MODELLING THE IMPLEMENTATION OF THE FULL COST RECOVERY APPROACH IN SPANISH IRRIGATED LANDS[1]

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The recent Water Framework Directive requires that Member States take account of the principle of recovery of the cost of water services, including environmental and resource cost. In doing so, Member States may have regard to the social, environmental and economic effects of the recovery as well as the geographic and climatic conditions of the regions. This rises the interest to develop economic management tools to assess water managers in implementing the full cost recovery approach. This motivates the aim of this paper to develop a methodology to assess the impact of cost recovery in Spanish irrigated lands.

The need to collect comprehensive field data is a serious limitation of traditional farm modelling methodologies to perform evaluation on a global scale. Most of existing analyses are restricted to the evaluation of impacts in limited areas making it difficult to establish general conclusions. This fact is particularly relevant when considering the high heterogeneity of irrigation areas in Spain. In this context, the development of methodologies adapted to work with the limited databases available and that can be applied to diverse situations are highly valuable.

In this paper, we develop a positive mathematical programming model to evaluate the impact of full cost recovery in a large number of irrigation districts representing the heterogeneous characteristics that can be found throughout the Spanish territory. The proposed model allow to simulate farmers' behaviour under full cost recovery scenarios. One of the main limitations of positive mathematical programming is that available options to the farmers are limited to the observed activities in the actual situation. We propose a cost transfer approach which allow us to simulate the adoption of new technologies and conversion to dryland crops.

The model interface allowed friendly use and easy replication to more than two hundred irrigation districts which were selected throughout the Spanish territory. Selection criteria have included community size, crop rotation, agronomic and climatic characteristics, water supply system, irrigation systems, etc. The model results shows the impact on water consumption, crop substitution, technology adoption, labour, farmers income, and the water agency revenues when different scenarios of cost recovery are considered. This allow us to suggest that this modelling approach may be used as a management tool to assist the implementation of the cost recovery approach of the new Water Framework Directive.

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1 INTRODUCTION

The recently passed EU Water Directive (WFD) draws up an integrated framework and establishes the basic principles for a sustainable water policy in the European Union. One of the most controversial issues in the passing of this directive was the implementation of the full cost recovery approach. In its article 9, the WFD establishes that Member States should take account of the principle of recovery of the costs of water services, including environmental and resource cost.

While the implementation of water pricing policies does not pose substantial problems within industrial, hydroelectric and urban users, it has become a highly controversial issue in what concerns agricultural users.

This fact is particularly remarkable in most Mediterranean countries which share several common features. First, irrigated agriculture accounts for a large share of final farming production and still plays an important role in the economic activity within some areas. Second, agriculture has traditionally been and still is the main water user. This is the case of the Spain where agricultural users account for a notable 80% of total water consumption and become key stakeholders in the water policy arena. Third, water infrastructures have been built to confront And fourth is the outstanding feature that an important share of water supply comes from highly regulated rivers and multiple reservoirs that serve several users.

The Water Directive also states that Member States may have regard to the social, environmental and economic effects of the recovery as well as the geographic and climatic conditions of the region or regions affected. This raises the need for economic tools to asses the design and evaluation of water pricing criteria within and across different water users.

The recovery of the costs of water services poses down very different questions depending on the situation (Iglesias et al., 1998). For example, the objectives to establish water pricing criteria may be quite different whether dealing with a new irrigation development or with a modernization programme (Blanco, 1999). Other key issues that should be considered are the existence of competing uses, the variability of inflows and the characteristics of the supply system, direct and indirect ecological effects as well as the socio-economic conditions surrounding the farming system.

By 2010 Member States shall ensure that water-pricing policies provide adequate incentives for users to use water resources efficiently. This motivates the objective of this paper to develop a meta-model that can be used as an assessment tool in implementing the WFD and designing efficient water pricing criteria within the farming sector.

