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Comparative analysis of water saving policies in agriculture: pricing versus quotas

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Abstract. The 'Water Framework Directive' 2006/60/EC (WFD) recognizes the fact that water management should include an economic analysis of alternatives. In the present paper we propose a methodology based on comparative analysis to carry out an in-depth assessment of the socio-economic impact of two alternative water policies aimed at resource saving: i) water pricing policies (at basin and regional level) and ii) quotas (reduction in the abstraction of daily use). For this purpose, we implement a linear programming model at the territorial level to simulate the effects in terms of water saving and socio-economic impact. This is complemented by an aggregated analysis based upon crop water production and response functions. We analyze the implications of various water policies for the irrigation of one of the most important basins in Spain: the Guadalquivir Valley in Andalusia. The results indicate that application of quotas is more suitable than water pricing policies to achieve a reduction in water use and bring about economic sustainability.

Keywords. Water saving – Water policy assessment – Irrigated agriculture – Linear programming – Integrated model.

Analyse comparative des politiques d'économie de l'eau en agriculture: tarification vis-à-vis des quotas

Résumé. *La « Directive Cadre sur l'Eau 2006/60/CE »(DCE) reconnaît que la gestion de l'eau devrait inclure une analyse économique des alternatives. Dans ce travail, nous proposons une méthodologie basée sur une analyse comparative pour évaluer l'impact socio-économique de deux politiques de l'eau alternatives, qui visent l'économie de l'eau: i) les politiques de tarification de l'eau (à l'échelle du bassin et de la région) et ii) les quotas (réduction du captage pour l'utilisation journalière). A cette fin, nous avons appliqué un modèle de programmation linéaire à l'échelle territoriale pour simuler les effets sur le plan de l'économie d'eau et des impacts socio-économiques. En plus, une analyse agrégée a été réalisée sur la base des fonctions de production et de réponse à l'eau des cultures. Parallèlement, nous avons évalué les implications des diverses politiques de l'eau pour l'irrigation de l'un des principaux bassins hydrographiques en Espagne : la vallée du Guadalquivir en Andalousie. Les résultats indiquent que l'application des quotas est un système plus performant que les politiques de tarification pour réduire l'utilisation de l'eau et déterminer la durabilité économique.*

Mots-clés. *Economie d'eau – Evaluation des politiques de l'eau – Agriculture irriguée – Programmation linéaire – Modèle intégré.*

I – Introduction

Agriculture is the main component of water use, with a share ranging from 60-70% of fresh water bodies in the Mediterranean regions. The main driving force behind the use of water in agriculture is irrigation water demand. The demand for irrigation water is increasing, and simultaneously other sectors are also expected to increase consumption in the near future. Non-agricultural sectors are using water more efficiently and they account for the lower share of the total abstraction; therefore it is generally agreed that the main changes in water management, to regulate water supply and demand, should take place in the irrigation sector.

Current management of water resources is subject to uncertainty and scarcity, and new institutions and technical tools are now being used, including the implementation of EC Directive

2000/60, the "Water Framework Directive" (WFD). The main objectives of the WFD are to restore good ecological and chemical status for all water bodies across the Community by 2015. Good ecological status for all water masses is defined as reaching the target of 40% use of renewable resources to satisfy the minimum ecological flow.

Within this period, changes are expected to the water regulatory framework and in the adoption of measures to achieve these goals. Nevertheless, WFD recognizes the fact that water management should include an economic analysis of alternatives.

Water pricing is seen in the WFD and in many other sources (OECD) as an efficient system for management of natural resources in general, and specifically for water management. It is seen as a way to 'internalize' cost, and reflects scarcity in resources that lack a proper market.

The economic theory suggests that the most suitable water pricing scheme is represented by direct pricing methods, based on volumetric systems. In this way, users will pay proportionally to their consumption, and a certain degree of fairness among users will be also pursued. Rodríguez Díaz (2004) shows that an irrigation district with volumetric (i.e. two-tier tariff) system in Guadalquivir (southern Spain) consumes on the average 10-20% less than the flat rate systems, regardless of the amount of the variable rate. However, numerous obstacles hinder progress in replacing flat rate with volumetric rate. Among them is the fact that it may not be efficient to do so, in a broad range of realistic situations. Work done by Tsur and Dinar (1997) illustrates how the gains in efficiency may not justify the costs of restructuring tariffs.

