Impacts of flatter rates and environmental top-ups in Greece: A novel mathematical modeling approach

Stelios Rozakis

Abstract

This paper examines evolutions of the Common Agricultural Policy decoupling regime and their impacts on Greek arable agriculture. Policy analysis is performed by means of 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 to incomes and subsidies. Nitrogen reduction incentives also result in moderate changes questioning their effectiveness.

Key words: *Interval Linear Programming, Min-Max Regret, Common Agricultural Policy, Arable cropping, Kopais, Greece*
JEL Classification: *C61, D81, Q12, Q18*

Introduction

After several periods of implementation of CAP 2003, discussions on the CAP future beyond 2013 converge in further reform, mainly driven by budgetary restraint priorities. Expenses devoted to the CAP are subject to severe criticism, likely imposing accountability on social and environmental cost effectiveness. Furthermore, 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 (average receipts from pillar I in Greece 54.4 €/ha, 29.5 €/ha in EU15, and even less for 12 new members 18.5€/ha).

For these reasons, various studies have been undertaken to evaluate the impacts of different policy measures meant to replace current direct payment regime. A comprehensive analysis in the context of the Health Check (EC, 2007) calculates impacts on allocation of the Net Value Added at the farm level in the EU25 for main products using FADN data. Despite its broad scope and valuable results, this study constitutes an accounting assessment not taking into consideration farmers' response concerning restructuring of the cropping plan to minimize negative impacts of policy measures to their welfare. In order to get reliable estimates useful for policy analysis, appropriate sector and regional models are required.

Agricultural Economics and Rural Development Department, Agricultural University of Athens, Iera Odos 75, 11855 Athens GR, e-mail: rozakis@aua.gr, Tel. : +30210 5294735, Fax : +30210 5294767

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, mathematical programming models have been widely suggested to agricultural economists (Salvatici *et al.*, 2000). In Greece, one can mention such models focusing on tobacco and cotton, staple crops that absorbed major alterations, following conventional linear programming (Mattas *et al.*, 2006) and also positive models incorporating downward sloping demand (Rozakis *et al.*, 2008), multi-criteria methods with non-interactive elicitation of the utility function (Manos *et al.* 2009) or increasing cost functions (Positive Mathematical Programming (PMP), Petsakos and Rozakis, 2009) in the objective function. Multi-criteria methods and PMP, that have dominated the recent literature concerning CAP analysis, 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 outperforming its LP counterparts.

Alternatively, risk incorporation into the model may also yield optimal plans beside feasible polygon vertices. Usually non-linear risk-related terms are introduced in the objective function seeking efficient diversification among activities as a means of hedging against risk. To implement such models, availability of covariance matrices – that require gross margin time-series of all candidate crops - is fundamental (Hardaker *et al.*, 2004). Consequently, it is fairly difficult to apply these methods to sector or regional models containing numerous farms, thus relevant publications even theoretically appealing are applied to limited number of representative farms (Petsakos *et al.*, 2008) or to limited activities or products (Katranidis & Kotakou, 2008).

In this paper a bottom-up approach is adopted to reflect the diversity of arable agriculture articulating numerous of farm sub-models in a block angular form, 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 (Leontief technology) and to avoid problems such as discontinuous response and overspecialization arising in single representative farm models. Moreover, it is 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, price and yield variations directly influence gross margins, as no crop specific subsidy exist anymore. Secondly, more important the sky-rocketed 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 that 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. 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 get a compromise solution. By means of experiments, an attempt was successively made to all elementary farm models to check whether it is reasonable to use the min-max regret criterion. 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 presumably improved predictive ability than the initial LP. This model specified for Kopais region is then used to evaluate policy scenarios of flatter direct payment rates and nitrogen reduction national incentives.

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 and the min-max regret algorithm are presented in section 3. Section 4 comprises the case study description and the model validation. Proposed policy scenarios and the results thereof are the focus points of section 5. Finally, conclusive remarks complete the article.

