 3. Model predictive capacity

ha	*alfalfa*	*cotton*	*wheat*	*Maize fodder*	*tomato*	*maize*	*Irrig wheat*	*oats*	***FK INDEX***
areas 2005	520,6	474,7	23,5	139	43,2	98	24,9	4	
LP	474,2	442,2	28,2	99,8	34,1	198,4	41,3	6,9	***90,43%***
ILP	488.7	446,6	31,3	108,2	34,3	167	29,2	19,4	***92,50%***
hybrid	488,6	453,6	28,3	108,2	34,1	163,5	30,3	19,1	***92,97%***
areas 2008	547,5	416,4	21,6	139,4	40,5	97,9	43,9	10	
LP	608.1	212.8	116.3	38.9	45.4	215.1	73.1	10.2	***76,88%***
ILP	313.3	691.0	24.9	94.6	27.7	111.3	40.9	9.0	***77.34%***
hybrid	450.6	483.5	30.8	129.7	34.0	118.2	60.8	9.0	***91.08%***

The principal effect of the ILP approach with the min-max regret is: when the difference between the gross margins is relatively small, the min-max regret approach gives more "balanced" solutions, more so when the interval coefficients get larger. In fact, as the intervals get larger, the gross margins for different crops start to overlap or, if they already have an intersection, this increases. It then becomes more difficult for the farmer to anticipate which crop will be more profitable. Hence, the min-max regret approach tends to return more and more balanced solutions as the size of the intervals increase. A detailed discussion on this point is presented by Kazakci and Vanderpooten (2002).

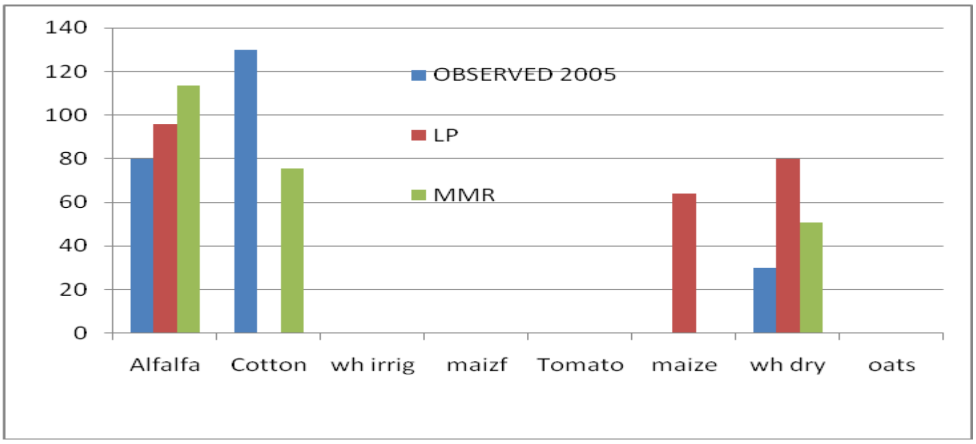

Figure 2. Min-max regret and the LP optimal vs. observed plan for a selected farm.

Thus some farmers maximize gross margin while others demonstrate regret-averse attitude as this one in figure 2. Preferences revealed by the farm-by-farm scrutiny lead us to attempt to model arable agriculture assuming different preferences among producers. For each individual farm elementary model a simple rule replaces the objective function with that, between gross margin maximization and min-max regret, performing better in terms of proximity of the resulted crop mix to the observed one. This way we end up with a hybrid model, by definition with a higher predictive capacity than the initial LP (figure 3). As a matter of fact the FK index at the aggregate level increases to 91% for the hybrid model approaching FK indices for the base year. We should mention at this point that a study in an arable region with similar characteristics (Thessaly) implementing PMP approach that by default calibrates perfectly to the base year, has predicted 2008 crop mix with FK values 85-90% (Petsakos & Rozakis, 2010).