The development of this meta-model faces several challenges. First, is that this simulation tool should accommodate the wide range of different situations that can be found throughout the Spanish irrigation systems. Second, it should be adapted to exploit available data sources. Third, it should show friendly use and allow easy replication in a large number of irrigation districts. Forth and most important, it should convey useful information to the policy maker and asses the design of efficient water pricing criteria.

2 BACKGROUND

Policy analyses in the agricultural sector has traditionally relied on programming methods. This approach is based on simulation models that reproduce farmer's decisions assuming a profit maximising behaviour and allows analyse 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) Who conduct comprehensive field data to assess the socio economic impact of water pricing policies in several irrigation districts. One of the most severe criticism to linear programming is that the modeller is obliged to add arbitrary constraints in order to avoid too specialized solutions and so that the results calibrate to the observed situation. Both characteristics limit the potential of traditional farming models to perform policy evaluation in a relatively large number of areas.

In this context, the recently published positive mathematical programming method (PMP) overcomes some important limitations of traditional linear programming and has opened a promising research frontier (Howitt, 1995). Most important in this approach, is that it recovers additional information from observed data on farmer's behaviour allowing to automatically calibrate the model to the base situation. In this way, it avoids the need to introduce ad-hoc and non-empirically justified calibration constraints that tight the model to the observed situation. Furthermore, the resulting model is able to respond smoothly to changes in prices or constraints.

This methodology has been very favourably welcome among policy modellers and has given raise to an active research agenda. Paris and Howitt (1998) and Hecklei and Britz (2000) extend the original approach to recover a flexible cost function when there are several observations on farmers´ allocation decisions applying maximum entropy criteria. This approach has established a nexus between programming and econometric techniques.

While the standard method estimates cost or production functions for each land-use activity separately from each other, Röhm and Dabbert (2003) consider in their modelling framework the elasticity of substitution among interrelated crops and develop an empirical regional production model to evaluate agrienvironmental programmes.

Other recent contribution to PMP is the work of Preckel et al. (2002) who build up a PMP model that permit specifying existing information on the levels of both primal and dual variables. The authors illustrate their method through an evaluation of the impacts of market resistance to genetically modified grains.

One serious limitation in 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. In this paper, we extend the standard approach and propose a cost transfer method to incorporate the possibility of water saving technology adoption when simulating farmer's response to water pricing policies. We build a meta model that is applied to more than two than two hundred irrigation districts to analyse farmers response to water pricing policies.

The model results allow assessing the socio economic impacts of implementing a cost-recovery approach and convey answers to many questions that arise when designing water-pricing criteria.

3 METHODOLOGY

Given that water delivery costs and impacts of water prices are highly heterogeneous throughout the Spanish irrigations, models used for analyse water policies need to be disaggregated by region (ideally the level of disaggregation would be the irrigation district). Hence we have developed a methodology that can be easily applied to a large number of heterogeneous irrigated areas.

Data requirements was another decisive factor for model selection. Given the national scale of this study, we wanted to exploit available information as possible and limit the need to collect new field data. The positive mathematical programming approach, first developed by Howitt (1995), appeared as a suitable option. 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 analysis of policy changes.

One of the main disadvantages of positive mathematical programming (PMP) is that available options to the farmers are limited to the observed activities in the base-year situation. To overcome this difficulty, we have extended the standard PMP approach in order to allow the incorporation of new production activities and irrigation technologies. 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 conventional 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 calibration model can be compactly written (*j* denotes the crop type, *r* the irrigation technique and *i* the resource type):

$$\text{Max} \qquad Z = \sum_j \sum_r \left(p_j \; y_{jr} - c_{jr} \right) x_{jr} \tag{1}$$

subject to

$$\sum_j \sum_r a_{ijr} \; x_{jr} \quad \leq \quad b_i \, ; \qquad i = 1,2,\cdots,m \tag{2}$$

$$x_{jr} \quad \geq \quad 0 \, ; \;\; j = 1,2,\cdots,n \quad r = 1,2,\cdots,s \tag{3}$$

$$x_{jr} \leq x_{jr}^0 \; (1+\varepsilon) \tag{4}$$

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

The first order conditions for profit maximization are:

