Alternative irrigation water pricing policies: An Econometric Mathematical Programming Model

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Abstract

Considering the important role of irrigation in the socio-economic development of the Alentejo region in Portugal, this paper aims to assess the economic impact of water pricing in the context of the public irrigation scheme of Odivelas. The methodological framework uses Positive Mathematical Programming (PMP) and, as an alternative, Econometric Mathematical Programming (EMP) based on the estimation of optimality conditions. The model parameters were estimated using the entropy approach and information priors. The models were formulated on the aggregated scale of the irrigated scheme, considering the main regional irrigated crops as well as land, labour, capital and water resources. The main results lead to the conclusions that EMP model performs better than PMP and that under a two-part tariff approach the block pricing scheme is better than the volumetric pricing scheme.

Keywords: *estimation, entropy, EMP, water management, pricing policy.*

Résumé

Considérant le rôle important de l'irrigation dans le développement socio-économique de la région de l'Alentejo au Portugal, cet article a pour objectif d'évaluer l'impact économique de la tarification de l'eau dans le périmètre d'irrigation publique d'Odivelas. Le cadre méthodologique retenu utilise l''approche de la Programmation mathématique positive (PMP) et comme alternative, la Programmation mathématique économétrique (PME) basée sur l'estimation des conditions d'optimalité. Les paramètres du modèle ont été estimés en s'appuyant sur l'approche de l'entropie et de l'information à priori. Les modèles ont été élaborés à l'échelle agrégée du périmètre irrigué, compte tenu des principales cultures irriguées dans la région ainsi que des principales ressources, terre, travail, capital et eau. Les principaux résultats amènent à conclure que le modèle PME est plus performant que le PMP et que dans une approche tarifaire en deux parties, le système de tarification de bloc est à préférer au système de tarification volumétrique.

Mots-clés: estimation, entropie, PME, gestion de l'eau, politique de tarification.

1. Introduction

During the twentieth century, the world population grew from 1,600 million to 6,000 million people and improved living standards consequently leading to great and rapid growth in the demand for water (Gleick, 2000). In order to respond to this challenge, a supply side strategy based on new water extraction was followed (Sumpsi *et al*., 1998). This policy brought great benefits, such as increasing the supply of clean and reliable water, food production, hydroelectricity, and rural and economic development.

Nowadays, water for irrigation represents the major consumption of the available renewable fresh water, reaching over 70%, and demand should continue to grow in the foreseeable future (Tsur, 2005). To satisfy the existing level of per capita water use, new withdrawal is needed, but the expansionist policy followed in the past is no longer possible.

The paradigm of water management has been changing, with new policies focusing on efficiency improvements, water demand management and water reallocation among users (Kallis and Nijkamp, 2000). The Dublin conference in 1992 claimed that water must be treated as an economic good (Gleick, 2000). Since then, several efforts have been made to eliminate wasteful practices and encourage efficiency and conservation of water resources. For instance the European Union approved the Water Framework Directive (WFD) (2000/60/European Communities), which introduced a high degree of novelty to water policy, such as the "good status" of water bodies as an environmental objective, dynamic implementation with deadlines for different objectives, adoption of the concept of integrated river basin management and institutional change and environmental governance (Petersen, 2009).

Water is a common resource where use by one user will affect another user's enjoyment, and the exclusion of individuals involves high transaction costs (Hardin, 1968). Under the new paradigm, water must be treated as an economic good. The objective is to eliminate wasteful practices and encourage efficiency and conservation, but a purely market approach cannot be suitable for protecting water resources and ecosystems.

Several studies in the literature show that governments use decentralisation of irrigation water management, price systems, water rights and trading schemes to address water productivity and equity issues (Dinar and Maria-Saleth, 2005; Johansson et al., 2002; Tiwari and Dinar, 2002; Tsur et al., 2004; Roe et al., 2005; Veettil et al., 2011). The relationships between these instruments are important and produce different results according to the micro-environment of farmers (Liao et al., 2007). Farmers' willingness to pay for water is affected by the institutional context. When wa-

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ter rights are not well defined, the water price system is inefficient and will jeopardise the recovery of costs as well as efficient water allocation (Speelman *et al*., 2011)

Water policy and particularly water pricing policy is a major issue in Mediterranean countries. The impact of water pricing in the irrigation sector was well studied in the scope of the WFD. Several studies highlight that effects of pricing policies in the irrigation sector depend strongly on local, structural and institutional conditions (Varela-Ortega et al., 1998; Gómez-Limon and Riesgo, 2004; Noéme and Fragoso, 2004; Roe et al., 2005; Fragoso and Marques, 2009; El Chami *et al*., 2011).

Pricing policies for irrigation water pursue conflicting objectives such as economic efficiency, cost recovery, equity and resource conservation (Diakite *et al*., 2009). The adoption of transparent and clear allocation rules is a way to reduce water demand (Ray, 2007). A water pricing system set at marginal cost is the most efficient option, but water rights have to be well defined. Area-based or crop-based pricing methods are often preferred to volumetric-based pricing, because they are easier and cheaper to implement (Veettil *et al*., 2011).

