Enhancing Irrigation Efficiency but Increasing Water Use: The Jevons' Paradox

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Abstract:

In this paper we analyze the conditions under which increasing technical efficiency of water use in the agricultural sector might not reduce water demand and pressures on water ecosystems. Departing from this basic problem we discuss how policy measures performed to enhance water productivity in the agriculture might be transformed into effective alternatives to improve the conservation of water resources and then guarantee the successful implementation of the Water Framework Directive. A preference revelation model is presented in the third section of the paper and one empirical application to an irrigation district in southern Spain is used in the fourth section to discuss the effectiveness of water savings measures.

Key words: Water Framework Directive, Water Economics, Agricultural Economics, Simulation Models, Preference Revelation.

Agriculture and Water Policy in the Context of the Water Framework Directive

1. Water Efficiency vs. Water Policy: The problem

In the agricultural sector, particularly in European Mediterranean countries, pressure over water resources is above what is needed to obtain a good status of the water ecosystem, and also to guarantee water supply in adequate quality and quantity in the recurrent dry periods and even in future (Olsen, 2008). This is already recognised by national authorities since Hydrological Plans (e.g. Ministerio de Medio Ambiente, 2008) establish that a reduction in water withdrawals in all southern Mediterranean river basins is needed to guarantee future sustainability of water extractions. Water saving measures in irrigated agriculture such as improvements in distribution channels and the substitution of traditional irrigation techniques may have quantitatively important effects on water demand for the whole economy[1]. Efficiency measures are usually considered to be effective ways to obtain the same level of water services with lower water withdrawals and a better ecological quality of the water sources[2]. However, the implicit assumption that water savings from efficiency measures implementation will automatically translate into a reduction in water extractions is not necessarily true since the effect on water withdrawals will depend on how the economic agents react. In fact enhancing efficiency is equivalent to increasing water productivity and then the demand of water as a production input. The common wisdom according to which improving water efficiency is all we need to increase the amount of water left in nature may be as wrong as concluding that a higher labour productivity is a way to increase unemployment in the economy[3].

The following graphical example shows how in fact efficiency measures might increase water demand in agriculture. An irrigation technique can be properly defined by the relationship between the quantity of water used in a plot (applied water) and the quantity of the water effectively used by the crops (effective water)[4]: Typical irrigation efficiency of gravitation methods is about 0.5 but drip and sprinkler irrigation may increase irrigation efficiency up to 90% (Hanemann et. al. 1987). An increase in irrigation efficiency is not only a way to reduce the minimum water that needs to be applied in order to satisfy a certain level of water effectively used by crops. It is also a way to reduce the marginal cost of producing effective water with a given quantity of raw water. The final effect of a higher efficiency over water demand is then unclear as the quantity and the price effects may go in opposite directions. The answer will depend first on price elasticity of demand, which depends on the marginal productivity of effective water, and second, on how the setting of a more efficient irrigation technique affects the marginal cost of using water by, for example, increasing the need of energy and labour required for water delivery.

In what follows we present a graphical example with two assumptions: a decreasing marginal productivity of effective water and a marginal cost of applying water that does not increase with the irrigation technical shift. This is all that is needed to show that contrary to common wisdom a higher efficiency in the way water is used for irrigation might increase pressures on the water ecosystems.

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[1] For example, the Spanish Plan for the Modernization of Irrigated Agriculture (Plan de Choque de Modernización de Regadíos (Real Decreto 287/2006)) includes the expenditure of 2,049 million euros and expect to save 1.162 millions of cubic meters equivalent to 5% of the overall water used in the Spanish economy. The plan only includes a variety of water efficiency measures but water tariffs and property rights management are not included in the set of water saving measures.

[2] A reduction in water withdrawals increases the stock of water in the water source and therefore helps to reduce salt and the concentration of other contaminants and nutrients

[3] The possibility that efficiency improvements in the use of natural resources could not result in the expected reduction in resource use is known as the Jevons's paradox or rebound effect (see Alcott, 2005). For an application in the context of the WFD see Tirado, et. al. (2006)

[4] See Lynne et. al. 1987 and Carlson, et. al. 1993.

Provided no additional measures are taken water efficiency programs might then miss the target of protecting and improving the ecological status of water sources.