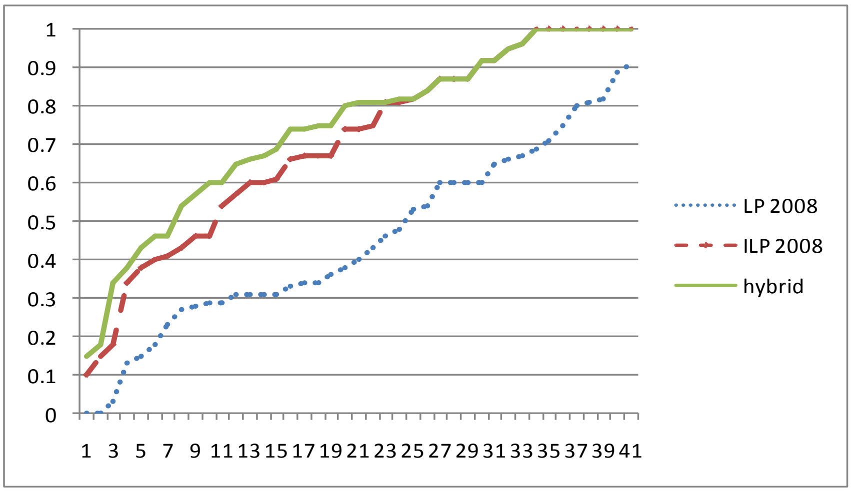

Figure 3. FK similarity indices for all farms in the model

CAP policy scenarios towards 2013 and model results

The hybrid model will be used to evaluate different policy scenarios harvested after the Health Check of the CAP in 2008 and preliminary evaluation of the first years of the implementation of the reform. Single payment, calculated on historical subsidies received by the farm during a reference period, may simply be recalculated on a regional basis resulting in flatter rates of direct payments. Each member state will have a margin to finance environmental preservation, on top of direct payments (top-up), using the rest of subsidies historically received under strict environmental justifications.

Table 4. Reduced profit by crop due to nitrogen reduction

	wheat	***tomato***	***cotton***	***maize***	***potato***	
% yield reduction	7%	15%	15%	19%	16%	%
Market price	130	150	300	150	150	€ */ t*
Sales loss	36.4	1852.5	276	379.5	1297.5	€*/ ha*
Fertilizing cost reduction	7.1	29.6	29.4	64.5	31.1	€*/ ha*
Differential gross margin (loss)	29	1823	247	315	1266	€*/ ha*

Focusing on nitrate pollution, we estimated impacts to yields and reduced receipts as well as gains from reduced quantities of fertilizers using growth model algorithms and nitrogen-yield functions (Rozakis et al., 2001) calibrated for soils in Kopais plain (see Appendix). Overall reduced profit for selected crops appears in table 4. These crops along with all relevant parameters have been included in the model as additional alternatives. In practical terms concerning the arable sector possible measures can be summarized in the following propositions:

1. No coupled subsidies anymore; only SFP remains
2. Flatter direct payment rates (national SFP) : average rate of €550 /ha
3. Flatter rates (hist. EU25): average rate of €305 /ha
4. Environmental top-up20: EU25 average rate of €305 /ha plus €200/ha for applying 25% nitrogen reduction (cotton, maize and wheat)
5. Environmental top-up30: nitrogen reduction supplement at €300/ha (cotton, maize and wheat)

Results of hybrid model optimization calibrated against 2008 data concern scenario 1, 3, 4 and 5 keeping the order of proposals mentioned in the previous section. Proposals 2 and 3 yield identical crop plans because decoupling payment does not by definition affect a farmer's short term decision, but simply changes the gross margin in accounting terms. Compared with "current CAP opt" situation, cotton is decreasing whereas grain and fodder maize significantly increase, with wheat, alfalfa and tomato at previous levels (figure 4).