$$\left(p_j \; y_{jr} - c_{jr} + \sum_{i=1}^{m} \lambda_i \; a_{ijr} - \mu_{jr} \right)_{x_{jr} = x_{jr}^*} = \; 0 \qquad \forall \; j,r \, / \, x_{jr}^* \neq 0 \tag{5}$$

$$\left(b_i - \sum_{j=1}^{n} a_{ijr} \; x_{jr} \right)_{x_{jr} = x_{jr}^*} = \; 0 \qquad \forall \; i \, / \, \lambda_i \neq 0 \tag{6}$$

$$\left(x_{jr}^0 \; (1+\varepsilon) - x_{jr} \right)_{x_{jr} = x_{jr}^*} = \; 0 \qquad \forall \; j,r \, / \, \mu_{jr} \neq 0 \tag{7}$$

where λ_i is the dual value for the *i* resource and μ_{jr} represent the dual values associated to the calibration constraints.

The first condition (5) can be rewritten:

$$\sum_{i=1}^{n} \lambda_i \; a_{ijr} = p_j \; y_{jr} - c_{jr} - \mu_{jr} \tag{8}$$

In this expression, the left hand side represents the marginal value of resources used for producing a unit of the *jr* activity while the right hand side can be interpreted as the marginal profit of this activity.

In the second step of the procedure, the vector μ_{jr} is employed to 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. If we choose a quadratic cost function :

$$CT_{jr} = \alpha_{jr} \; x_{jr} + \beta_{jr} \; x_{jr}^2 \tag{9}$$

using the first order conditions the vector of marginal values μ_{jr} allows us to estimate parameters α_{jr} y β_{jr} for this function, according to:

$$c_{jr} + \mu_{jr} = \alpha_{jr} + 2\,\beta_{jr} \; x_{jr}^0 \tag{10}$$

$$\text{with} \qquad c_{jr} = \alpha_{jr} \quad ; \quad \alpha_{jr'} = \max\left\{ c_{jr}, \left((p_j \; y_{jr} - p_j \; y_{jr'}) + c_{jr'} \right) \right\} \tag{11}$$

where *r'* represent the subset of irrigation technologies that do not exist in the observed situation but could probably enter the solution if the economic environment change.

Once the cost functions have been derived, we are able to define the non-linear model that allows us to simulate hypothetical cost recovery scenarios :

$$\text{Max} \sum_j \sum_r \left(\left(p_j y_{jr} \right) x_{jr} - \left(\alpha_{jr} x_{jr} + \beta_{jr} \left(x_{jr} + \sum_{r'} x_{jr} \right)^2 \right) - t \sum_j \sum_r w_{jr} \; x_{jr} \right) \tag{12}$$

subject to:

$$\sum_j \sum_r a_{ijr} \; x_{jr} \quad \leq \quad b_i \tag{13}$$

$$x_{jr} \quad \geq \quad 0, \tag{14}$$

The objective function (12) integrates a water charges component that allows us to simulate cost-recovery scenarios. In this term, *t* is the cost-recovery level, and *w* is the water use per unit of production activity.

This non-linear model reproduces the activity levels observed for the base-year situation and allows us to simulate hypothetical cost recovery scenarios.

4 EMPIRICAL APPLICATION

Using this methodological framework, we developed the meta-model SERCA (*Simulación de Escenarios de Recuperación de Costes del Agua*), that allowed easy application to more than two hundred irrigation districts, selected throughout the Spanish territory. Selection criteria have included community size, crop rotation, agronomic and climatic characteristics, water supply system, irrigation systems, etc.

Data sets have been limited to existing data availability. For each irrigation district, information about production activity levels, water use per crop, water charges, variable costs per activity, expected crop prices and yields, and agricultural policy subsidies and constraints were easily available. We also considered total cropland, total irrigated land and water availability.