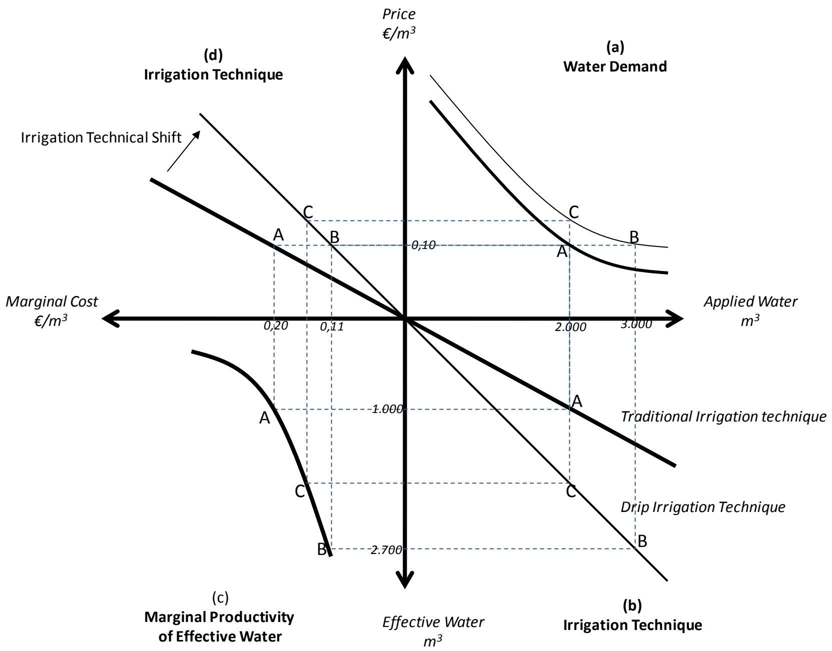

Figure 1 Efficiency Improvements and Water Demand

The irrigation technique is represented both in panels (b) and (d) in the Figure 1. In (d) irrigation technique is shown as a technical ratio between applied water and the amount of water actually used by plants. In (b) irrigation technique is shown as the relation between the water price of used water, that includes the market price of used water and the marginal cost of putting it into the irrigation system (in the vertical axis) and the marginal cost of the water effectively used (in the horizontal axis). As shown in the Figure the shift towards a better irrigation technique simultaneously increases the proportion between applied and effective water and reduces the marginal cost of the water effectively used by crops. The marginal productivity of effective water is represented as a decreasing function in panel (c) and this function does not depend on the irrigation technique. An improvement in the irrigation technique will increase the productivity of the irrigation system by increasing the ratio between effective and used water and by reducing the marginal cost of effective water. The derived demand of water for irrigation as shown in the figure will shift outwards with any technical improvement in irrigation.

In order to show the problem, an initial situation is represented in the diagram by using the upper case A in the four panels of the diagram. In this case, the farmer pays a price of ten cents for 2,000 cubic meters that, given the inefficient irrigation technique, are transformed into 1,000 cubic meters used by crops implying a marginal cost of 20 cents per cubic meter of effective water. If after the irrigation technique substitution the price of water remains constant, the quantity of water demanded will be higher resulting in an increase in water extractions. This is shown in the diagram by using the upper case B in the four panels. We might also consider a situation in which the quantity of water use property rights is fixed. This situation is shown in the diagram with the upper case C in the four panels. In this case enhancing the efficiency in water for irrigation will result in a higher marginal willingness to pay for the existing water rights and, apart from the incentive to engage in illegal extractions, this result shows that if no action is taken over water prices or quantities, all water saved will be used to increase market production and the ecological quality of water bodies will not improve.

Implementing the water framework directive means asking for policy packages and not for single water saving actions. The previous example implies that some other measures need to be implemented so that the effect of higher water efficiency leads to a water source improvement. The additional measures required to transform a water efficiency program into a water policy instrument are of two kinds, those aimed at reducing water supply (by taking some water use permits out of the market) and those aimed at increasing the water price (by setting it above the financial supply cost and incorporating the environmental or scarcity value of water).

