

# Water demand management in the Mediterranean, progress and policies

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*Advanced modelling tools for integrated assessment of water and agricultural policies*

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## **ADVANCED MODELLING TOOLS FOR INTEGRATED ASSESSMENT OF WATER AND AGRICULTURAL POLICIES**

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### **Abstract**

In Spain, as in most Mediterranean countries, water is a strategic resource and a major constraint for agricultural production. Recent trends on European Union (EU) water and agricultural policies reinforce the integration of sustainability principles in farming and the need of meeting the challenge of reconciling water and agricultural policies.

On the one hand, the Water Framework Directive, approved in 2000, establishes the basic principles for a sustainable water policy in the European Union. According to this Directive, water demand management policies will provide incentives to use water in a more efficient way and therefore contribute to the environmental objectives.

On the other hand, the Mid-Term Review of the Common Agricultural Policy (CAP), agreed on June 2003, represents a complete change in the way the EU support the farm sector. While "decoupling" will make EU farmers more competitive and market oriented, "compliance" will ensure the respect of environmental, food safety and animal welfare standards.

The versatile nature of these new policy measures will lead to a multiplicity of support schemes, rising the interest of developing economic tools flexible enough to take into account the different features and concerns of the rural areas. This motivates the aim of this paper to develop a modelling tool aimed to guide the design of regional or local strategies in the Spanish farming systems.

In this sense, we develop a positive mathematical programming model that allows us to simulate farmers' behaviour and to assess the environmental and socio-economic impacts of different water and agricultural policy options. This modelling tool, well adapted to work with the limited databases available, has been applied to a large number of farming systems representing the heterogeneous characteristics that can be found throughout the Spanish territory. Chosen scenarios focus on some recently envisaged policy alternatives, such as water demand management under the Water Framework Directive, or the decoupling scheme in the Mid Term Review of the CAP. Model results allow us to suggest that this modelling approach may be used as a management tool to assist the design of sound policy measures.

**Keywords:** water and agricultural policies, policy impact analysis, positive mathematical programming.

## Introduction

A better understanding of the linkages between agriculture and water resources is crucial if we want to move towards more sustainable water policies. In most Mediterranean countries, irrigated agriculture accounts for a major share of final farming production and still plays an important role in the economic activity within some areas. Agriculture has traditionally been and still is the main water user, but agricultural policies often intensify overuse and pollution of water resources.

Recent trends on EU water and agricultural policies reinforce the integration of sustainability principles in farming and the need of meeting the challenge of reconciling water and agricultural policies.

On the one hand, the new EU Water Framework Directive (European Commission, 2000) draws up an integrated framework and establishes the basic principles for a sustainable water policy in the European Union. One of the major WFD innovation is that provides a European policy basis for sustainable water management and the elaboration of policies for river basins. According to the WFD, the use of economic instruments plays a key role in the development of a sustainable water policy, and Member States shall ensure by 2010 that water-pricing policies provide adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives.

On the other hand, the Common Agricultural Policy (CAP) has evolved throughout time reflecting the continuously changing concerns of European societies and its rural areas. The reform of the CAP agreed on June 2003 completely changes the way the EU supports its farm sector. The key elements of the new CAP are "decoupling", a single payment scheme (SPS) independent from production, which will make EU farmers more competitive and market oriented; and "cross-compliance", which will ensure the respect of environmental, food safety and animal welfare standards. Moreover, there is less emphasis on market and income support measures within Pillar 1 and an increasing importance of rural development programs. Member States have a considerable degree of flexibility, either to implement the single payment scheme, to develop environmental standards or to establish rural development programs.

These new water and agricultural policy trends pose important challenges for policy modellers:

- There is an increasing interest for developing analytical tools at the regional or local level, flexible enough to simulate the rising variety of policy instruments (water pricing, decoupling, cross-compliance, modulation,...).
- We need models able to simulate potential changes in cropland allocation and technological choice, and able to work with the available statistical information, in order to allow for regional comparison.
- There is an increasing need to integrate environmental issues in economic analysis.