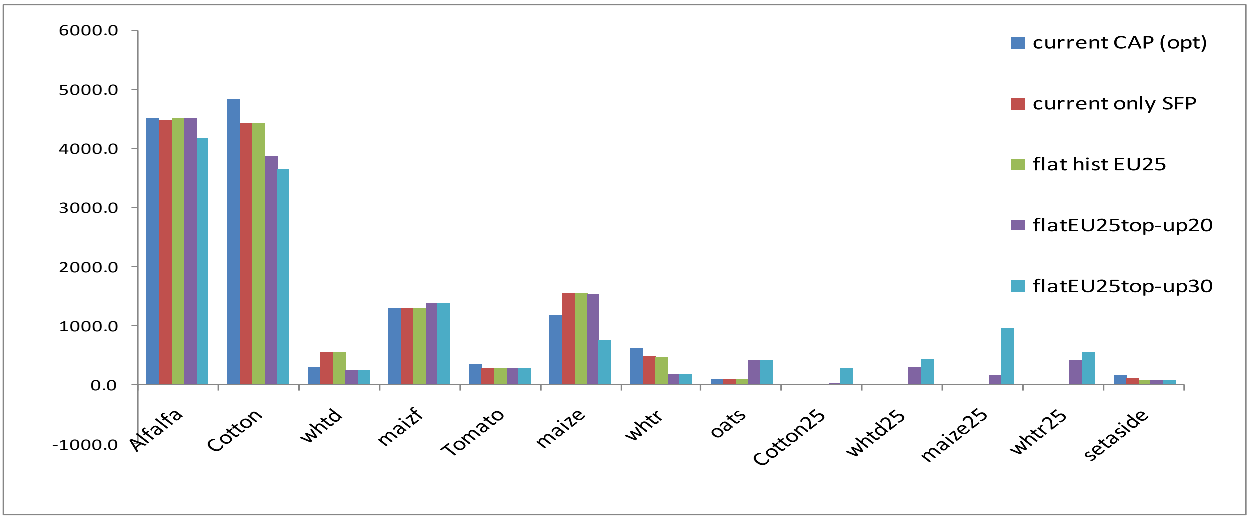

Figure 4. Total areas cultivated by crop for examined policy scenarios (hybrid model)

In the case of nitrogen reduction measures, important areas of cotton, maize and irrigated wheat pass into nitrogen-extensive cultivation and to set aside. We calculated total gross margin (GM), budgetary burden (BG) and quantities of water (WQ) and fertilizers (FQ) applied in order to evaluate scenarios against conflicting objectives.

Table 5. Policy scenarios performance on social and environmental criteria

Scenario	Gross margin M€		water (k m3)		Budgetary burden (k€)		Fertilizers (t)	
Current (yardstick)	1.043	% differential from current	658	% diff.	703.8	% diff.	170.9	% diff.
scenario 1	0.750	-28%	656	0%	393.5	-44%	176.5	3%
scenario 3	0.644	-38%	656	0%	288.1	-59%	176.3	3%
scenario 4	0.674	-35%	650	-1%	266.1	-62%	174.8	2%
scenario 5	0.683	-34%	635	-3%	279.4	-60%	169.4	-1%

Abolition of coupled subsidies (concerning mainly cotton and secondly wheat) result in GM reduction of along with decrease of the amount of subsidies BG of 44%. If the single payment becomes flatter compared with current levels at the mean EU25 level, reductions reach around

38% and 59% respectively for GM and BG values. Water consumption remains at previous levels whereas fertilizer use is slightly increased. The above changes result from internal crop plan changes made by the farmers, who attempt to attain optimal margins taking uncertainty into account. Under scenarios 4 and 5 beside flat rate fee supplementary support farmers that apply nitrogen reduction by 25% versus observed levels contribute to small but non negligible gross margin increase (3-6%) without significant decrease to the total fertilizer quantity. The risk prudent attitude adopted by the majority of farmers does not allow for notable changes in the crop mix under environmental policy scenarios although there is a clear difference when nitrogen decrease top-up area subsidy increases from €20 to €30 per ha (figure 4). The linear sector model, if used in all farm sub-models, would result in total nitrogen reductions by 20% for scenario 5 due to the quasi-abandonment of cotton to the benefit of nitrogen-extensive maize and wheat (figure 5).