All that is needed in our example is a decreasing marginal productivity of effective water and a marginal cost of transforming applied into effective water which does not change when the irrigation technique. The stylized example presented does not show many of the complexities of the problem in real situations. If water demand is inelastic to price (and then to reductions in the marginal cost of producing effective water) then water demand will not increase with irrigation efficiency improvements. On the other hand, if a more efficient irrigation technique implies the use of energy or additional labour to produce effective water, as might be the case, the positive effect over water demand might be compensated by the implicit price increase. The effect of water efficiency improvements on water demand also depends on how flexible farmers are to adapt to the new situation. In many cases crop surface is limited by CAP constraints and decisions over permanent crops have a higher opportunity cost than that over temporary crops. The evidence of opposite effects does not allow us to extract a clear conclusion over the effectiveness of the so called "water saving measures" as a means to reduce water use and water demand. What the example clarifies is that the proper knowledge of water demand for irrigation and of the cost structure of irrigation systems is a critical requirement to assess any water policy package. The real effect of water saving and the ancillary measures required to reduce water extractions will differ from case to case and the design of optimal policy packages will become an empirical question. In the next section we present a simulation model to determine both the water demand (for applied water) and the marginal water productivity (for applied water). These results will allow us to discuss the design of effective policy packages in the context of the Water Framework Directive in a case study of southern Spain.

Farmers' decisions depend on many technical, economical, policy and environmental constraints. Additionally in the case of water demand these constraints vary with place to place according to land vocation, access to water rights, water tariffs and availability of irrigation infrastructure in such a way that large scale or aggregated model might be uninformative about the driving forces behind water demand. Nevertheless local and low scale model required detailed information and their results might not be easy to generalize or aggregate. The need to represent complex decision problems with limited information have 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 De Frahan et al (2007) and Heckelei and Britz (2005). 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[5]. Once these dual variables are identified, they are used to specify a nonlinear 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 way guarantees that both the profit maximization and the cost minimization problems give simultaneously to an optimal solution which exactly matches the baseline activity levels (see Howitt, 1995, and Paris and Howitt, 1998)[6].

PMP procedures guarantees full calibration and offer other advantages over previous results. The nonlinear cost guarantees smooth simulation results avoiding overspecialisation and

[5] 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 an subject to a set of resource constraints.
[6] The dual variables, obtained in the first stage and used to built the nonlinear 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 (see Howit, 1995 and Heckelei and Britz, 2005).

corner solutions that are traditional in linear models built with a small number of activities and with numerous resources, 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 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[7] 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 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 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 using standard economic analysis by using a multi-attribute utility function. Moreover the difficulties of running proper elicitation procedures with detailed data and the programming and optimization tools available at this time made these exercises difficult to apply in the detail needed to make them useful for policy assessment and project analysis[8].

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).

2. The Model

In this paper we present a simulation methodology able to calibrate observed decisions with a procedure rooted in basic microeconomic theory which allow to reveal farmers' preferences without assuming linear preferences (as in MCDM) or implicit costs functions which are not observable (as in PMP). A behaviour model obtained this way will allow us not only the

[7] A general review of the literature can be found in Dyer et al (1992) and Hayashi (1999).
[8] 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.

obtention of simulation results but a clear interpretation of farmer's responses to changing incentives and resource and policy environments.

Farmers' Preferences

Farmers decide on crops surfaces but care about expected profits, risk bearing, managing problems and other attributes of 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 observe decisions respond to a decision problem of the following kind:

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

s.t.: $0 \le x_i \le 1$

$$\sum_{k=1}^{n} x_k = 1$$

$$X \in F(x)$$

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* crop 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 ($z = z(x) \in R^m$) For example, farmers might prefer decisions with high expected profits, highly predictable yields and prices and 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 these question consist 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 which 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[9]. One practical solution consist 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 which 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 ($P(z_o)$)[10]

$$\begin{gathered} \underset{\tau(x)}{Max}(\varphi) \\ s.t.: \tau(x) = \varphi\big(\tau_o(x)\big) \\ 0 \le x_i \le 1 \\ \tau(x) \epsilon P(z) \\ \tau(x_o) \epsilon P(z_o) \\ \sum_{k=1}^{n} x_k = 1 \\ X \in F(x) \end{gathered} \quad (5)$$

The solution of this set of maximization problems will be an application assigning a distance $\varphi_l\ (l = 1, \dots, 2^m)$ 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:

$$\underset{\tau}{Min}\ \varphi_l - 1$$

Where:

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

$$l = (1 \dots . 2^m)$$

The solution of this problem gives us the set $(\tau^*)$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 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[11].