This motivates the aim of this paper to develop a methodology well adapted to assess the environmental and socio-economic impacts of different policy options at the regional or local level and aimed to guide the design of regional or local strategies in the Spanish farming systems.

## Background

Policy impact analysis in the agricultural sector has traditionally relied on either mathematical programming models or econometric models. Even if econometric techniques have been used for assessing agricultural policies (Moore et al., 1994), programming models have been proven very useful for this purpose because they allow to explicitly model complex technological or institutional constraints. Moreover, the need to simulate policy scenarios far away from past experience makes difficult the application of econometric techniques (Taylor and Howitt, 1993; Gibbons, 1986).

The traditional mathematical programming approach is based on models that reproduce farmer's decisions assuming an optimising behaviour and allow analysing policy changes at a detailed and disaggregated scale. However, most of existing works focus on a more or less concrete empirical application since this approach requires exhaustive and expensive fieldwork and data collection. Varela et al. (1998), for instance, conduct comprehensive field data to assess the socio-economic impacts of water pricing policies in several irrigation districts.

The well-known positive mathematical programming method (PMP), first developed by Howitt (1995), overcomes some important limitations of traditional mathematical programming. Most important in this approach is that it recovers additional information from observed data on farmers' behaviour, allowing an automated model calibration. A growing number of water and agricultural policy analysis apply this methodology (Gohin and Chantreuil, 1999; Graindorge et al., 2001; Arfini, 2001). The original PMP approach has been extended in many ways (Paris and Howitt, 1998; Hecklei and Britz, 2000; Röhm and Dabbert, 2003; Preckel et al.; 2002)

One serious limitation of PMP is that model activities are restricted to those existing in the observed situation. Thus, it does not allow considering technology adoption or new activities, even when these might become plausible strategies under certain policy changes. Blanco and Iglesias (2005) have extended the standard approach to incorporate the possibility of water saving technology adoption and additional crops when simulating farmer's response to new agricultural policies. They have built a meta-model and applied it to a wide range of heterogeneous irrigation districts to analyse farmers' response to agricultural policies.

Integrating environmental goals in economic models is not an easy task. A major limitation related to agriculture and water quality has been the lack of well-established relationships between agricultural practices and water quality. Non-point source pollution is a dynamic and site specific process. Emissions from non-point sources are either impossible to observe or their observation is prohibitively expensive. Hence, the use of agri-environmental indicators (OECD, 2001) is the most common method to integrate environmental concerns in economic analysis.

Water pollution by nitrates is by far one of the main environmental problems associated with agricultural activities. Nitrates are highly soluble and migrate easily into groundwater through the soil, making it difficult to establish a link between nitrogen supply and water pollution. One proxy to deal with water pollution is to measure the amount of applied fertilizer.

## Methodology

Given that farming systems and impacts of agricultural policies are highly heterogeneous throughout the Spanish irrigations, models used for analysing agricultural policies need to be disaggregated by region. Hence we have developed a multi-output multi-input agricultural supply model allowing us to work at a disaggregate level and that can be easily replicated to a large number of heterogeneous irrigated areas.

Data requirements were another decisive factor for model selection. Given the national scale of this study, we wanted to exploit available information as much as possible and lower the need to collect new field data. The positive mathematical programming approach, first developed by Howitt (1995), appeared as a suitable option. Within this approach, the model is calibrated recovering information from observed behaviour in the year-base situation, reducing the subjective role of the modeller in the calibration procedure. Compared to conventional mathematical programming, the main advantages of this approach are an exact representation of the reference situation, lower data requirements and a smooth response of model results to continuous changes in exogenous parameters when the model is used for impact analysis.

One of the main disadvantages of positive mathematical programming (PMP) is their limited capability to simulate activities non-observed in the base-year situation but that could be adopted if the policy scenario changes. To overcome this difficulty, we have extended the standard PMP approach in order to allow the incorporation of new production activities and irrigation technologies (Blanco and Iglesias, 2005). We propose a cost transfer approach which allows us to simulate the adoption of new irrigation technologies and the switch from irrigated to dryland crops.

