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Assessing irrigation efficiency improvements by using a preference revelation model

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Abstract

This paper develops a general preference model to explain farmers' decisions. Contrary to better known and most commonly used simulation models, the one presented in this paper allows to calibrate, simulate and explain farmers' decisions without assuming linear preferences (as in many multi criteria decision models) or unobservable implicit cost functions (as in positive mathematical programming models). The model is calibrated for crop decisions in the Genil Cabra irrigated area in the Guadalquivir valley (South Spain) as the resulting empirical model is used to study how farmers react by adjusting these decisions when efficiency in the use of water is improved under different scenarios regarding water use rights. The main conclusion of the paper is that the potential water savings from enhancing irrigation technique (636 m^3 ha^{-1}) are overcome by increasing water demand due to higher per drop water productivity when sunflower is replaced by maize. For that reason water price increases and/or reduction of water use rights is a necessary condition to convert water savings through improved efficiency into lower water use and better conserved water sources.

Additional key words: agricultural policy; mathematical programming; water demand for irrigation.

Resumen

Evaluación de la mejora de la eficiencia del regadío utilizando un modelo de revelación de preferencias

El artículo presenta un modelo de revelación de preferencias que permite explicar las decisiones de cultivo de los regantes. Al contrario de los modelos de simulación más conocidos y utilizados, el que se presenta en este trabajo no exige asumir preferencias lineales (como en el caso de las técnicas multicriterio) ni acude a funciones inobservables de costes implícitos (como en los modelos de programación matemática positiva). El modelo propuesto se calibra para la comarca agraria del Genil Cabra en el valle del Guadalquivir (sur de España) y el modelo empírico resultante se utiliza para estudiar las reacciones de los agricultores a las mejoras en la técnica de riego bajo distintos contextos de derechos de propiedad. La principal conclusión del trabajo es que los ahorros potenciales de agua que se consiguen con la mejora técnica del sistema de riego (636 m^3 ha^{-1}) son compensados por los aumentos de la demanda derivados de la mayor productividad del agua cuando el girasol es sustituido por maíz. Por este motivo, para conseguir una reducción efectiva del uso del agua y, por tanto, una mejora en las fuentes del recurso, es necesario aumentar los precios y/o reducir la cantidad de derechos de propiedad.

Palabras clave adicionales: demanda de agua de riego; política agraria; programación matemática.

Introduction

As a result of the progressive deterioration of water ecosystems and the increasing demand for environmental quality, the protection and restoration of water resources have become major targets of the European water policy. For instance, the Water Framework Directive (OJ, 2000) aims to achieve a good water status for

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Abbreviations used: CAP (common agricultural policy); GAMS (general algebraic modelling system); MCDM (multi criteria decision making); MOTAD (minimization of total absolute deviation); PMP (positive mathematical programming).

European surface water and groundwater by 2015 in terms of environmental quality and availability of water for human uses. Given this new focus, finding those policies with the most favourable trade-offs between potentially competing objectives has become a priority. Emphasis on environmental quality contradicts the traditional approach of coping with water scarcity by means of increasing supply and asks for the articulation of water management policies in order to find an adequate balance between the ecological targets and the provision of water services for production and consumption activities. Most of the measures available for water demand management consist in reducing the water services requirements of the different economic activities by somehow improving the efficiency with which water is used. But the real effectiveness of this kind of measures critically depends on how farmers are allowed to adapt crop decisions to the new situation and on whether they have or not access to the water potentially saved. In fact enhancing efficiency means a higher per drop productivity and –other things equal– a higher demand for water. These water programs are now being questioned even when the reduction in water use is a precondition for farmers to receive the financial support used by the administration to put the program into practice. This paper studies whether improved irrigation efficiencies in the Genil Cabra irrigated area in the Guadalquivir valley (South Spain) have resulted in lower water use or not.

Material and methods

Farmers' decisions depend on many technical, economical, policy and environmental constraints. Additionally, in the case of water demand these constraints vary from place to place, according to land vocation, access to water rights, water tariffs and availability of irrigation infrastructure, in such a way that a large scale or aggregated model might be uninformative about the driving forces behind water demand. Nevertheless local and low scale models require detailed information and their results might not be easy to generalize or aggregate. The need to represent complex decision problems with limited information has extended the use of Positive Mathematical Programming (PMP) to simulate farmers' behaviour and to obtain water demands of which many are reported, for example, in Heckelei and Britz (2005) and in De Frahan *et al.* (2007). The general idea of PMP consist, first, in using information contained in dual variables of the calibration constraints to bound the solution of the linear profit maximizing problem to the observed activity levels[1]. Once these dual variables are identified, they are used to specify a non linear objective function such as the production cost and guaranteeing that the marginal cost of the activities are equal to its price in the observed activity levels. This action guarantees that both the profit maximization and the cost minimization problems lead simultaneously to an optimal solution which exactly matches the baseline activity levels (Howitt, 1995; Paris and Howitt, 1998)[2].