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

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[9] 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.

[10] 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.

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

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)[12]. 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:

$MTR_{kp} = MSR_{kp}$, that is to say: $\beta_{kp} = -\frac{\partial U/\partial z_p}{\partial U/z_q} \quad p, q \in (1,..l); p \neq q$

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:

$U(\tau) = \prod_{r=1}^{l} z_r^{\alpha_r} \qquad \sum_{r=1}^{l} \alpha_r = 1$

The marginal substitution relationship among any pair of attributes is:

$$-\frac{\partial U/\partial z_p}{\partial U/z_q} = -\frac{\alpha_p}{\alpha_k}\frac{z_k}{z_p}$$

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

$$-\frac{\alpha_p}{\alpha_k}\frac{z_k}{z_p} = \beta_{kp}$$

[12] 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.

$$\sum_{r=1}^{l} \alpha_r = 1$$

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 α parameters 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 which 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 which 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. Calibration errors can be measured both in the decision and in the attribute space, for example, a percent deviation such as:

$$\epsilon_\tau = \frac{1}{l}\sum_{r=1}^{l}\left(\frac{\left(z_r^{o\,2} - \tau_r^{*\,2}\right)^{1/2}}{z_r^0}\right) \epsilon_x = \frac{1}{n}\sum_{k=1}^{n}\left(\frac{\left(x_k^{o\,2} - x_k^{*\,2}\right)^{1/2}}{x_k^o}\right)$$

3. An empirical application:

To illustrate the complexities of designing effective water policy packages in the agricultural sector we present a case study for the Sahagun Irrigation District in central Spain. We take this case as representative both of a highly EC subsidies supported agriculture and of a region where important efficiency gains are possible. Under the Agenda 2000 framework the almost 8,000 hectares irrigated use 18.51 million of cubic meters with an efficiency rate of 0.65 to obtain an expected gross benefit of 458 €/Hectare of which CAP subsidies represent more than 50%. Water is priced at a flat rate and the only variable cost is the application cost of the current irrigation technique which has been estimated in only 1.5 eurocents per cubic meter. The example chosen is then the kind of situation where the CAP reform might have an important effect over water demand as a consequence of reducing or eliminating production linked subsidies and also a case where further water savings might be obtained by enhancing irrigation efficiency and higher water prices.

Table 1

The Sahagun Irrigation District Basic Data

Surface	Has	7382
Production	€/Hectare	711.87
Direct Cost	€/Hectare	252.46
Capital Cost	€/Hectare	173.47
Subsidies	€/Hectare	241.05
Expected Gross Margin	€/Hectare	458.81
Expected Variable Margin	€/Hectare	270.61
Water Applied	Million m^3	18.51
Effective water	Million m^3	12.03
Water Application Cost	€/m^3	0.015
Water Efficiency	Effective/Applied Water	0.65

To study this situation the model has been calibrated by using the observed cropping decisions from 2000 to 2005 under the Agenda 2000 PAC policy framework. The basic results are represented in Table 2 showing expected profit and risk aversion as the relevant attributes of farmers' preferences allowing to reproduce observed farmers' decisions with an error of 1,8% in predicting the crop profile and 1.4% percent in predicting expected margin and its standard deviation.