Modeling the Farmers' Behavior: The mathematical formulation

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

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

The sector model contains f farm problems such as the one specified above. The basic farm problem is linear with respect to xf, the primal n × 1-vector of the n cropping activities. The m × n-matrix Af and the m × 1-vector bf represent respectively the technical coefficients and the capacities of the m constraints on production. The vector of parameters θf characterizes the fth representative farm (ycf yields for crop c, vcf variable costs, pcf prices dependent on quality). κ stands for the vector of general economic parameters (p prices not dependent on farm, subc subsidies specific to crops).

The constraints can be distinguished in resource, agronomic, demand and policy ones. The model enables a comparative static analysis, 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:

- Cross compliance obligation in order to receive the single payment (crop – rotation with legumes in 20% of the eligible land).
- 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 modeling difficulties, by proceeding only with simple information on the variation range of the objective function coefficients represented by intervals. 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: $\max\{cx : c \in \Gamma, x \in S\}$ (ILP)

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

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

Let $\Pi = \{x \in S : x = \arg\max\{cy : y \in S, c \in \Gamma\}\}$ be the set of potentially optimal solutions and Y be the set of all the extreme objective functions: $Y = \{c \in \Gamma : c_i \in \{l_i, u_i\}, \forall i = 1..n\}$. 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 follow this kind 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. Ishibuchi and Tanaka, Inuiguchi and Sakawa and also Mausser and Laguna (1998) proposed different methods with this second perspective. Following this perspective, the next section introduces the selected approach, namely the minimization of the maximum regret approach, and the procedure 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. The min-max regret solution procedure is implemented here as proposed in the literature (Inuiguchi and Sakawa, Mausser and Laguna, 1998, 1999). The mathematical translation of this hypothesis that is, the presentation of the formal problem and the algorithm of min-max regret are presented in the following paragraphs.

Suppose that a solution $x \in S$ is selected for a given $c \in \Gamma$. The regret is then: $R(c,x) = \max_{y \in S}\{cy\} - cx$ and 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: $\min_{x \in S}\{\max_{c \in \Gamma}\{\max_{y \in S}\{cy\} - cx\}\}$ (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. The relaxed *MMR'* problem is:

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

where $C = \{c^1, c^2, \ldots, c^p\} \subset \Gamma$.

This problem is equivalent to: $\min r$ (*MMR'*)

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

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

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 Γ \ 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 $\bar{x}$: $\max_{c \in \Gamma}\{\max_{y \in S}\{cy\} - c\bar{x}\}$ (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 of CMR $x_{c^{p+1}} \in S, c^{p+1} \in \Gamma$ yields $R_{\max}(\bar{x}) > \bar{r}$, 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. The difficulty in this resolution process lies in the quadratic nature of the CMR problem. Mausser and Laguna (1998) used their results to formulate a mixed integer linear program equivalent to CMR which is less costly to solve. Thus, in this exercise the equivalent problem mixed-integer formulation is used.

Graphically, the above algorithm can be nicely illustrated in the two dimensional space (figure 1). The CMP juxtaposes 'regret cut' lines in the variable space until finding the minimum regret. Then the task undertaken by the MMR basically corresponds to the projection of the regret-cuts-intersection-point to the feasible area. The regret optimal solution most likely lies on a side of the feasible area as in figure 1.