PMP procedures guarantee full calibration and offer other advantages over previous results. The non linear cost guarantees smooth simulation results avoiding overspecialisation and corner solutions that are traditional in linear models built with a small number of activities and with numerous resource, technical economic and policy constraints. Moreover these models might be criticised by the way they deal with the parameter specification problem. There is an infinite set of parameters and functions able to lead the model to a perfect calibration and each set of parameters and functions leads to a different response behaviour to changing economic prices and policy constraints.

So far the construction of water demand simulation models is confronted with a trade off between the model's capability to provide numerical results for policy evaluation and coherence with basic economic principles. Apart from PMP, most of the existing simulation models that have been successfully incorporated as tools for policy evaluation in many advanced countries[3] are based on multi-criteria decision methods (MCDM) (Romero and Rehman, 1984; Romero *et al.*, 1987; Berbel, 1989; Berbel *et al.*, 1991; Rehman and Romero, 1993; Sumpsi *et al.*, 1993; Berbel and Rodríguez-Ocaña, 1998; Berbel and Gómez-Limón, 2000; Gómez-Limón and Riesgo, 2004). In order to obtain

[1] This linear model consist in maximizing the profit associated to a vector of activity levels (x, represented by surfaces dedicated to a set of crops) with prices and unitary costs considered as constant and subject to a set of resource constraints.
[2] The dual variables, obtained in the first stage and used to build the non linear objective function in the second, are assumed to capture any type of aggregation or model specification bias, any kind of risk attitude or price expectation as well as any lack of data or data measurement error (Howit, 1995; Heckelei and Britz, 2005).
[3] A general review of the literature can be found in Dyer *et al.* (1992) and Hayashi (1999).

relevant policy results, they assume that farmers' preferences can be represented by a weighted sum of different criteria, such as expected profits, risk and sometimes management issues. The algorithm used to calibrate the weights of the attributes in the linear utility function (following Romero and Rehman, 1984) has proved is effectiveness to reproduce the baseline decision. Moreover, the assumption that farmers respond with linear preferences to changes in the policy, resource and economic environment and, similar to PMP, the use of a calibration mechanism effective but not rooted in explicit economic principles- are nevertheless issues prone to discussion.

To find models using a preference representation coherent with basic economic principles we need to go back two or three decades to Rausser and Yassour (1981) and Delforce and Hardaker (1985). These applied models of farmers' decisions try to provide a clearer intuition of the logic behind farmers' decisions by using standard economic analysis and by implementing a multi-attribute utility function. Moreover the difficulties of running proper elicitation procedures with detailed data and the programming and optimization tools available at that time made these exercises difficult to apply because of the details needed to make them useful for policy assessment and project analysis[4].

One useful insight of MCDM with respect to PMP methods is the extensive demonstration on how farmers do not simply act as profit maximizing agents and on how taking other decision attributes, such as risk aversion and avoidance of management complexities into account, provides a better explanation of current decisions. Some versions of MCDM have been developed to include risk avoidance explicitly, as in the "target MOTAD" (Minimization of Total Absolute Deviation), developed by Tauer (1983) and MOTAD (see Watts *et al.*, 1984 for a comparison). Others include a risk premium in the discount factor (*e.g.* López Baldovín *et al.*, 2005) or provide an evaluation of farmers' attitudes towards risk by using alternative utility functional forms (*e.g.* Torkamani and Haji-Rahimi, 2001).

The model

In this paper we present a simulation methodology able to calibrate observed decisions with a procedure rooted in basic microeconomic theory, which allows to reveal farmers' preferences without assuming linear preferences (as in MCDM) or implicit costs functions that are not observable (as in PMP). A behaviour model obtained this way will allow us not only the obtention of simulation results but a clear interpretation of farmers' responses to changing incentives and resource and policy environments.

Farmers decide on crop land surfaces but care about expected profits, risk bearing, managing problems and other attributes in the decisions they take. We assume that the explanation of any decision, consisting in a distribution of the available land among the different crop options, relies on an underlying utility function formed by the many attributes farmers use to assess all the alternatives they have given crop prices and costs, resource availability and the other relevant economic, agronomic and policy constraints. According to that we may assume that observed decisions respond to a decision problem of the following kind:

$$\underset{x}{Max}\ U(x) = U(z_1(x);\ z_2(x);\ z_3(x) \qquad z_m(x)) \quad [1]$$

$$s.t.: 0 \le x_i \le 1 \quad [2]$$

$$\sum\nolimits_{k=1}^{n} x_k = 1 \quad [3]$$

$$x \in F(x) \quad [4]$$

where $x \in R^n$ is the decision profile or the crop portfolio, showing one way to distribute the land among crops, and each x_i measures the share of land devoted to the crop *i*. The set of *n* crops includes a reservation option (x_n) consisting in devoting a share x_n of the land to rain fed agriculture. From the farmer's perspective any particular crop may be considered as an asset with a known present cost and an uncertain value in the future (as crop yields and prices are not known in advance). As the available land is taken as given, this investment may be represented as a percentage (x_i) of the available land.