Table 2: The Sahagun Irrigation District: Calibration Parameters

α_1	Expected Profit	**0.12**
α_2	Risk Aversion	**0.88**
$\mathbf{e_f}$	Distance to the Efficiency Frontier	**2.73%**
$\mathbf{e_a}$	Crop Profile Calibration Error	**1.82%**
$\mathbf{e_d}$	Profit and Risk Calibration Error	**1.41%**

3.1. Efficiency Gains from Improving Water Irrigation Systems:

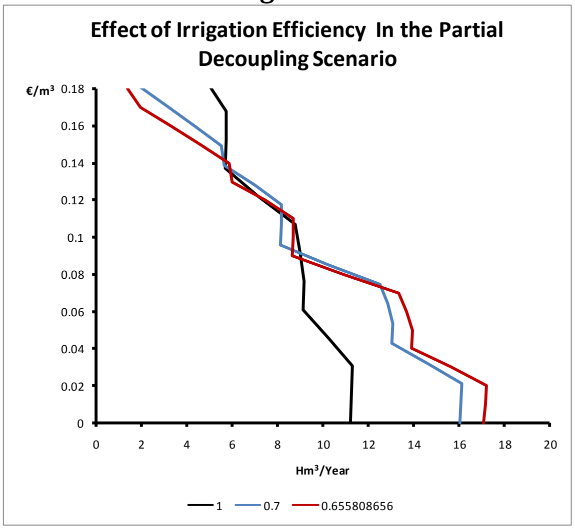
Apart from water tariffs as both price recovery and incentive instruments to reduce water use in agriculture, most of the gains are expected to come from a set of measures designed to reduce water extractions required to obtain any given production level. These measures imply a higher efficiency in extracting water, transporting it to irrigation districts, delivering it to farmers and applying it to crops. We reduce our analysis to enhancing irrigation efficiency by an improved water application technique resulting from the setting of a more effective irrigation infrastructure. As said in the introduction, the effect of such technical advances depends on whether water costs are relevant for farmers' decisions and then water demand changes with the reduction of the marginal cost of effective water.

The overall change in water demand resulting from a water efficiency improvement is the result of two opposite effects. The first one is a quantity effect associated with a lower water requirement to obtain a certain production level, the second is a price effect associated with the higher water productivity and, equivalently, with the lower marginal cost of the water effectively used by crops. The joint effect will crucially depend on whether water demands are responsive to price increases (or to water marginal costs reductions). Simulation results allow us to evaluate the effect of water efficiency improvements under different agricultural policy scenarios as shown in Figure 3. As can be observed in the case of the Sahagun Irrigation District under the current agricultural policy scenario where subsidies are partially decoupled from production and most of land use restrictions are still applied, the effect of a higher irrigation efficiency is different depending on water price elasticity.

At low water prices, water demand is determined both by institutional constraints and water location rents and water demand is inelastic. Farmers do no reduce water demand as far as its use is still a profitable way to obtain the production linked subsidies and market rents. The percentage of water saved is easily calculated by considering the difference between irrigation efficiency before and after the technical improvement[13]. In this case we have a pure quantity effect and water savings may be calculated as the reduction in the quantity of water required to implement the given crop profile.

[13] This percentage of water saved with respect to the initial situation can be easily obtained as $1 - \beta_o/\beta_1$ where β_0 and β_1 represents irrigation efficiency before and after the technical shift. This way increasing the ratio between applied and effective water from 60% to 90% reduces water demand by 30%, provided there are no further price effects.

Figure 2



As water tariffs increase the price effect becomes the dominant one and irrigation efficiency improvements are more likely to increase water demand. Higher prices in this case play a particular role in capturing the rents obtained by farmers even if these rents are the result of production linked subsidies or of location and water access advantages. In our case with a price higher than 14 eurocents irrigation efficiency improvements cannot be considered effective measures to reduce water scarcity or to reduce the pressures over the water environment.

As mentioned above, the access to water and irrigation facilities is an important factor that determines the financial viability of agriculture in Southern Spain, and that is why the reduction of incentives to cultivate, as implied by the CAP reform, does not lead to a reduction of the irrigated surface or by its substitution for rain fed agriculture. At least in the Sahagun Irrigation District, the CAP reform will not reduce the cultivated land or the activity of agriculture. This result might not be generalised as it depends on local conditions, including soil characteristics and agronomic vocation, production patterns and farmers' attitudes towards income, risk and management. Effects may also differ depending on the time horizon and might be different in the short term, as considered in the case study, and in the long term when the technologies, prices and the market environment may change.

4. Concluding remarks

The successful implementation of the WFD requires decision support models able to cope with the complexities of farmers' decisions that are dependent on local conditions such as soil, weather and the availability of irrigation facilities. These models do not only need to have sufficient detail at local decision scales but also to be rooted in the microeconomic principles necessary to understand the logic behind observed decisions.