Changes in pricing schemes might achieve results in terms of water saving, but increased water charges will not always provide the right incentive for users to save the resource. This is the case, for example, when water price elasticity of demand is close to zero, which can occur when the total water bill accounts for only a small proportion of farmers' total production costs or income; when alternative crops or irrigation practices are not available due to technical, social or economic constraints, or when the bulk of total water charges consists of fixed costs. Bontemps *et al.* (2003) show that water demand in southern France is inelastic for low available volumes, and depends crucially on weather conditions. Dono and Severini (2001) add further evidence from southern Italy to the inelasticity hypothesis, and suggest that water demand becomes increasingly inelastic as water charges increase, because the crops that may be able to pay higher prices are mainly high-value vegetables and fruits, which can support high increases in water price. Massarutto (2003) concludes that the demand inelasticity hypothesis should be framed in relation to the concept of 'exit price.' He claims that the effects on water demand are due to the fact that if water prices are below the exit threshold, they result in reduced demand caused by marginal adaptation of irrigation demand to price variations. Water demand elasticity is always very small, especially once the most obvious water saving techniques have already been implemented. Above the exit price, water demand falls to zero because farmers do not cover input costs and they should not use water. Finally, where water is a very limiting factor, like in Mediterranean areas, farmers will potentially respond to increasing water price by intensifying the agricultural activity and by shifting cultivation patterns towards more efficient crops. Moreover, improved water use efficiency will not be effective in reducing the overall water demand (at farm level), since the amount of water consequently made available by enhanced efficiency may be easily used to increase the irrigated area on the same farm (Gatta *et al*., 2007).

Rieu (2005) shows that, although demand in Charente (France) is elastic, local authorities have established quotas to avoid negative effects on farmers' income. Montginoul and Rieu (2001) report that irrigators in Charente (France) are charged two-tier tariffs, nevertheless, because the variable rate is lower than the marginal benefit of water use on the farms. This implies the need to impose water quotas in years of scarcity. In situations of water scarcity where volumetric control is possible, such as in Iran, Tunisia, Morocco, France, Italy, Spain, Jordan, and the United States, water quotas are often used (Molle and Berkoff, 2007).

Quotas are generally easy to understand, equitable, effective in reducing diversion, and have less impact on net revenue than price-based regulations. Quota allotments are often used in these situations to mitigate equity issues or resource management issues and water conservation (Johansson *et al*., 2002). Generally with quotas the farmers are allowed to make the best use of a limited amount of resource, for which they pay a tariff.

The objective of this research is to evaluate alternative policies of water saving, considering the fact that the most important yield will be provided by agriculture.

In this research we have adopted a methodology based on comparative analysis to carry out an in-depth assessment of the socio-economic impacts of two water policy scenarios aimed at resource saving: i) water pricing policies (at basin and regional level) and ii) quotas (reduction in abstraction of daily use). For this purpose, we have implemented integrated linear programming models at territorial level that simulate farmers' behaviour and their response to the different policy scenarios in terms of water saving and socio-economic impacts. The model has been integrated with the water production functions.

II – Methodology

We implemented integrated linear programming models at territorial level that simulate farmers' behaviour and their response to the different policy scenarios.

The models' objective function optimizes water allocation within the farm clusters by solving how to best allocate land among different crops and irrigation levels, and at the same time, maximize profit from water use. The resulting optimum cropping pattern is the temporal and spatial combination of different crops that return the maximum net margin above water use within the given agronomic and socio-economic constraints.

The basic assumption used in the development and application of the model includes the following: (1) the objective function determines the optimal water input into each cluster-farm based on maximizing the net margin associated with the cropping pattern and per capita water consumption; (2) water allocation is performed on an annual basis according to monthly availability; (3) the water used by each cluster-farm generates a return that is independent of the quantities allocated to the other farmers; (4) water crop functions are taken into account.

The model assumes the neoclassical economic hypothesis of profit maximization (net margin) and it was performed in the short term.

Table 1. Income definition.