The PMP method to calibrate mathematical programming models to observed activity levels typically involves a two-step procedure for implementation. In the first step, we solve a linear programming model bounded to observed activity levels by calibration constraints. In the second step, we use information contained in dual values of the calibration constraints in order to specify a non-linear objective function such that, once the calibration constraints are removed, the new programming model reproduces almost exactly the observed activity levels.

The model maximises total net income of the study area subject to resource and policy constraints. Decision variables are  $x_{jr}$ , where subscript  $j$  is for crop type and subscript  $r$  is for irrigation technology. The calibration model can be compactly written (subscript  $j$  denotes the crop type,  $r$  the irrigation technology and  $i$  the resource type):

$$\begin{aligned} \text{Max} \quad & Z = \sum_j \sum_r (p_j y_{jr} - c_{jr}) x_{jr} \\ \text{subject to} \quad & \sum_j \sum_r a_{ijr} x_{jr} \leq b_i; \quad i=1,2,\dots,m \\ & x_{jr} \geq 0; \quad j=1,2,\dots,n \quad r=1,2,\dots,s \\ & x_{jr} \leq x_{jr}^0 (1 + \varepsilon) \end{aligned}$$

where  $Z$  denotes the objective function value,  $c$  is a  $(n \times 1)$  vector of variable cost per unit of activity;  $x$  is a  $(n \times 1)$  vector of production activity levels (hectares per crop and irrigation technology);  $p$  and  $y$  are vectors of (expected) output prices and yields, respectively,  $a_{ij}$  represents a  $(m \times n)$  matrix of coefficients in resource/policy constraints,  $b_i$  is a  $(m \times 1)$  vector of available resource quantities,  $x^0$  is a  $(n \times 1)$  vector of observed production activity levels and  $\varepsilon$  denotes a vector of small positive numbers.

The objective function maximizes net farm income. Net income is defined as total sales value minus irrigation costs and other variable costs. Resource constraints include constraints on total cropland available, total irrigation water available and agricultural policy.

The addition of the calibration constraints forces the optimal solution of the linear programming model to almost perfectly reproduce the observed base-year activity levels  $x^0$ . The solution of the linear model allows us to obtain the dual values associated to the calibration constraints, which give us extra information about the cost functions.

In the second step of the procedure, we specify a non-linear objective function such that the marginal cost of the model activities are equal to their respective revenues at the base-year activity levels  $x^0$ . We have chosen a quadratic cost function:

$$CT_{jr} = \alpha_{jr} x_{jr} + \beta_{jr} x_{jr}^2$$

The solution of the linear model allows us to estimate parameters  $\alpha_{jr}$  y  $\beta_{jr}$  for this function. In order to allow for new activities, we propose a cost transfer approach. Data (prices, yields, production costs, etc.) for the new activities (dryland crops and new irrigation technologies) come from surrounding agricultural areas. In the case of new irrigation technologies, cost function parameters are approximated using the optimality conditions. The idea consists on extending the assumption of optimal farmers' behaviour. We suppose that if the new irrigation technology does not enter the observed solution it is because marginal cost exceeds marginal benefit. Assuming technology adoption costs, we can approximate parameters  $\alpha_{jr}$  y  $\beta_{jr}$  in order to obtain a calibrated model where the new irrigation technologies do not appear in the baseline scenario but can enter the solution if the policy scenario changes.

Once the cost functions for all activities have been derived, we are able to define the non-linear model that maximises total net income of the irrigation study area by allocating land and irrigation water across crops:

$$\begin{aligned} \text{Max} \quad & \sum_j \sum_r \left( (p_j y_{jr}) x_{jr} - (\alpha_{jr} x_{jr} + \beta_{jr} (x_{jr})^2) \right) \\ \text{subject to:} \quad & \sum_j \sum_r a_{ijr} x_{jr} \leq b_i \\ & x_{jr} \geq 0, \end{aligned}$$

This non-linear model reproduces the activity levels observed for the base-year situation and allows us to simulate hypothetical water and agricultural policy scenarios. The model structure is flexible enough to incorporate the main environmental constraints and policies.