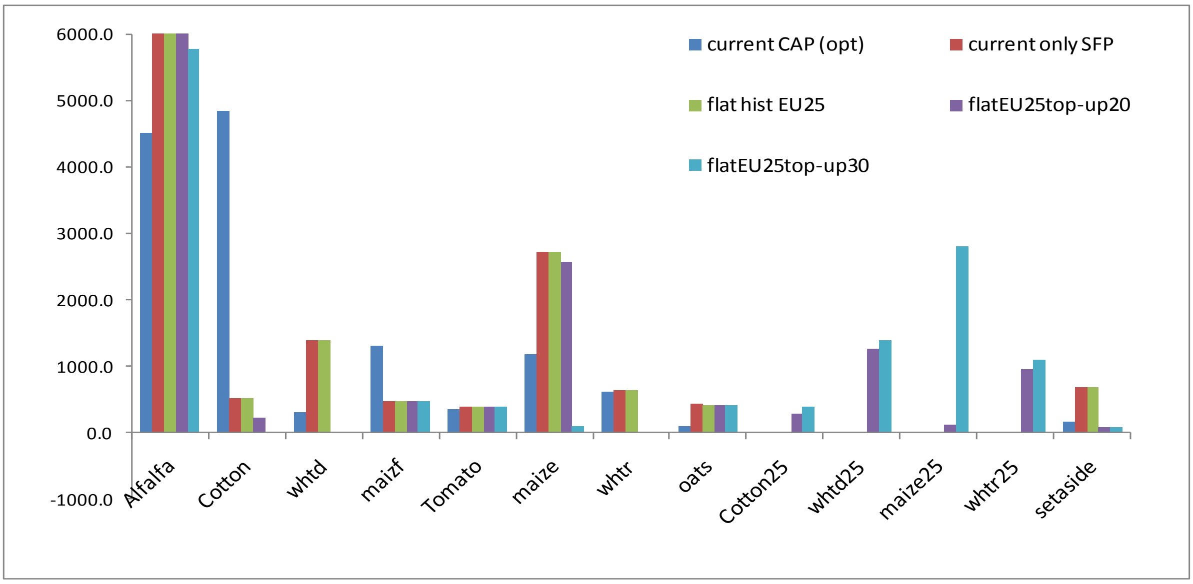

Figure 5. Total areas cultivated by crop for examined policy scenarios (LP)

These counter-intuitive results by the hybrid model due to the majority of farmers that aim at minimizing maximum regret instead of maximizing gross margin may contribute to design more effective environmental measures. Assuming that the hybrid model predicts much better as verified against 2008 observations, policy makers should question the effectiveness of flat area supplements to enhance environmental policies. One could suggest crop dependent rates, since reduced profits due to nitrogen reduction are much higher for maize and cotton comparing to wheat. Furthermore, policy makers could opt to subsidy investments with presumably significant N decreases, for instance to promote the adoption of drip fertilization.

Conclusions

The aim of this study was to improve the representative capacity of a sector supply model in order to provide reliable estimates on impacts of policy measures on cultivated arable land in Kopais plain, Greece. Uncertainty was introduced in the optimization process and has been modeled by means of interval coefficients at the objective function level. The resulting model from this approach is an "Interval Linear Programming Model".

Within this framework, we considered 41 elementary linear programming models corresponding to the farms specializing in cereal production. Then it was assumed that farmers' behavior could be represented using the min-max regret criterion. To test this hypothesis, the min-max Regret (MMR) algorithm was implemented for each of the elementary models. The aim of the algorithm is to find the solution minimizing the maximum regret for a linear programming model with objective function coefficients in the form of intervals.