A) Gross output	• Income • Subsidy
B) Expenses on Variable costs	• Inputs • Services • Salary • Rent
C) **A-B = GROSS MARGIN**	
D) Expenses on Fixed costs	• Asset Depreciation • Irrigation fees
E) **C-D = NET MARGIN**	
F) Remuneration	• Own labour • Interest on financial capital • Interest on asset • Own land
G) **E-F = PROFIT**	

The objective function was subjected to a set of constraints depending on the cluster features. These include total area, availability of water and labour, crop rotations and CAP subsidies. Specific restrictions for farm types regarding existing quotas of tree crops were included.

For each cluster a different model was developed.

The aggregation of farmers was performed by cluster analysis. The current crop mix, irrigated land, water consumption, farm size and farmer age were taken as the classification criterion.

This research uses a methodology based on comparative analysis to carry out an in-depth assessment of the economic impacts of two water policy scenarios aimed at resource saving: i) water pricing policies (at basin and regional level) and ii) quotas (reduction in abstraction of daily use).

1. An application case

A. Area description

The Guadalquivir River Basin (GRB) is located in southern Spain; it has a surface of 57,527 km^2 and a population of more than 4.2 million people in 476 municipalities (MIMAM-CHG, 2005).

The GRB is located in a semi-arid area with fluctuating precipitation and increasing man-made pressures.

The administrative water right[1] for agriculture is set to 3,365 hm^3/year. The level of abstraction is high (close to 50% in an average hydrological year) with inter-annual fluctuating precipitation; therefore the fulfilment of the administrative water right is low. Agriculture accounts for almost 87% of the administrative water right (unrestricted year), however, in case of scarcity or drought, other sectors have legal priority over irrigation to fulfil their needs.

The minimum ecological criterion applied to Guadalquivir implies limiting consumptive use below the target of 40%·(6,900hm^3 vs. 2,760 hm^3). This level of consumption is close to the current overall sector average use of 2,942hm^3 (42% of renewable resources) and consequently achievement of the 40% target implies an overall reduction of 6.5% of the current level of consumption.

Irrigated agriculture produces more than 60% of the basin's agricultural GVA (Updates of Art 5 DMA MIMAM-CHG, 2005). The Guadalquivir River Basin has an estimated irrigated area of 752,000 ha, which accounts for 25.5% of the total area under cultivation. Water used for irrigation is 80.9% surface water, 18% groundwater and 1.1% wastewater, but the trend is towards increasing use of groundwater.

Since 1900, the irrigated area in the Guadalquivir has increased by 500% from 142,000 ha in 1904 to 715,000 ha in 2004 and 752,000 ha in 2008. The increase in irrigated area has been particularly rapid in the last decade, coming up to around 60% in the period 1988-2004 (Parias, 2007). Due to this expansion, water consumption has increased considerably. As a result, there is now significant pressure on local water resources. Growth in the use of irrigation water, has coincided with a series of drought years and reduced aquifer recharge, and this has meant increased difficulties in ensuring supply.

Today, the irrigated area is grown with six main crops. Olive trees cover 45% of the irrigated area and consume 31% of water used; cotton occupies 10% and uses 17% of the water, rice occupies 5% and uses 12% of the water; maize covers 6% and accounts for 10% of water use; vegetables cover 6% and use 7% of the water; winter cereals (mainly wheat) account for 8% of the irrigated area and 6% of the water consumed.

The water is allocated through a system of crop-based water quotas, coupled with a binomial tariff (flat rate for 90% and volumetric for 10%). The current average tariff in the GRB is 0.0178 €/m^3 for abstraction, plus a distribution tariff amounting to a total of 0.0346 €/m^3.

The costs and the prices are interrelated and managed by the Confederacion Hidrografica Guadalquivir (CHG).

B. Empirical application

Empirical application was carried out in the Fuente Palmera area (GRB). The area covers 1,500 ha, 38% irrigated with 5,000 m^3/ha of water rights allocation. Water is paid by farmers at volumetric tariff with a price of 0.04 €/m^3.

By cluster analysis two types of agricultural systems were obtained: extensive cereals and intensive tree crop systems. For each cluster a different model was developed.

Data for application of the model were based on official statistics at 2005 prices (production functions, input and output prices, technical coefficients and crop patterns) and additional information was obtained by survey.

Table 2. Cluster features.