Farmers have preferences over attributes of the decision profile:

$$(z = z(x) \in R^m) \quad [5]$$

For example, farmers might prefer decisions with high expected profits, highly predictable yields and prices and

4 The model has been programmed and implemented in GAMS (general algebraic modelling system) allowing the use of an extensive database for an explicit use of the preference revelation theory.

not too much managing actions apart from planting and harvesting. To accept taking high risk options risk adverse farmers will ask for compensation, for example, with higher expected profits, and the same can be said about the willingness to accept crop decisions with more roundaboutness and demand for management skills.

Finally *F(x)* represents the space of feasible decision profiles, given the resource, policy, economic and balance constraints.

Let us assume that we have an observed decision profile and we know the whole set of constraints defining the feasible decision set. Assume also that we can measure a set of potentially relevant decisions attributes such as, for example, the expected profit, the variance of the expected profit, the hired labour demanded, the cost of inputs over the total cost and many other things that might be relevant in the farmers' point of view. The first problem we need to deal with to reveal farmers preferences is to know which among the potentially relevant attributes are the relevant to explain the observed decision. Our method to answer this question consists in saying that the relevant set of attributes is the one to which the observed decision is closest to the attribute possibility frontier. In other words, if farmers care only about profits and risk, the observed decision attributes must be very close to the attribute frontier formed only by these two attributes and the same can be said about any potential set of attributes. In these conditions the answer to the question of which is the relevant set of attributes in explaining farmers' decisions is the one that leads the observed decision attributes the closest to the associated attribute efficiency frontier.

The practical mathematical problem consists in looking for the attribute efficiency frontier starting in the point determined by the observed decision profile. In real situations this efficiency frontier cannot be defined analytically with a closed mathematical function and the only way to represent it is by numerical methods[5]. One practical solution consists in extending a ray from the origin, passing through the observed decision attributes and extending them as far as possible in the space of feasible attributes. This way we can measure the distance from the observed attributes to the efficiency frontier attributes. We can repeat this procedure for any set of potentially relevant attributes and the best candidate to reveal farmers' preferences will be the one that was closest to its associated efficiency frontier. Formally the following problem must be solved for any member of the Power set (P(z) and for its associated observed attributes in the Power set ($P(z_o)$)[6].

$$\underset{\tau(x)}{Max(\varphi)} \qquad [6]$$

$$s.t.: \tau(x) = \varphi(\tau_0(x)) \qquad [7]$$

$$0 \le x_i \le 1 \qquad [8]$$

$$\tau(x) \in P(z) \qquad [9]$$

$$\tau(x_0) \in P(z_0) \qquad [10]$$

$$\sum_{k=1}^{n} x_k = 1 \qquad [11]$$

$$X \in F(x) \qquad [12]$$

The solution of this set of maximization problems will be an application assigning a distance $\varphi_l (l = 1, \ldots, 2^m)$ to each member of the power set P(z). The relevant set of attributes wil be the one with the lower distance to the efficiency frontier measured by the parameter $(\varphi - 1)$. In synthesis the preference eliciting problem can be presented as:

$$\underset{\tau}{Min} \quad \varphi_1 - 1 \qquad [13]$$

where:

$$\varphi_l = ArgMax\left[(\varphi) s.t. \tau(x) = \varphi(\tau_0(x));\ 0 \le x_i \le 1; \sum_{k=1}^{n} x_k = 1;\ X \in F(x);\ \text{for all } \tau \in P(z)\right] \qquad [14]$$

$$l = (1 \quad 2^m) \qquad [15]$$

The solution of this problem gives us the set (τ*) of attributes that better explains current farmers' decisions. Among the many factors that might be of relevance in farmers preferences, this set of attributes is the one which takes the observed decision closer to the

[5] For example, in the profit-risk space any point over the efficiency frontier is defined as the minimum possible risk given the expected profit, or as the maximum expected profit given the risk of the decision. By solving many limited optimization problems we can obtain different points over the frontier but we cannot integrate them into a single function.

[6] A power set P(Z) is the set of all the 2^m subsets of the set Z and the power set $P_0(Z)$ is the set formed by the 2^m subsets of the numerical set of observed attributes.

attribute efficiency frontier. If this calibration procedure takes us close enough to the efficiency frontier we can obtain the implicit value of all the attributes over the efficiency frontier by analyzing how attributes change in the surroundings of this reference point, and this information is all we need to integrate a utility function representing farmers' preferences[7].

Once a farmer's decision is shown as close as possible to the efficiency frontier, the second stage consists in obtaining the farmers' preferences that explain the observed decision as a utility maximizing choice. Taking into account the relevant decision attributes obtained in the calibration stage, the multi-attribute utility function is the one that is able to represent farmers' preferences in such a way that the observed decision becomes the optimal choice.