Hence this methodology allows for assessing the environmental and socio-economic impacts of new agricultural related policies and may convey useful information to policy makers.

### **Empirical application**

This methodological framework has been applied to a wide range of irrigation districts, throughout the Spanish territory. Criteria for irrigation district selection have included area size, cropping systems, agronomic and climatic characteristics, water supply system, irrigation methods, etc.

Data sets have been limited to existing data availability. For each irrigation district, information about production activity levels, inputs use per crop, water charges, variable costs per activity, expected crop prices and yields, and agricultural policy subsidies and constraints were available. We considered long term decisions so all costs in the model are variable. We also considered constraints on total cropland, total irrigated land and water availability.

The model allows us to reproduce the strategies adopted by farmers when a new policy measure applies. In general, there are three ways that a farmer can respond. First, the farmer can alter the crop mix. Second, the farmer can adopt modern irrigation technologies. Finally, the farmer can reduce the total irrigated land, increasing the proportion of dryland crops (adopting new activities).

This meta-model allows analysing the economic and environmental impacts of water and agricultural policy scenarios. Impacts on cropland allocation, irrigation technologies, water consumption, farm net income, employment and inputs use are assessed. The model has been built using the GAMS modelling language (Brooke et al., 1998) and the model interface allowed us to replicate the model in an easy way in a wide range of irrigation areas.

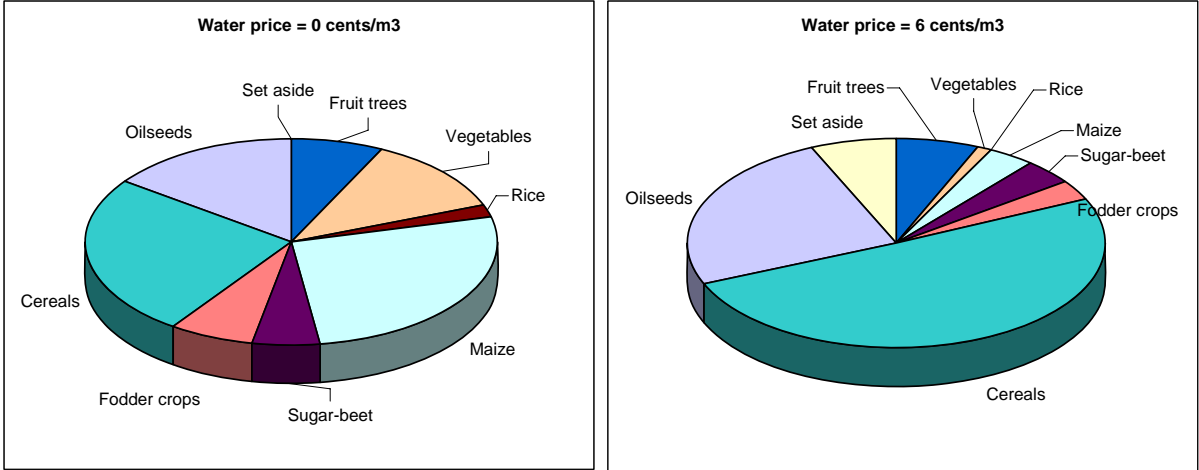
In order to illustrate the capabilities of this methodological approach to assess the implementation of water pricing mechanisms and the impacts of agricultural policy changes, we discuss some preliminary results obtained for two particular irrigation districts: one of them located in the Guadiana river basin (Centre Spain) and the other in the Guadalquivir river basin (Southern Spain). In both cases, irrigation is carried out with surface water; the river basin authority takes the mayor responsibility for operation, maintenance and management of the water delivery system; and farmers are charged on a per unit area basis.