	Cluster 1 **Extensive cereals**	**Cluster 2** **Intensive arboreal**
Crop pattern		
Wheat	52.8 %	0 %
Cotton	20.3 %	1 %
Sunflower	7.8 %	0 %
Corn	7.5 %	8.3 %
Vegetable	0.4 %	1 %
Olive	2.5 %	59.2 %
Citrus	2.3 %	29.9 %
Set-aside	6.3 %	0.6 %
Farm size	28.8 ha	16.8 ha
Farmer age	57 years	46 years
Irrigation system	Aspersion	Drop
Income	915 Euro/ha	4,328 Euro/ha
Subsidies (CAP)	413 Euro/ha	52 Euro/ha
Employment	6.3 day/ha	33.4 day/ha

C. Policies scenarios

The baseline case refers to an average year (2005) and represents the basis of the assessment of change impact. Two water saving scenarios have been implemented: (1) water pricing; and (2) restrictions/quotas. Both scenarios have been designed to deliver (within existing constraints and case study characteristics) the same outcome in terms of water saving. This makes it possible to undertake the comparative analysis among the scenarios from an economic point of view. The case study has been investigated in the context of unchanged technology and alternative water supply.

Table 3. Policies scenarios.

Scenario	Approach	Assumptions	Limitations/uncertainties
Water pricing	- Aggregated area response to rise in price is simulated. Curve is built by aggregating water demand and value for 2 cluster farm.	- Water demand is a function of water value, and therefore, the response to water price is the marginal water value.	- The models make use of average values, but there are uncertainties regarding variation in yields, costs and prices. - Uncertainties in real irrigated area, i.e. illegal extractions are not known exactly and have been estimated at 20% of the 'legal area'.
Restrictions/quota	- Farm response model is developed to simulate cropping pattern responses to quota.	- Average water right is used as baseline (average year is similar to 2005 conditions).	

III – Results and discussion

Figure 1 shows the water demand of each cluster and the aggregate demand of Fuente Palmera. The response curve obtained by the LP model illustrates the existence of a rigid response in this area where a large percentage of land is devoted to olive and citrus.

Simulation of the water saving response in Fuente Palmera shows that when prices go up to 0.1€/m^3 (a 150% increase compared to the current level), the potential water saving amounts to 9% because the cultivation of maize (a low value crop) is abandoned. The simulation results show that in order to achieve a 40% water saving, a price of 0.4€/m^3 needs to be implemented. This is 9 times higher than today's price and reduces the farmers' net margin by 47% because the additional savings imply the abandonment of profitable crops such as cotton (cf. Figure 2).

The increase in price may result in different impacts for each local condition, i.e. a price increase of present level induces a drastic change where herbaceous crops such as maize are cultivated, inducing water saving and changes in land use and irrigation systems (Cluster 1); while this increase does not affect the consumption for citrus or olives that require a higher price increase of over 0.50 €/m^3 to induce significant changes (Cluster 2).In areas of high value crops such as citrus, olives and vegetables, prices on water abstraction need to be substantially increased in order to achieve water savings. When prices go over the ´break-even point', well above current levels, an increase in price will lead to savings, but not without severely affecting the farmers' income. The case of Cluster 2 with 60% of olive is an example of this consequence.

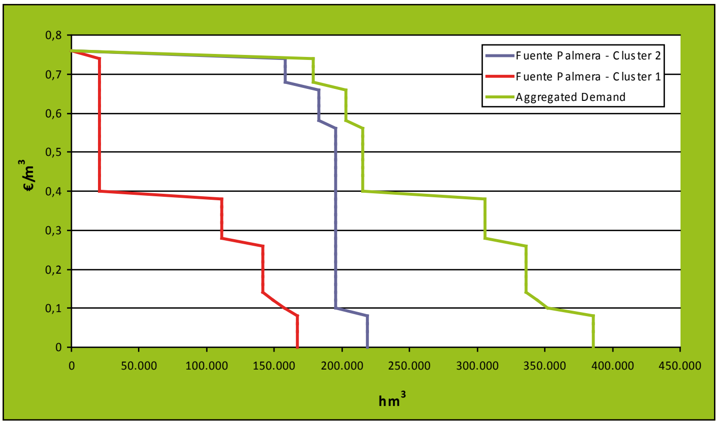

Figure 1. The water demand in Fuente Palmera.