Analysis of the results and the comparison with the optimal solutions of the LP for the elementary models showed that in many cases the MMR approach gave better balanced and distributed solutions, and this more so when the overlapping of the interval profits for various crops increased. We also observed that our hypothesis was only partially true. Although some improvements were achieved, the proximities obtained by the MMR approach were not always satisfactory enough to support that the farmers decide on their surface allocations according to the logic of min-max regret. Thus the profit maximizing attitude is retained in about 30% of the farms so we ended up with a hybrid block angular model with two possible objective function specifications for each farm (block).

The MMR approach softened the abrupt nature of the linear programming, for which any minimal difference between the unitary margins implies the exclusion of the least profitable crop. These counter-intuitive results by the hybrid model, caused by the majority of farmers aiming at minimizing maximum regret instead of maximizing gross margin, may contribute to produce more effective environmental measures. Assuming that the hybrid model predicts more accurately as verified against 2008 observations, policy makers should question the effectiveness of flat area top-ups to achieve environmental goals. One could suggest crop dependent rates, since reduced profits due to nitrogen reduction are much higher for maize and cotton compared to wheat. Furthermore, policy makers could opt to subsidy investments with presumably significant N decreases, for instance to promote the adoption of drip fertilization.

Further research could be oriented in methodological improvements such as testing the robustness of the MMR model for various interval levels, and more important to combine ILP with multi-criteria utility functions that presumably would improve the predictive ability of farm models. On the other hand empirical application could include other regions and agricultural activities, ideally constructing a national agricultural sector model. Such a model would take into account interactions among regions and activities thus resulting in better estimates of scenarios under discussion. Furthermore, aggregate impacts including economic welfare but also environmental and social indicators should be treated by multicriteria algorithms able to pinpoint compromise solutions assisting in the selection of the most efficient measures in the horizon of 2013 assuming further drastic CAP reforms.

References

Ackrill, R.W., Ramsden, S.J., & Gibbons, J.M, (2001). CAP reform and the rebalancing of support for cereals and oilseeds: a farm-level analysis. *European Review of Agricultural Economics*, 28(2), 207-226.

Bitran G, (1980). Linear multiple objective problems with interval coefficients. *Management Sciences* 26:694-705.

Chinneck J. W. and K. Ramadan (2000). Linear programming with interval coefficients. *Journal of Operations Research Society* 51:209-220.

European Commission, DG for Agric. and Rural Development, 2007. Impact of a change towards flatter rates of direct payments, in "Impact Assessment of the Health Check of CAP, Annex F: Microeconomic analyses", Brussels, December.

Finger J.M., M.E. Kreinin (1979) A measure of 'Export similarity' and its possible uses. *Economic Journal* 89: 905-912.

Guindé, L., Millet, G., Rozakis, S., Sourie, J-C., and D. Treguer (2005) The CAP mid-term reform impacts to French cereal farms: a regional supply modelling approach. in F. Arfini (ed.), *Modelling Agricultural Policies: State of the Art and new Challenges*, Parma: MUP

Hardaker J.B., R.B.M. Huirne, J.R. Anderson and G. Lien. (2004). *Coping with Risk in Agriculture*, Wallingford UK: CAB International

Inuiguchi M. and M. Sakawa. (1995) Minmax regret solutions to linear programming problems with an interval objective function. *European Journal of Operations Research* 86:526-536.

Ishibuchi H. and H. Tanaka. (1990) Multiobjective programming in the optimization of the interval objective function. *European Journal of Operations Research* 48:219-225.

Katranidis, S.D. and Kotakou, C.A. (2008). Are CAP Decoupling Policies Really Production Neutral? Proceedings of the 12th Congress of the EAAE, Ghent.

Kazakçi A.O., S. Rozakis, and D. Vanderpooten (2007) Energy crop supply in France : A min-max regret approach. *Journal of the Operations Research Society* 58(11): 1470-1479

Kazakci A.O., and D. Vanderpooten. (2002). Modelling the uncertainty about crop prices and yields using intervals: The min-max regret approach. In Rozakis & Sourie (eds.), *Options Méditerannéenes*, Special Issue *'Comprehensive modeling of bio-energy systems'*, A-48:9-22.