Using basic economic principles and knowing the efficiency frontier in the surroundings of the observed decision allows one to integrate such a utility function. Rational decisions imply that, in equilibrium, farmers' marginal willingness to pay in order to improve one attribute with respect to any other is equal to the marginal opportunity cost of this attribute with respect to the other. In other words, the marginal transformation relationship between any pair of attributes over the efficiency frontier is equal, in equilibrium, to the marginal substitution relationship between the same pair of attributes over the indifference curve tangent to the observed decision.

The calibration model allows us to obtain the relative opportunity cost of each of the relevant attributes with respect to the others. This opportunity cost is measured by the marginal transformation relationship between any pair of attributes (β_{kp}). This value can be obtained numerically by solving partial optimization problems in the proximity of the observed decision (as for example, searching by how much expected profits would need to be reduced in order to have a 1% less uncertainty or, equivalently, what is the maximum expected profit attainable with a slightly lower risk level)[8]. The numerical results of the marginal relationship of transformation of any pair of attributes in a reference point over the efficiency frontier (β_{kp}) is the basic information to integrate the farmers' utility function.

Provided farmers act rationally, in equilibrium, the value (β_{kp}), representing the relative opportunity cost of any attribute in terms of any other, is equal to the marginal substitution relationship between the same pair of attributes (which represents the farmers' willingness to pay for marginal improvement of a given attribute in terms of any other). In other words, in equilibrium, decisions over crop surfaces are such that:

$$MTR_{kp} = MSR_{kp}, \text{ that is to say:}$$

$$\beta_{kp} = -\frac{\partial U / \partial z_p}{\partial U / z_q} \; p, q \in (1, \ldots l); p \neq q \qquad [16]$$

This information for the reference point over the efficiency frontier is enough to integrate a utility function leading to the observed decision as the optimal decision given the existing resource, economic, balance and policy constraints. For example, if we assume a constant returns of scale Cobb Douglas utility function of the kind:

$$U(\tau) = \prod_{r=1}^{l} z_r^{\alpha r} \sum_{r=1}^{l} \alpha r = 1 \qquad [17]$$

the marginal substitution relationship among any pair of attributes is:

$$-\frac{\partial U / \partial z_p}{\partial U / z_q} = -\frac{\alpha_p \, z_k}{\alpha_k \, z_p} \qquad [18]$$

and the preference revelation problem is the solution of the following system:

$$-\frac{\alpha_p \, z_k}{\alpha_k \, z_p} = \beta_{kp} \qquad [19]$$

$$\sum_{r=1}^{l} \alpha_r = 1 \qquad [20]$$

where the numerical values of the attributes (τ) correspond to the point in the efficiency frontier closer to the observed decision attributes, the values of βs, representing the opportunity cost of any attribute in terms of each other, are marginal transformation relationships at the same point, and the only unknowns are the pa-

[7] The optimal solution of and the reference point in the efficiency frontier provide all the information to measure the calibration error in the atributes space.

[8] The calibration procedure requires a convex efficiency frontier, meaning, for example, that decisions with higher expected returns are associated with higher risk levels. This hypothesis is explicitly tested in the calibration stage of the model by showing that the marginal transformation relationship between two positive attributes would need to be positive.

rameters of the utility function. According to the Walras' Law in this system the number of independent equations is equal to the number of attributes (condition that is guaranteed by the constant returns of the utility function represented in the last equation) and the system has a unique solution. Once this solution is obtained the model is calibrated in the sense that the optimal decision ($x^* \in R^n$) and its associated to the decision attributes ($\tau^* = \tau(x^*) \in R^l$), is the one that leads the observed decision ($x^o \in R^n$) and the observed decision attributes ($\tau^o = \tau(x^o) \in R^l$) closer to the efficiency frontier.

The overall preference revelation model provides three kinds of calibration errors.

— The first error is provided by the solution of the preference elicitation model and measures the distance between the observed attributes and the attribute efficiency frontier. And is obtained from expression [13] as:

$$\in_f = (\varphi - 1) \qquad [21]$$

— The second calibration error measures the distance between the observed attributes and the calibrated ones and can be measured as:

$$\in_\tau = \frac{1}{l}\sum_{r=1}^{l}\left(\frac{(z_r^{o2} - \tau_r^{*2})^{1/2}}{z_r^o}\right) \qquad [22]$$

— The third error measures the relative distance between the observed crop pattern and the optimal crop profile as follows:

$$\in_x = \frac{1}{n}\sum_{k=1}^{l}\left(\frac{(x_k^{o2} - x_k^{*2})^{1/2}}{x_k^o}\right) \qquad [23]$$

The mean calibration error can then be defined as:

$$\in = \frac{\sqrt[2]{\in_f^2 + \in_\tau^2 + \in_x^2}}{3} \qquad [24]$$

The Genil Cabra irrigated area

The study area is located in the Guadalquivir Valley in Southern Spain and constitutes part of the Campiña Baja in the province of Cordoba. The Genil Cabra irrigation area presents a typical combination of permanent and temporary crops including wheat with the 30% of the area, olives (29%), sunflower (16%) cotton and garlic (8% each) and other crops.