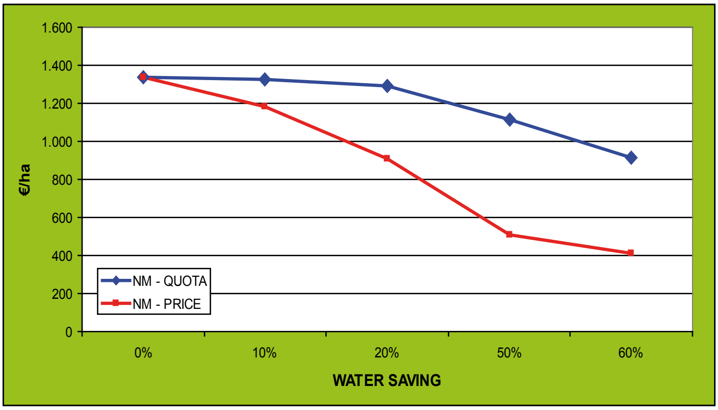

Figure 2. Farmers' net margin.

The use of quotas may achieve objectives of water saving with a moderate economic impact on farmers' income, but the use of prices requires reaching high tariffs to produce a significant reduction in water use. This is due to the high level of productivity of Mediterranean crops and systems which imply the extreme low elasticity of demand.

At the same time, water use efficiency increases when quotas are applied (Figure 3).

The analysis of efficiency of the water policies (euro/m^3) shows a great difference between the two systems, thus demonstrating that the introduction of quotas increases the efficiency levels when compared with pricing. Since water demand has a low elasticity, the price increase produces a direct withdrawal from the farmers.

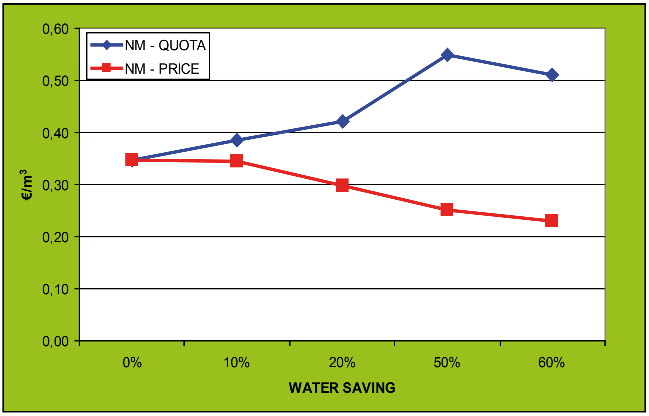

Figure 3. Water use efficiency.

The overall purpose of the proposed water management scenarios is to save water in order to contribute to sustainable water management and restoration of a sustainable water balance at a regional level.

The use of quotas may achieve ecological objectives of a minimum flow and 40% use of renewable resources with a moderate impact on farmers' income, but the use of prices requires imposing high tariffs in order to produce a significant reduction in water use. This is due to the high level of productivity of Mediterranean crops and systems which imply the extremely low elasticity of demand, and therefore, of the price in some areas.

For this basin, the use of quotas appears to be a better instrument than pricing to achieve water savings, because the impact on farmers' income is less when compared to the severe impact of water pricing. This is due to water scarcity and to the high value of the cultivated crops. Quotas can also be implemented because the majority of farmers using surface water have access to supply through a Water Users' Association. However, a moderate water price increase to recover the full cost of surface water is also expected in the GRB.

Additional work is needed in various fields: (i) knowledge of the long-term adaptation of farmers to scarcity and water pricing; (ii) analysis of the impact of seasonal use of water by agriculture (iii) knowledge of the impact of climate change in the basin.

The situation in the GRB makes water saving and water demand management compulsory since there is no alternative water supply available to reach a balance in the use of water resources.

IV – Conclusion

This research analyses the impact of two policy instruments to save water in irrigation. The case study shows that pricing has a dramatic effect on farmers' income. On the contrary, the use of quotas allows water saving at a reduced cost for farmers, because water is used more efficiently and concentrated on the more productive crops by improved management of the irrigated area and of the irrigation supply per hectare.

This result shows the need for further research on the use of water saving instruments on a local scale and at the aggregated basin level.

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[1] The Administrative water right ("concesión") is the water allocated to a user according to Spanish Water Law. However, in practice the full unrestricted water allocation is rarely supplied as there is great intra-annual and inter-annual variability in precipitation.