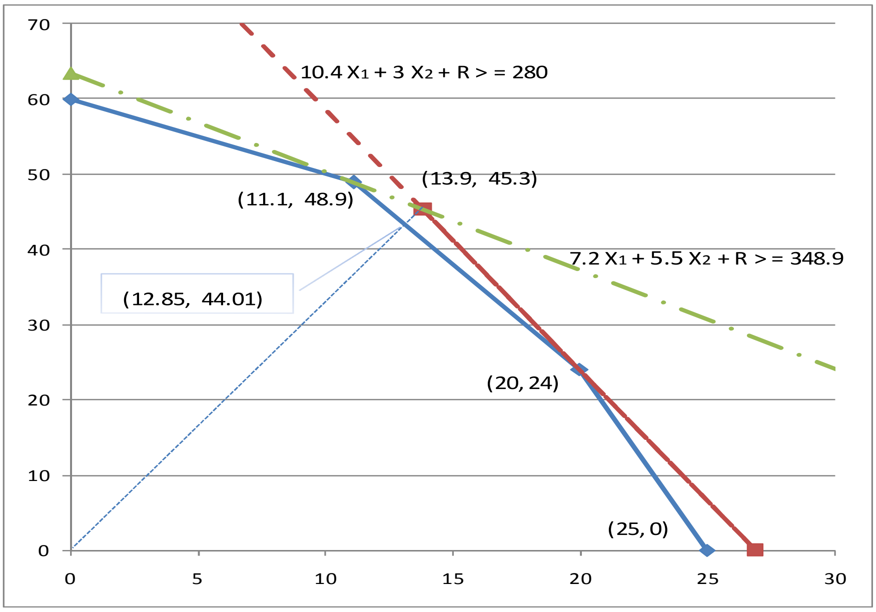

Figure 1: Variable space, feasible area and regret cuts.

Case study and model validation against observed crop mix

Surveyed farms are located in Kopais plain (in Continental Greece, about 100 km north from Athens) of a total surface of 25 thousand ha. Farm data concerning production plans for period 2005-06 were collected in the context of a doctoral dissertation (Lychnaras, 2008) aiming at evaluating perennial energy crop penetration. 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. 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, while the single payment received in 2006 varies between 100 and 1200 €/ha (average 370 €/ha), denoting the importance of the SFP for farm viability.

Gross margin hereafter net of subsidies modifies the risk and return conditions within which arable farms operate. As a matter of fact, in the current context, decoupling downgrades subsidy stability factor in the formation of gross margin, so that the natural uncertainty about yields combined with an increasing uncertainty about prices enlarge the gross margin variation range. 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 ±30-50% have been used for wheat, cotton and maize (products exposed in exogenous shocks) while for locally traded goods such as fodder maize, alfalfa, oats and tomato, expected gross margins are retained so that the number s of interval-valued coefficients are up to five.

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 observes is a 15% decrease of cotton cultivated area. 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.

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%
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%

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

The validity of the arable sector model has been checked by comparing optimal activity level outcome from LP and ILP models with the observed ones. The CPLEX solver linear and mixed-integer algorithms have been used for this purpose. To evaluate the proximity of the optimal solution x_k^{opt} to the observed activity level x_k^{obs} for the crop k, the following distance (FK) measure, that indicates the "similarity" of crop plan patterns proposed by Finger and Kreinin (1979), is used:

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

If cultivated area of crop i in the observed and the optimal set are identical (Xiobs = Xiopt for each i) the index will take on a value of 100. If crop plan patterns are totally dissimilar (for each Xiobs > 0, Xiopt = 0 and vice versa) the index will take on a value f zero. As table 3 shows, both models satisfactorily "predict" base year 2005 (FK of 90-92% for aggregate crop plan). The predictive capacity of LP and ILP models are updated according to the current institutional context is modest with 77 and 78% respectively. Examining results at the farm level, one observes that in the 2005 period ILP model has performed better only in 6 farms, whereas in the 2007-08 one, ILP model predicts better in 29 farms. The hybrid model retained comprising 12 profit seekers and 29 risk prudent farmers increases predictive capacity to 91%. Notice that a similar regional PMP model in Thessaly that by default calibrates perfectly to the base year, has predicted 2008 crop mix with FK values 85-90% (Petsakos & Rozakis, 2009). 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 however, models contain one-digit interval coefficients has kept the model size manageable.

CAP policy scenarios and results

The hybrid model will be used to evaluate policy scenarios under discussion. Single payment, calculated on historical subsidies received by the farm during a reference period, may be recalculated on a regional basis resulting in flatter rates. Furthermore, each member state may compensate loss caused by flatter rates under strict justifications to finance environmental preservation on top of direct payments (top-up) using the rest of subsidies historically received.