Kutcher G.P. and R.D. Norton (1982) Operations research methods in agricultural policy analysis. *European Journal of Operational Research* 10:333-345

Loomes G., R. Sugden. (1982). Regret theory: An alternative theory of rational choice under uncertainty. *Economic Journal* 92:805-824.

Lychnaras, V. 2008. Economic analysis of perennial energy crops in Kopais plain under CAP 2003 reform conditions, Dept of Agricultural Economics and Development, Agricultural University of Athens

Manos B. and G. Kitsopanidis 1986. A Quadratic Programming Model for Farm Planning of a Region in Central Macedonia, Greece, *Interfaces*, 16 (4): 2-12.

Manos B. and G. Kitsopanidis 1988. Mathematical programming models for farm planning in Greece, *Oxford Agrarian Studies* XVII, p. 9.

Manos B., T. Bournaris, J. Papathanasiou, P. Chatzinikolaou, (2009) Evaluation of tobacco cultivation alternatives under the EU CAP. *Journal of Policy Modeling* 31: 225–238.

Mattas K., E. Loizou, S. Rozakis, E. Tzouvelekas (2006) Agricultural modelling: an input-output approach, in in F. Ferretti (ed.), *Leaves and Cigarettes : Modelling the tobacco industry, with application to Italy and Greece*, Milano: Francoangeli Publisher

Mausser H. E. and M. Laguna. (1998). A new mixed integer formulation for the maximum regret problem. *International Transactions of Operations Research* 5:389-403.

____. (1999). A heuristic to minimax absolute regret for linear programs with interval objective function coefficients. *European Journal of Operations Research* 117:157-174.

____. (1999). Minimizing the maximum relative regret for linear programs with interval objective function coefficients. *Journal of the Operations Research Society* 50:1063-1070.

Petsakos A., S. Rozakis (2009) Critical Review and State-of-the-Art of PMP Models: An Application to Greek Arable Agriculture, in *Research Topics in Agricultural and Applied Economics*, A. Rezitis (ed.), Bentham Science Publishers (forthcoming)

Petsakos A., S. Rozakis and K. Tsiboukas (2009). Risk optimal farm plans in the context of decoupled subsidy payments: the case of cotton production in Thessaly, *Journal of Farm Management* 13(7): 467-483

Rommelfanger H. (1989). Linear programming with fuzzy objectives. *Fuzzy Sets and Systems* 29:31-48.

Rozakis S., N. Danalatos and K.Tsiboukas, (2001) Crop rotation in Thessaly: bio-economic modelling for efficient management, *MEDIT* N° 4: 50-57

Rozakis S., K. Tsiboukas and M. Korasidis, (2008) CAP Reform Impacts To Greek Cotton Farmers: A Mathematical Programming Approach. *Journal of Agricultural and Food Economics* 3(1-2): 95-116

Salvatici L., G. Anania, F.Arfini, P. Conforti, P. De Muro, P. Londero , P.Sckokai (2000) Recent developments in modelling the CAP: hype or hope? 65th EAAE Seminar "Agricultural Sector Modelling and Policy Information Systems", Bonn, Germany.

Shaocheng T. (1994). Interval number and fuzzy number linear programming. *Fuzzy Sets and Systems* 66:301-306.

Shimizu K. and E. Aiyoshi. (1980) Necessary conditions for min max problems and algorithms by a relaxation procedure. *IEEE Transactions on Automatic Control* 25:62-66.

Sourie J.-C., G. Millet, E. Kervegant, and P. Bonnafous. (2001). Incidences de l'agenda 2000 sur l'offre de céréales, d'oléagineux et de protéagineux : applications du modèle MAORIE. *Etudes Economiques* 38, INRA, Thiverval-Grignon, France.

Steuer R. (1981). Algorithms for linear programming problems with interval objective function coefficients. *Mathematics of Operations Research* 6 :333-349.