Each irrigation district responds to the increase in water prices in an optimal way depending on its water situation and agricultural patterns. In general, there are four ways that a farmer can respond. First, the farmer can alter the crop mix, towards a higher proportion of less water-intensive crops. Second, the farmer can adopt water-conserving technologies (which imply higher water-system costs). Third, the farmer can extensify production. Finally, the farmer can reduce the total irrigated land, increasing the proportion of dryland crops. These responses are all aimed at minimizing the reduction in farm net income resulting from the increases in water price. Our model allows all four options and, in general, we find a combination of responses.

The model interface allowed us to replicate the model in a easy way. We introduce a data file (excel format), we run the program (using the GAMS modelling language) and we obtain the model results in an output file (excel format).

This meta-model allowed us to analyse the economic impacts of cost recovery scenarios on cropland allocation, irrigation technologies, water consumption, farm net income, employment and water agency revenue.

In order to illustrate the capabilities of this methodological approach to asses the implementation of the cost recovery of water services, we discuss the results obtained for a particular irrigation district (Canal de Montijo, in Guadiana river basin). The river basin authority takes the mayor responsibility for operation, maintenance and management of the water delivery system. Farmers are charged on a per unit area basis.

Figure 1 presents model results on cropland allocation under different cost recovery scenarios. Increasing prices induce farmers to change cropping patterns to less water-intensive crops. For instance, a cost-recovery level of 3 cents/m^3, induces a partial substitution of more water-intensive crops (rice, corn) by less water-intensive crops (cereal, sunflower). A cost-recovery level of 6 induces a diminution of rice and corn and an increase changes in cropping patterns.

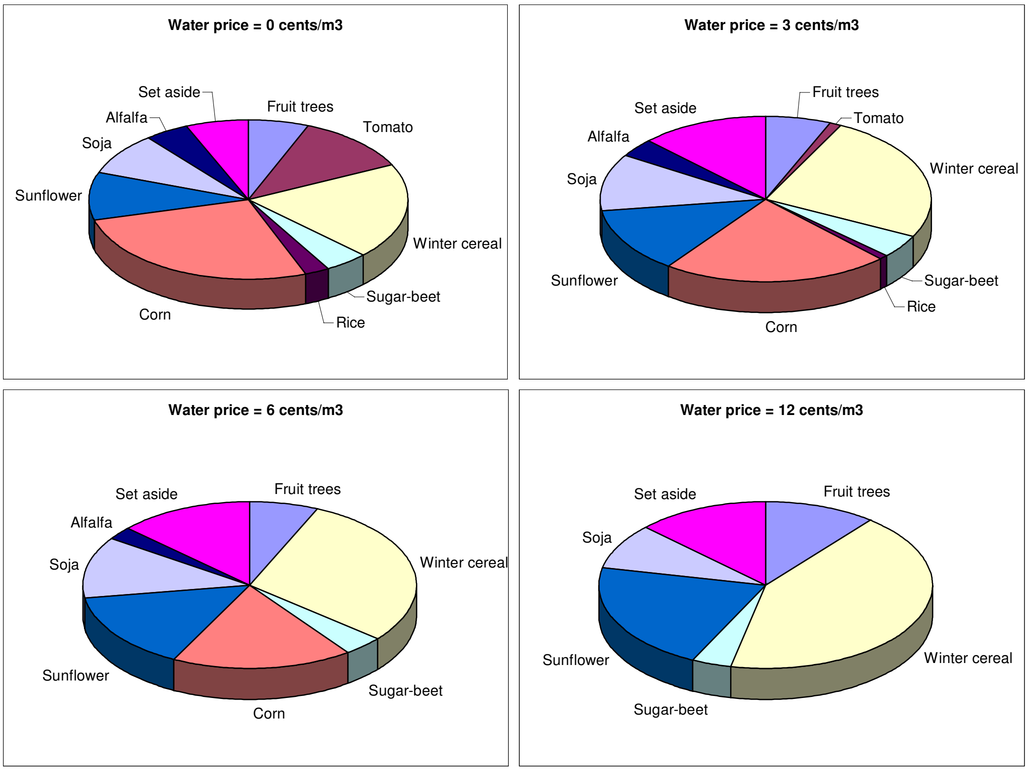

Figure 1. Cropland allocation

The SERCA model also allows for an adjustment of irrigation technologies. As Figure 2 shows, in the base-year situation, surface irrigation is the predominant technology (drip irrigation is only used for the 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 (3 cents/m³) induces a high technological change.