Formally allotted water-use rights use amount to 4,000 m^3 ha^{-1}, but due to structural water scarcity the water received every year falls short behind this figure and effective use is in the range between 2,000 and 3,000 m^3 ha^{-1}, and even lower in drought years. This water use rights are conceded by the river basin authority which use a set of predetermined rules to decide on the amount of water available at the star of the cropping season. Water use rights are attached to land ownership and are defined on a given amount of water per hectare. In the study area all the water used proceed from surface sources is entirely under the control of the water authority not presenting the problems associated with illegal water abstractions that are common in southern Spain. Average irrigation efficiency is estimated to be 70% in the baseline and the efficiency improvements resulting from the application of the existing modernization plan can increase this figure to 88% mainly as a result of installing drip irrigation infrastructure.

Available data[9] make possible to calculate the benefits obtained by farmers along the last six years. Moreover these data correspond to a period when farmer's decisions were affected by the existing common agricultural policy. This policy has now shifted from production-based incentives to a new system, were a decoupled payment is received irrespectively of the current production. This change in agricultural policy also means that farmers are now allowed to decide freely about what crops to plant, except in the cases when payments are conditioned to the maintenance of a maximum surface of some specific crops. For this study it would have been desirable to have a long period of time to observe how farmers would adapt to the new agricultural policy but this will only be possible in some years from now. In the study the important prices increases registered by cereals (a 40% increase in the lasts four campaigns), sunflower (55% in the last two years) and maize (21% in two years) are also taken into consideration. In the opposite side cotton prices has been reduced in 70%. This price changes are in part attributable to the partial decoupling of the CAP (Common Agricultural Policy) financial support (where a part

[9] The information sources used to gather the database are fully explained in Maestu *et al.* (2008) that was originally developed on behalf of the Ministry of the Environment as part of the decision support system developed to support the implementation of the Water Framework Directive in Spain (op. cit.). The model was implemented in GAMS and the specific programs are available from authors upon request.

of the subsidy is still coupled to production levels). Other marginal crops still conserve production payments and the maximum surface is still controlled in accordance. The alternative to irrigation is the rainfed agriculture from which data were also collected.

Data on crop yields and surfaces were obtained from the River Basin Authority (*Memorias de Riego* elaborated by the *Confederación Hidrográfica del Guadalquivir*). Water requirements were also obtained from this publication. Production costs and inputs used in the area were obtained from a periodical publication from the Ministry of the Environment and Agriculture (*Análisis de los Sistemas de Producción del Ministerio de Medio Ambiente y Medio Rural y Marino*). Market prices were obtained from the Ministry of the Environment official publications (*Anuario de Estadística Agraria*). All prices and costs were translated to constant values of 2008 according to the prices perceived for products and paid for inputs as published by the Ministry. To calibrate the model only variable costs were considered as far as they are the only costs relevant to explain crops decisions in any moment of time. The measure of crop profitability is then the gross variable margin. Table 1 shows the basic data per crop.

Model constraints include soil and water availability, land vocation in the area (only crops previously observed in the area are allowed), maximum crop surfaces for CAP regulated crops, good agronomic practices represented by crop rotations and upper and lower bounds to the surface of permanent crops in the short run.

The scenarios

The calibrated model allows running different simulations scenarios with respect to water allowances in order to assess prospective changes in crop patterns (represented by land distributions among crops) and an overall water use, resulting from enhancing irrigation efficiency to different values from the current 70% to a maximum of 88%.

Two general scenarios were considered. In the first case it is assumed that farmers are allowed to apply the same amount of water as before the change; in this case the maximum water volume applied remains constant. In the second it is assumed that water allowances are reduced by the water authority in order to maintain the quantity of the water effectively used by crops; in this case applied water volume is reduced in proportion to the increase of irrigation efficiency and the maximum applied water becomes a decreasing function of irrigation efficiency. Figure 1 presents the water constraint used in each scenario[10].

Table 1. Basic data per crop per hectare

Crop	Surface (ha)	Price (€ kg^{-1})	Yield (kg ha^{-1})	Subsidy (€ ha^{-1})	Variable cost (€ ha^{-1})	Gross variable margin (€ ha^{-1})	Water requirements (m^3 ha^{-1})
Wheat	4,604.0	0.22	3,583	40	611.67	208.53	1,321
Corn	89.7	0.20	13,5667	0	1,660.17	1,002.90	7,483
Dry bean	125.6	0.25	2,950	55.57	453.23	338.16	1,761
Potato	271.1	0.24	28,666	0	2,862.42	4,062.12	2,157
Cotton	1,328.0	0.26	2,992	1,214.41	1,391.90	596.35	4,138
Sunflower	2,416.3	0.40	1,645	0	318.88	333.48	1,387
Lucerne	250.8	0.14	14,333	0	522.07	1,416.88	6,603
Asparagus	73.7	1.79	4,006	0	6,349.44	830.98	2,641
Melon	181.7	0.31	37,500	0	2,800.10	8,759.72	3,962
Garlic	1,222.7	1.19	12,083	0	4,531.80	9,852.02	3,742
Onion	206.3	0.19	48,333	0	1,611.06	7,760.57	3,742
Vine	179.0	0.52	12,210	0	1,771.32	4,638.43	2,201
Olive	4,400.0	0.65	7,614	0	1,480.58	3,490.31	1,959
Rainfed	0	0.18	2,409	0	383.78	39.75	0

Source: Own calculation from different sources.