For both irrigation districts, we have simulated the implementation of water pricing mechanisms in different agricultural policy situations. The agricultural policy options are:

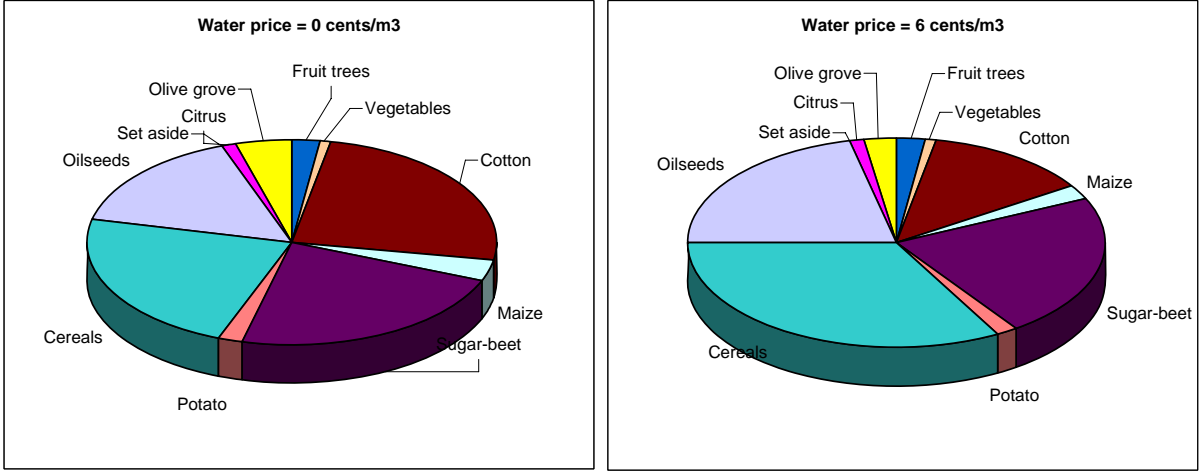
- Baseline Scenario: It corresponds to the Common Agricultural Policy that apply in the region in the year base situation (due to data availability we consider 1999 as the baseline situation)
- Partial Decoupling: It corresponds to the Single Payment Scheme, considering that 75% of payments are decoupled from production (this scenario corresponds to the envisaged option in Spain for arable crops).
- Full Decoupling: It corresponds to the Single Payment Scheme, considering the option of total decoupling.

The single farm payment is related to the baseline situation and future prices are assumed stable (except for cotton, in which case the support regime completely changes).

If we look first at the Baseline Scenario, Figures 1 and 2 present model results on cropland allocation under different water prices in Guadiana and Guadalquivir irrigation districts respectively. Increasing water prices induce farmers to change cropping patterns to less water-intensive crops. In the Guadiana irrigation district, for instance, a water price of 6 cents/m<sup>3</sup> induces a partial substitution of more water-intensive crops (rice, corn) by less water-intensive crops (cereals, sunflower).