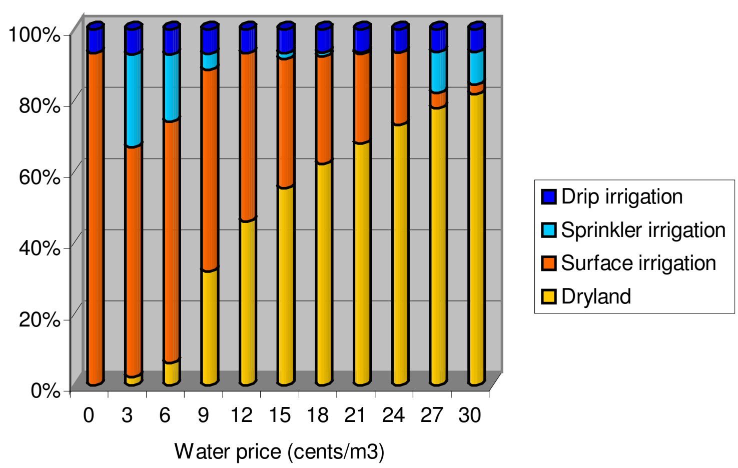

Figure 2. Irrigation technology

Results on water consumption show that low water prices induce significant water savings, that can be explained by the technological change and the crop substitution effects. For instance, a level of 3 cents/m³ induce a reduction in water use of 30% and a level of 6 cents/m³ induces a reduction in water use of 40 %. For high water prices, only the fruit trees are irrigated.

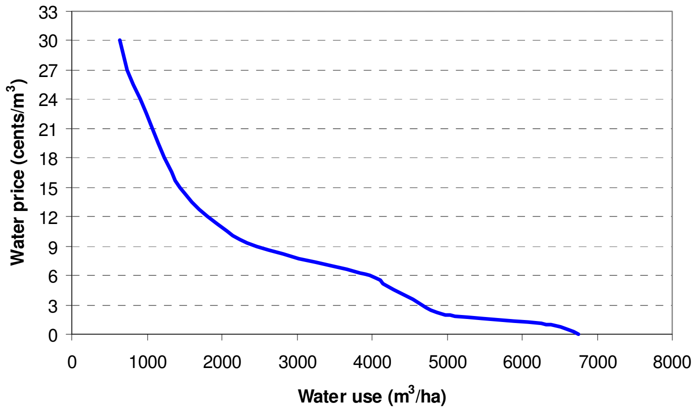

Figure 3. Water consumption

The loss in farm net income is mitigated by the adjustment made in response to water price increase. The result is a smaller percentage decline in farm income than the decline in water use. For example, a 3 cent/m³ water price induces a water use reduction of 30 % and a income reduction of 15 %.

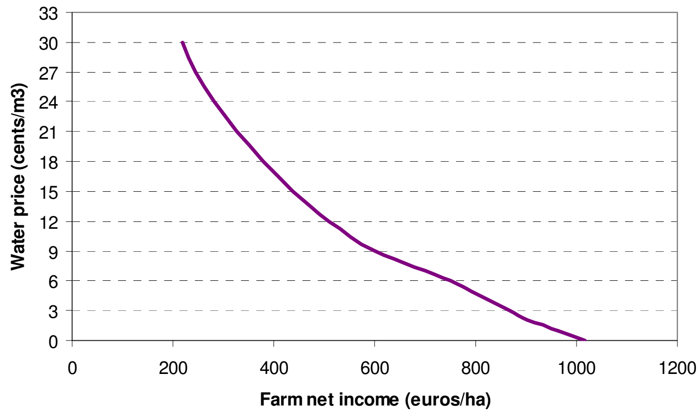

Figure 4. Farm net income

The impact of water prices on labour is very important for low water price levels. Figure 5 shows that water and labour exhibit important complementarity. This is particularly true for low water prices.