[10] A third scenario consisting in setting the maximum water supply as equal to the minimum amount required to satisfy current crop evapotranspiration with the maximum efficiency in the irrigation system was also considered but results were discarded as they did not provide any relevant information to understand actual farmers choices.

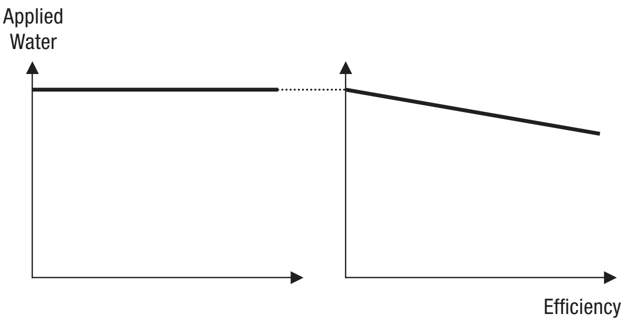

Figure 1. Maximum water allowance in the two simulation scenarios.

Results

When deciding over what combination of crops to plant, within the set of feasible options, farmers might prefer those that simultaneously give them the higher expected profit with the lower uncertainty and that are less demanding in terms of management and dedication. From this intuition we can deduce that the potential relevant attributes of the farmers' utility function are profits, risk and management complexity. The first one is easily measured by the expected net profit per hectare of each crop (taking into account yields, prices and variable production costs observed in the past). The same data on crop yields and prices allows measuring the risk of any crop decision as the standard deviation of the overall expected profit. Measuring management complexities is more difficult as many empirical indicators are available, in the implementation of the model three alternative indicators were tested: the average per hectare demand of hired labor of a crop decision, the amount of per hectare demand of family labor and the nonlabor operational cost (seeds, fertilizers, energy, hired machines, etc.) per hectare. Nevertheless none of these three attributes was identified as relevant in farmers' decisions (as the resulting attribute frontier were not convex or its weight in the utility function was not higher than zero).

For this example we assume that farmers prefer decision with high expected returns that are secure and require lower effort levels in terms of total labor, hired labor and intermediate the use of intermediate inputs. For this reason the following five decision' attributes with the potential to explain current farmers' decisions were considered:

— *Expected profit per hectare.* This attributed is measured by the above explained gross variable margin and formally defined as:

$$z_1(x) = \Sigma_i x_i \pi_i \qquad [25]$$

— *Avoided risk*. Taking a crop decision (x) implies bearing a certain risk that can be measured by the standard deviation of the expected profit per hectare ($\pi(x)$), as follows:

$$\sigma(\pi(x)) = x^T VCV(\pi(x))x \qquad [26]$$

Where $VCV(\pi(x))$is the variance covariance matrix of the per hectare crop profits. If we obtain $\overline{\sigma}$ as the risk associated to the crop decision $\overline{x}$ leading to the maximum expected profit, we can define the risk avoided by any alternative crop decision x, as:

$$z_2(x) = \overline{\sigma} - \sigma(\pi(x)) \qquad [27]$$

— *Total labor avoided*. The first way to measure management complexities avoidance is throug the reluctance to use too much labor to implement the desired decision. The total labor required per hectare for a single crop i is measured by N_i. Then the labor used per hectare is defined as $N(x) = \Sigma_i x_i N_i$. The per hectare labor required to implement the crop decision leading to the maximum expected profit can be defined as $\overline{N}$ and the labor avoided by any crop decision x can be defined as:

$$z_3(x) = \overline{N} - N(x) \qquad [28]$$

— *Hired labor avoided*. Labor includes household and hired labor. A potential attribute in the utility function is the avoidance of hired labor (H). Similar to the previous case we can define $H(x) = \Sigma\, x_i N_i$, as the per hectare amount of hired labor required to implement a crop decision x. If $\overline{H}$ is the per hectare hired labor required for the maximum profit decision then avoided hired labor of any decision x, it can be defined as:

$$z_4(x) = \overline{H} - H(x) \qquad [29]$$

— *Direct cost avoided*. Direct costs (D) include all the seeds, fertilizers, hired equipment and all other intermediate expenditures required to implement a particular crop decision x. We define the per hectare direct cost of a crop i as D_i, and the direct cost of a crop decision as: $D(x) = \sum x_i D_i$. If $\overline{D}$ is the direct cost corresponding to the maximum expected profit decision, the direct cost avoided by implementing the decision x, can be defined as:

$$z_5 = D(x) - \overline{D} \qquad [30]$$

Table 2 shows the results obtained for all the coefficients of the utility function $(\alpha_j; j=1,\ldots 5)$ associated to all the possible subsets of decision attributes. Table 2 also shows the above explained four of calibration errors (see expressions [21] to [24]).