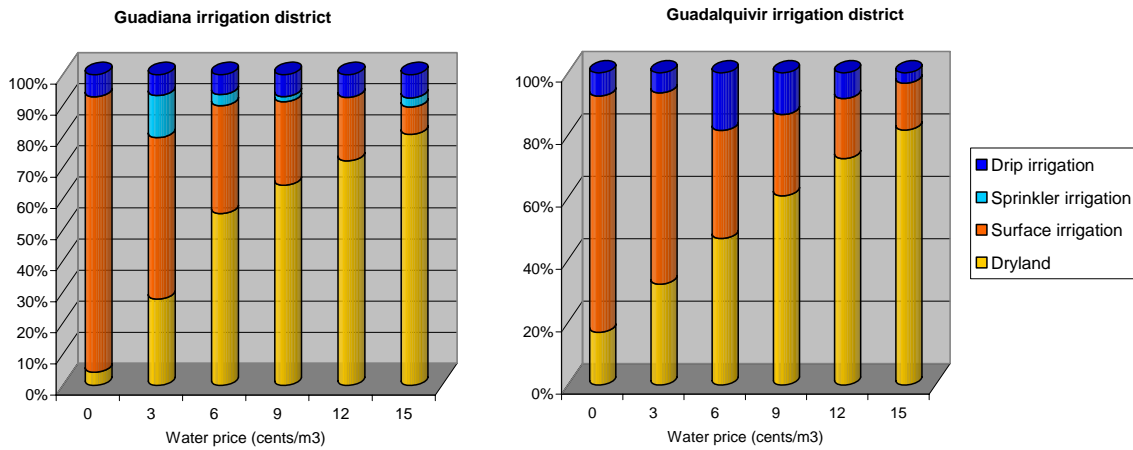


**Figure 1.** Cropland allocation (Guadiana irrigation district)



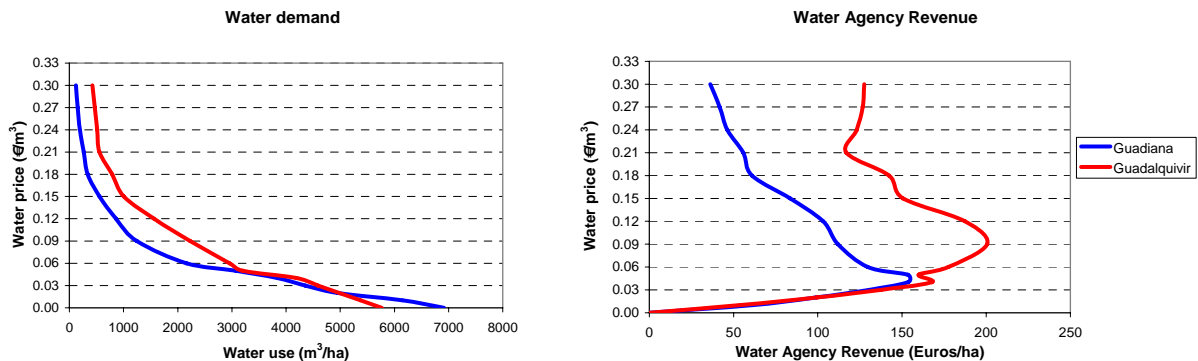
**Figure 2.** Cropland allocation (Guadalquivir irrigation district)

In the Guadalquivir irrigation district, crop substitution for low water prices is not so significant. In this case, technology change is the first adaptation strategy adopted by farmers. Actually, the model also allows for an adjustment of irrigation technologies. As Figure 3 shows, in the base-year situation, surface irrigation is the predominant technology in both irrigation districts (drip irrigation is only used for fruit trees). As water price increases, farmers adopt water-saving technologies, switching from surface irrigation to sprinkler and drip irrigation methods. We remark that even low water prices induce a high technological change (a change to sprinkler irrigation in the Guadiana irrigation district and to drip irrigation in the Guadalquivir irrigation district).



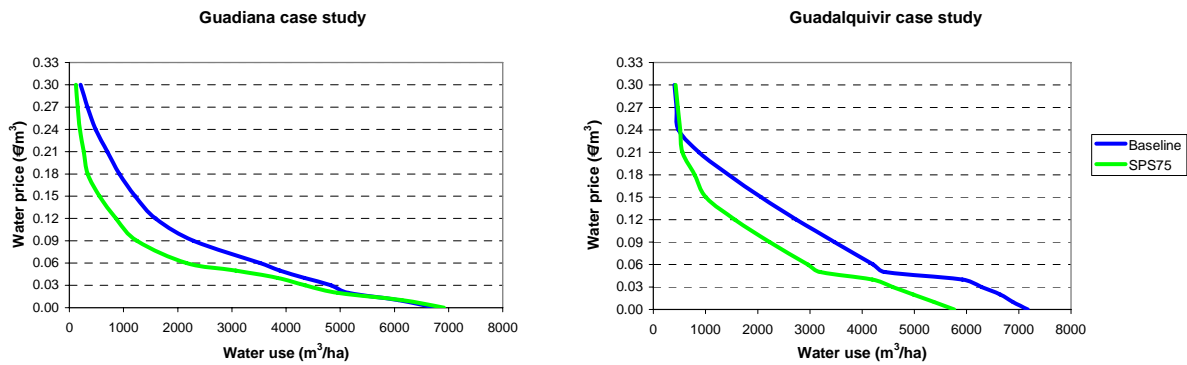
**Figure 3.** Irrigation technology

Regarding water abstraction (Figure 4), results show that low water prices induce significant water savings, which can be explained by the technological change and the crop substitution effects. In the Guadiana irrigation district, for instance, a water price of 3 cents/m<sup>3</sup> induces a reduction in water use of 37%, and for high water prices only the fruit trees are irrigated. In the Guadalquivir irrigation district, water demand is more inelastic for low and medium water prices, reflecting the greater productivity differential between irrigated and dryland crops. Regarding water agency revenue, results show that water savings and cost recovery may become conflicting objectives for a large range of water prices.