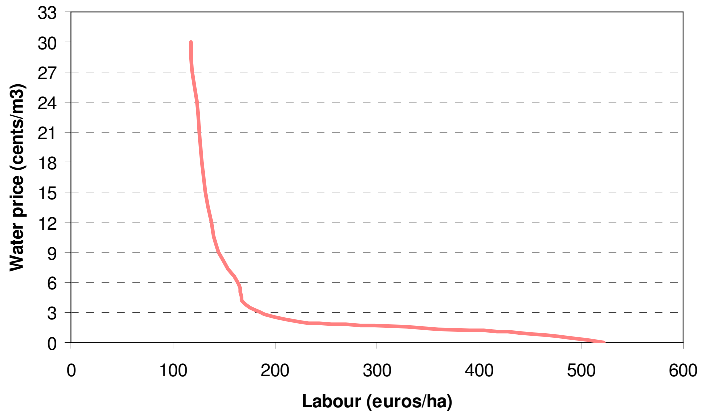

Figure 5. Labour

Figure 6 depicts water agency revenue for different water prices and reveals that water savings and cost recovery may become conflicting objectives for a large range or water prices.

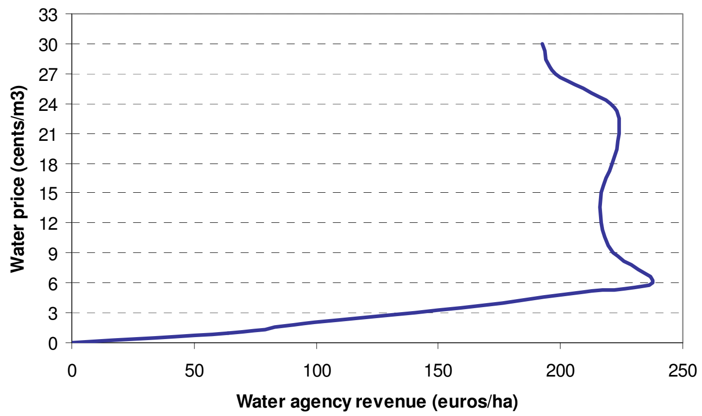

Figure 6. Water agency revenue

5 CONCLUSIONS

The full-cost recovery approach established in the Water Framework Directive poses an important challenge in Mediterranean countries like Spain where agricultural users traditionally pay very low water charges.

Its implementation implies an important change of water policies and raises the need to carefully define water pricing criteria taking into account environmental, socio-economic or regional specific characteristics. This context confers an important social value to the development of methodological tools that may convey detailed and disaggregated information to guide the design of water prices and provides the motivation for this paper.

We developed a positive mathematical programming meta-model to evaluate the impact of full cost recovery in a large number of irrigation districts representing the heterogeneous characteristics that can be found throughout the Spanish territory.

Our modelling framework overcomes one serious limitation of the standard positive mathematical programming approach where available options to the farmers are limited to those observed in the actual situation. We proposed herein a cost transfer approach, which permit us to simulate the adoption of new technologies as well as the conversion to dryland crops as plausible responses to water prices.

Also important is that model inputs and data requirements have been accommodated to exploit existing information and limited data available. Model interface permits friendly use and easy replication to more than two hundred irrigation districts that were selected throughout the Spanish territory.

Finally we have showed through an empirical application that our model results convey specific and detailed information about the impact on water consumption, crop allocation decisions, technology adoption, labour, output supply, farmers' income, and the water agency revenues when different scenarios of cost recovery are considered. This may become useful information to guide the design of water pricing criteria

These characteristics suggest that this modelling approach may be used as a management tool to assist the implementation of the cost recovery approach as established in the new Water Framework Directive.

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