Williams P.H. 1999. *Model Building in Mathematical Programming*, 4th ed., John Wiley & Sons Ltd: New York.

Wilson, P., Gibbons, J.M., & Ramsden, S. J. (2003). The impact of cereal prices and policy on crop rotations and supply response, *Journal of Agricultural Economics, 54*(2), 313-323.

APPENDIX. The biological input component

Fertiliser quantities are endogenous to the model, that is, they depend on soil and irrigation system in use. Nitrogen is applied during basic fertilisation before sowing and later during the cultivation period. N units required are calculated based on relationship shown below according to soil type and attributes.

Organic nitrogen concentration in soil (%) = organic matter · (C/organic matter) / (C/N)

Mass of organic nitrogen in soil = (plough depth · bulk density) · organic N concentration

Basic N uptake = organic N mass · mineralisation coefficient

N uptake = yield . (1-moisture content) . minimum concentration

N required = N uptake - basic N uptake

If drip irrigation is applied then basic fertilisation amounts to the one third of N required, the rest applied during irrigation. Otherwise, half of total N quantity is applied during basic fertilisation with the rest applied using fertiliser system. Recovery fraction that defines the quantity of N effectively absorbed by the plant is higher when drip system is used to fertilise resulting in less fertiliser needed at the first place.

fertiliser quantity = N required / (fertiliser N content · recovery fraction[vii])

Table A-1. Calculation sequence of nitrogen application based on soil type

	relationships	values		unit	source
soil type		2Mt	F1	text	spatial DataBase
organic m%	1	1.5%	0.5%	%	constant
c/org matter	2	0.67	0.67	#	constant
C/N	3	12	12	#	constant
organic N%	4=(1·2)/3	0.00084	0.00028	%	spatial DataBase
plough depth	5	0.3	0.3	m	spatial DataBase
bulk density	6	1200	1200	kg/m3	constant
soil mass	7 = 5·6	360000	360000	kg/stremma	model
org N mass	8 = 4·7	301.5	100.5	kg/stremma	model
mineralisation	9	0.01	0.01	%	constant
basic N uptake	10 = 8·9	3.015	1.005	N units	model
plant type		**cotton**		**text**	**parameter**
yield target	11	360	330	kg	spatial DataBase
moisture content	12	0.1	0.1	%	spatial DataBase
minimum concentration	13	0.025	0.025	%	constant
N uptake	14 = 11·(1-12)·13	8.1	7.425	N units	model
N required	15 = 14-10	5.085	6.42	N units	model

Endnotes

[i] All farmers receiving direct payments (even when they are not yet part of the SPS) are subject to cross-compliance including requirements regarding public, animal and plant health, animal welfare, and the maintenance of all agricultural land in good agricultural and environmental condition.

[ii] In an ILP model specified for French arable farms (Kazakci et al., 2007) the number of interval coefficients approached ten in some cases resulting in longer but still manageable solution time spans

[iii] This is the 35% of total subsidy allocated to cotton growers by the cotton regime under the previous CAP. In order to guarantee cotton supply to ginners, coupled area subsidy to cotton has been increased at 800 €/ha, subject to total budget limits, to be implemented in the 2008-09 cultivation period.

[iv] We use this term to explain a short rotation scheme of common vetch (legume crop) with cotton or maize which takes place during the same cropping season: Vetch is sown in winter (November-December) and remains in the field until it is removed by tillage operation in spring (March-April) that also prepares the field for the subsequent sowing of cotton or maize. This means that vetch is not considered for the total land constraint.

[v] Any payment entitlement must be accompanied by an eligible hectare, in order for the farmer to receive the payment.

[vi] The model written in GAMS code is available upon request.

[vii] recovery fraction is set to 0.70 when drip irrigation system is used, otherwise to 0.50

If no drip system then 50% first and the rest top-dressing

Else if drip system exists then 30% first and the rest in equal shares through irrigation