The minimum average calibration error allows obtaining the following utility function as the best representation of observed crop pattern decisions (see solution S3 in Table 2).

$$U(x) = z_1^{0.981} z_2^{0.019}$$

This implies that farmers are close to expected profit maximizers with risk aversion playing a minor but positive role in explaining crop decisions.

Simulation results (see Figure 2a) show that, provided farmers have access to the same amount of water as in the baseline situation, they will use all water available and enhancing irrigation will not be an effective mean to reduce water scarcity or to reduce pressures over the water supplying sources. All the benefits for the improvement will come from the higher yields resulting from increased amounts of the water effectively used by the crops. The main change in the crop pattern will be a substitution of sunflower by the more water-intensive maize, increasing by 560 m^3 ha^{-1} water requirements from 2,172 m^3 ha^{-1} to 2,732 m^3 ha^{-1} and increasing too the gross variable margin at a maximum of € 60 ha^{-1} (see Figure 3).

If water allowances are reduced simultaneously with the irrigation efficiency improvement, as shown in Figure 2b for the scenario 2, farmers will also use all the available water, but the effective water will remain constant as the total amount of water applied is reduced. Crop patterns remain unaltered and the water

Table 2. Potential parameters in the multiatribute utility function and callibration errors. Data in percentage

Solution	α_1	α_2	α_3	α_4	α_5	$\in_f$	$\in_\tau$	$\in_x$	$\in$
S1	100.0					6.3	10.6	6.2	4.6
S2	97.6	2.4				3.9	3.0	3.6	2.0
S3	98.1	1.9				3.2	1.7	3.3	1.6
S4	97.1	2.9				4.5	4.1	4.0	2.4
S5	77.7	2.6	19.7			2.9	9.7	8.9	4.5
S6	78.2	2.3	19.5			2.7	8.9	9.2	4.4
S7	77.4	3.1	19.5			3.6	10.3	8.4	4.6
S8	77.4	2.3	20.3			2.4	9.6	9.3	4.5
S9	71.8	3.1		25.1		3.0	11.5	7.7	4.7
S10	72.3	2.9		24.8		3.3	11.1	7.7	4.6
S11	71.5	3.6		24.8		3.4	11.7	7.6	4.8
S12	71.5	2.9		25.6		2.4	11.6	7.9	4.7
S13	90.7	2.1			7.3	5.1	2.8	3.7	2.3
S14	91.3	1.8			7.0	3.3	1.8	3.5	1.7
S15	90.3	2.7			7.0	4.6	4.3	4.2	2.5
S16	90.3	1.8			7.9	7.5	1.9	3.5	2.8
S17	74.2	2.3	18.8		4.7	5.1	9.7	10.4	5.0
S18	74.7	2.2	18.6		4.5	3.8	8.9	9.6	4.6
S19	74.0	2.9	18.6		4.5	3.8	10.3	8.8	4.7
S20	74.0	2.2	19.4		4.5	3.7	9.7	10.1	4.8
S21	74.0	2.2	18.6		5.3	9.2	9.4	14.4	6.5
S22	67.4	2.9		23.5	6.2	4.5	12.0	13.4	6.2
S23	67.9	2.7		23.3	6.1	4.2	11.7	13.4	6.1
S24	67.2	3.4		23.3	6.1	3.6	12.3	13.3	6.2
S25	67.2	2.7		24.0	6.1	3.6	12.2	13.5	6.2
S26	67.2	2.7		23.3	6.7	6.5	11.9	13.4	6.4
S27	24.4	0.7	61.5	12.0	1.3	13.5	17.5	20.6	10.0
S28	24.6	0.7	61.5	11.9	1.2	21.5	17.5	20.6	11.5
S29	24.4	0.9	61.5	11.9	1.2	4.7	17.5	20.6	9.1
S30	24.4	0.7	61.7	11.9	1.2	22.6	17.5	20.6	11.7
S31	24.4	0.7	61.5	12.2	1.2	6.8	17.5	20.6	9.3
S32	24.4	0.7	61.5	11.9	1.5	11.7	17.5	20.6	9.8

Source: Own calculation.