Table 2: 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*
Differential gross margin	29	1823	247	315	1266	*€/ha*

Focusing on nitrate pollution, impacts to yields and reduced receipts as well as gains from reduced quantities of fertilizers are estimated using growth model algorithms and nitrogen-yield functions calibrated for soils in study area (Rozakis *et al*., 2001). Overall reduced profit for selected crops appears in table 2. These crops along with all relevant parameters have been included in the model as additional activities. Various measures can be summarized in the following propositions:

- No coupled subsidies anymore only SFP remains
- Flatter direct payment rates (national SFP) : average rate of 55 €/ha
- Flatter rates (hist. EU25): average rate of 30.5 €/ha
- Environmental top-up20: EU25 average rate of 30.5 €/ha plus 20 €/ha for applying 25% nitrogen reduction (cotton, maize and wheat)
- Environmental top-up30: nitrogen reduction supplement at 30 €/ha

Proposals 2 and 3 yield identical crop plans because decoupling payment does not by definition affect farmer's short term decision, simply changes gross margin in accounting terms. Thus hybrid model results on proposals 1, 3, 4, and 5 appear in Figure 2. Compared with "current CAP opt" situation, cotton is decreasing whereas grain and fodder maize significantly increase, with wheat, alfalfa and tomato in previous levels.

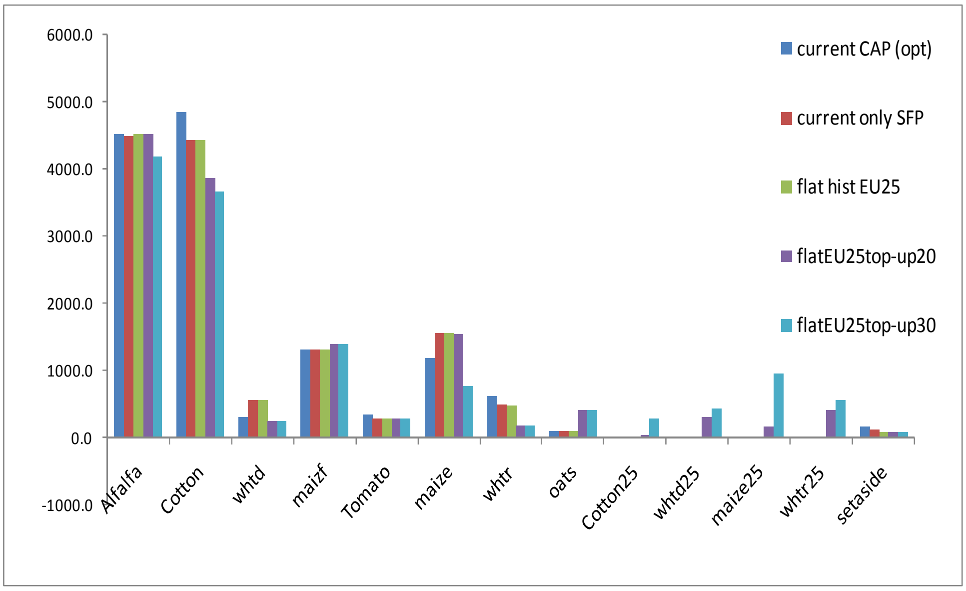

Figure 2: Total areas cultivated by crop by policy scenario (hybrid model)

In the case of nitrogen reducing measures, important areas of cotton, maize and irrigated wheat pass into nitrogen-extensive cultivation and in 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.

Abolition of coupled subsidies (concern mainly cotton and secondly wheat) results in 28% GM reduction along with decrease of the amount of subsidies BG of 44%. If single payment becomes flatter compared with current levels at the mean EU25 level, reductions reach percentages 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. 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 €/ha (figure 2). 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.

Conclusive remarks

The MMR approach softened the abrupt nature of the linear programming, for which any tiny difference between the unitary margins implies the exclusion of the least profitable crop. 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.

References

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

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. *Eur J Operation Research* 86:526-536.

Ishibuchi H. and H. Tanaka. (1990). Multiobjective programming in the optimization of the interval objective function. *European J 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, D. Vanderpooten (2007). Energy crop supply in France : A min-max regret approach. *J of the Operations Research Society* 58(11): 1470-1479

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

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

Mattas K., E. Loizou, S. Rozakis, Tzouvelekas E. (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 Publ.

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

Mausser H. E. and M. Laguna (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

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

Rozakis S., K. Tsiboukas and M. Korasidis, (2008). CAP Reform Impacts To Greek Cotton Farmers, *J 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.

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

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