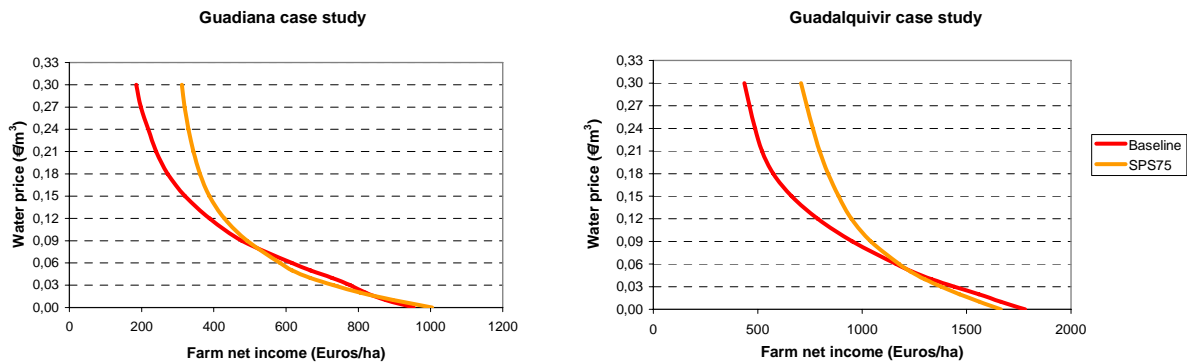
**Figure 4.** Baseline Scenario: Water demand and Water Agency Revenue

If we look now at the Partial and Full Decoupling scenarios, model results show that the Single Payment Scheme will have a significant influence on production decisions. Compared to the baseline situation, full decoupling induces farmers to change cropping patterns and to reduce the irrigated area. COP irrigated surface decrease and new dryland crops appear. These crop substitution effects are more acute in the Guadalquivir study area where cotton production is very important (CAP reform implies a radical change in the cotton support regime). Also, differences in productivity between irrigated and dryland crops are much higher in the Guadiana area, so the shift to dryland crops is softer in this area than in the Guadalquivir irrigation district. As a consequence of this trend to a diminution of irrigated lands, the partial decoupling scenario will induce a decrease in water use in both irrigated areas (Figure 5).



**Figure 5.** Water demand: Comparison of Baseline and Partial Decoupling scenarios

Model results also allow us to evaluate socioeconomic and environmental impacts (Figure 6). Water quality implications of water pricing mechanisms are not straightforward. Actually, there are a close correspondence between crop activities and fertilizer use.



**Figure 6.** Farm income: Comparison of Baseline and Partial Decoupling scenarios

## Concluding remarks

Recent institutional and policy changes pose an important challenge on modelling. The model presented in this paper has been developed as a ready-to-use toolkit for policy makers, aimed to assess the environmental and socioeconomic impacts of water and agricultural policies in Spanish irrigated lands.

Compared to conventional farm modelling methodologies, the positive mathematical programming approach has lower data requirements and is well suited to work with the limited databases available, making it easier to perform analyses on a global scale. While working at a disaggregate level, model structure has proved great flexibility to incorporate new policy instruments (cross-compliance and other CAP requirements) and to integrate environmental constraints and policies.

Finally we have showed through an empirical application that the model conveys specific and detailed information about the impacts on environmental indicators, water consumption, crop allocation decisions, technology adoption, farm income, and public expenditure when different scenarios of water and agricultural policies are considered. These characteristics suggest that this modelling approach may be used as a management tool to analyse the

linkages between water and agricultural policies and to assess the economic and environmental impacts of new policy measures at a disaggregate level.

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