Water efficiency measures are only effective to reduce water demands when farmers do not adjust cropping decisions to the lower marginal costs resulting from higher water productivity. This can be the case when cropping decisions are means to obtain local rents resulting both from production linked subsidies and from market rents resulting from the availability of irrigation facilities and access to water. On the other hand, prices are effective as incentive to reduce water use provided they are high enough for these water rents to be less relevant in explaining crop decisions. Depending on price elasticity and location rents water efficiency improvements might in fact increase or decrease water demand. The real effect of water efficiency improvements then becomes an empirical problem.

In order to contribute to the understanding of the trade-offs between agricultural and water policy, on one side and between efficiency and policy measures on the other, we present a multi attribute utility simulation model and illustrate its potential with a case study. Contrary to most of the simulation models currently used to prospect for agriculture and water policy we present a model that offers an effective calibration procedure without the cost of assuming linear and cardinal farmers´ preferences and that allows to represent the farmers' efficiency frontier. This model based on multi attribute preferences also allows us to distinguish between the marginal productivity of the water effectively used by crops and the underlying demand for water to be applied in the plot. This distinction is crucial to understand the effect of efficiency improvements over water demand.

The challenge of implementing the European WFD in many respects depends on the ability to coordinate the many economic activities using water as an input in such a way that economic growth is compatible with the effective protection and the improvement of water ecosystems. Given the importance of agriculture as the main water user in many European countries, we hope the ideas presented in this paper can help to understand the complexities of the task and contribute to the design of effective river basin management plans as required by the new water policy in the EU.

Appendix 2: Crop Data of the Sahagun Irrigation District.

	Wheat	barley	Oatmeal	Rye	Maize	beans	Chickpea	Peas	Veza	Potato	Sugar Beef	Flax	Sun flower	Soya Bean
Average price (1995-2005)	0.15	0.13	0.14	0.13	0.15	1.52	0.77	0.21	0.21	0.17	0.05	0.00	0.23	0.21
Average Yield (kg)	5477.63	4827.63	3434.38	2012.25	9178.13	2191.75	2210.88	1726.75	1543.63	37954.99	69435.43	1600.00	2275.00	2100.00
Seeds and Inp. Cost €/Kg	0.04	0.04	0.08	0.06	0.03	0.15	0.35	0.15	0.06	0.03	0.01	0.62	0.07	0.17
Other Variable Cost €/Ha)	151.98	147.24	209.82	94.51	112.46	170.20	564.88	195.75	229.64	292.77	220.68	1274.65	187.56	149.40
Hired wage Cost	26.98	30.12	24.87	17.00	51.33	66.16	48.37	27.98	13.81	612.76	119.32	5.15	30.10	73.29
Family labour units	102.12	99.71	66.78	52.87	187.51	264.10	172.61	64.55	55.49	771.43	432.70	26.67	82.80	0.00
Ground water Cost €/m^3	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Reused water cost €/m^3	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Expected Variable profit (€)	378.63	229.08	-80.48	26.01	805.24	2723.51	266.28	-162.25	-85.68	4293.49	2646.29	-2336.60	72.47	-110.65
Water Application Cost	35.00	28.75	25.62	18.85	85.16	26.70	40.31	38.37	69.32	84.42	88.39	66.02	64.21	0.00
Effective Water	2490.69	2045.50	1822.90	1341.37	6059.41	1899.95	2868.32	2730.46	4932.07	6006.49	6288.95	4697.83	4568.53	0.00
Applied Water	1633.42	1341.45	1195.47	879.68	3973.81	1246.00	1881.07	1790.66	3234.49	3939.11	4124.35	3080.88	2996.08	0.00
Land Surface (Hs)	1901.00	1356.00	1824.00	20.00	908.00	11.00	7.00	881.00	73.00	0.00	50.00	0.00	66.00	0.00
x_i	0.25	0.18	0.24	0.00	0.12	0.00	0.00	0.11	0.01	0.00	0.01	0.00	0.01	0.00

Source: Ministry of the Environment (2007) Database MODERE for the Analysis of Water use in the Spanish Agriculture and the Art 5 Report of the WFD.

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