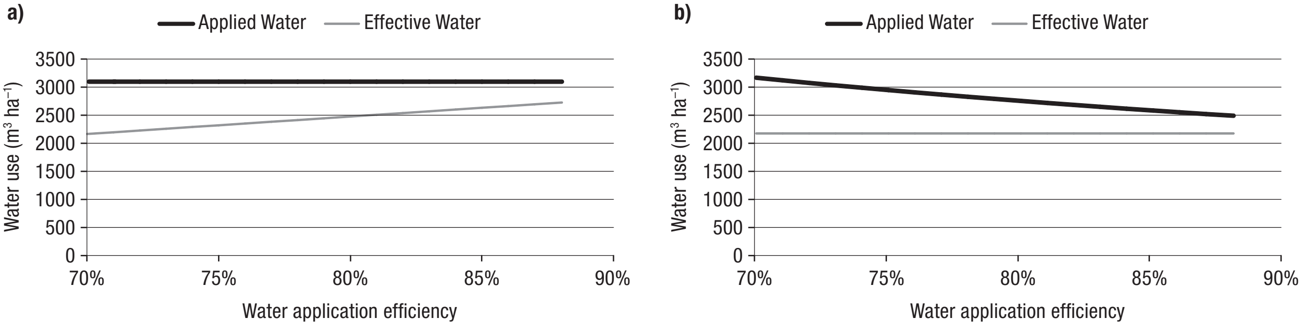

Figure 2. Water use in a) scenario 1 and b) scenario 2.

saved will amount a maximum of 636 m^3 ha^{-1} that will not be used anymore in the irrigated area. Gross variable margin will remain unaltered in this case, as shown in Figure 3.

Discussion

When deciding about improving the way water is used in the economy, public officers and stakeholders must make clear what the policy objective to which this decision is expected to contribute is. In many situations, particularly when water is scarce with respect to the existing water use rights, enhancing water efficiency might be considered as a necessary condition to reduce water abstraction, but –as the Genil Cabra case study makes clear– this is not a sufficient condition. What is required in this case is a specific policy oriented to transfer the water saved in the agricultural sector to the natural system by reducing the amount of water farmers are allowed to use. Otherwise, these savings will be used to increase production and market revenue. It is clear that increasing irrigation efficiency does not necessarily make more water available for other uses. Water availability for other uses can only be increased by decreasing consumption (Burt *et al.,* 1997). The decision to whether enhancing efficiency is an instrument for water conservation or alternatively a mean to promote agricultural production and income is a policy question that needs to be considered and solved in a transparent way in the public arena.

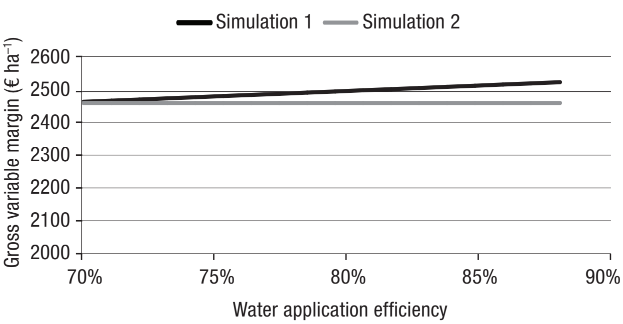

Figure 3. Gross variable margin in the two scenarios.

In addition to that, some other aspects would need to be considered in the assessment of how water efficiency improvements might impact over water bodies. A most effective use of the water in the agricultural sector also means lower returns and lower water availability. Moreover, although lower irrigation returns might reduce water supply, this also reduces pollution loads from fertilizers and other agrochemical products improving water quality downstream and underground. In the case study the maximum amount of water saved that can be potentially left in the water sources amounts to 636 m^3 ha^{-1}. Even assuming that water use rights are reduced, the lower returns will also mean that covering the existing demands downstream will lead to a further degradation and to an increased scarcity in all the water sources downstream. Assessing these effects is out of the scope of this paper, but some evidence on the importance of assessing irrigation returns can be found in Bielsa and Duarte (2000). Evidence collected by Playán and Mateos (2006), shows that the shift towards more water intensive crops might reduce water resources at a river basin scale but the lower irrigation returns might improve environmental quality. All these effects would need to be considered in assessing the effectiveness and the opportunity cost of improving irrigation efficiency as a water management instrument.

Our case study made clear that, whatever the opportunity cost of reducing irrigation returns, the status of the affected water bodies will be worse in the scenario 1, when water use rights are maintained, that in scenario 2, when these rights are reduced.

The analysis presented in our case study provides relevant information to compare different options to reduce water pressures in a cost effectiveness framework. In scenario 1 we show that 560 m^3 ha^{-1} saving is associated to an opportunity cost of € 60 ha^{-1}. The higher irrigation efficiency thus opens the option to save water at a cost of € 0.108 m^{-3}, a figure that can be compared with the other options available in the river basin to simultaneously reduce water scarcity and improve the status of water bodies.

Finally sharing the benefits of the higher efficiency between water use in agriculture, allowing farmers to benefit from a higher water availability, and water conservation, leaving more water in nature, might also be a condition to reach a mutually beneficial agreement between farmers and the water authority in order to make possible the implementation of the program. The example presented in the paper provides the information required to consider the different options available.

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