The objective is to compare the two most efficient tariffs set at marginal cost, volumetric and block, in the context of a two-part tariff scheme. The paper also aims to explore the relationship between the best water allocation and water recovery cost, and find the pricing scheme that allows maximum total welfare (farmers and suppliers' surpluses). The study adopts a framework based on the Positive Mathematical Programming (PMP) and Econometric Mathematical Programming (EMP) models. These two models were applied to the irrigation scheme of Odivelas, which is a representative area of irrigated agriculture in the Alentejo region, southern Portugal. Results are explored in terms of comparing PMP and EMP models and of assessing water pricing policy results for water demand, irrigated area allocation, and farmers and suppliers' surpluses.

The paper is organized as follows: The next section concerns material and methods and includes a brief description of the case study, some considerations about demand and supply of irrigation water and pricing policies that provide the methodological framework for the Positive Mathematical Programming and Econometric Mathematical Programming models that follow; Section three deals with model results regarding models and alternative pricing policies and their discussion. Finally, section four presents the main conclusions.

2. Material and methods

This case study is applied to Odivelas irrigation scheme in the Alentejo Region, southern Portugal. Odivelas irrigation scheme is a public irrigation system dating from the 1960s. The climate is Mediterranean, with water being scarce in the summer, and frequent sequences of dry years. The main water sources are the lakes of Alvito and Odivelas with a storage capacity of 129,000 and 70,000 thousand m^3, respectively. The water flows by gravity in the River Sado, from Alvito to Odivelas from where it is irrigated through a distribution network over 300 Km in length.

The irrigated area is 12,354 ha, and is divided into three blocks of of 5,545 ha (45%), 1,300 ha (11%) and 5,500 ha (44%). In the first block, water is delivered by gravity and in the other two it is delivered under pressure. The last block of 5,545 ha was only completed in the 21^{th} century to be integrated in the hydraulic network of the Alqueva project, which is one of the biggest irrigation systems in Europe. Water fees are charged in a two-part tariff which includes a fixed rate for all the irrigation area and a volumetric rate proportional to water consumption.

2.1. Methodological framework

Water pricing is based on micro-economic theory, and the three basic elements for establishing a policy are water value, full water cost and water price (Rogers *et al*., 1998; 2002). Water value is determined by the demand side and must include benefits to users, benefits from returned flows, indirect benefits and intrinsic values. The full water cost is given by the supply side and comprises the operating and maintenance cost (O&M), capital cost, opportunity cost and costs of economic and environmental externalities. Those authors define as full supply cost the sum of O&M and capital cost. Water price is the amount set by the institutional sector to ensure cost recovery, equity and sustainability, and may or may not be subsidised. Despite some ambiguity¸ water pricing can be established on both the demand and supply side (Fragoso & Marques, 2009).

The demand for irrigation water is the derived demand from agricultural products in markets. It can also be obtained based on the farmers' willing to pay to have an additional unit of water. In both cases, the derived demand for irrigation water can be obtained by solving a profit maximisation problem for different levels of water constraint. A positive approach, based on regression analysis, can also be used to obtain the derived demand for irrigation water. However, this approach has a few problems, as data may not be available and the variation of water prices is typically small, which leads to low accuracy of estimates (Tsur, 2005).

The full supply cost of water can be separated into variable cost and fixed cost. The first is directly associated with the water quantity supplied and latter does not vary with the supply quantity. Typically variable cost is an increasing and convex function, average cost function has a U-shape, and marginal cost is a non-decreasing function that crosses average cost at its minimal point. If water price is lower than average cost, the operating profit does not cover fixed cost, and the supplier is operating at a loss. In the short term, the supplier will continue operation since the operating profit is positive, but in the long term the supplier will have to be compensated by farmers or the public budget.

Total welfare is the sum of farmers and suppliers' surpluses. The efficient water price that maximises total welfare is given by the marginal cost pricing rule. Usually in large irrigation projects, the interception between average cost and marginal cost functions occurs at the decreasing part of average cost function, when it is above marginal cost function. Thus, the supplier's operating profit does not cover the fixed cost, and to maintain the operation in the long term, the supplier will have to be subsidised. The long term funding supplier raises the cost recovery issue, which often leads to average cost pricing. A move from marginal cost to average cost pricing can allow the supplier's profit to become positive, but the farmer's profit diminishes, and this loss is greater than the supplier's gain, which makes total welfare lower than what is obtained under the marginal pricing rule (Tsur, 2005).

For several reasons, different water pricing methods are implemented throughout the world (Tsur and Dinar, 1997): *Volumetric*: Water is charged by direct measurement of water volume consumption; *Ouput/input*: Irrigation water is charged based on output produced or on input used other than water; *Area*: Water is charged by irrigated or irrigation area; *Block-rate*: Different volumetric rates vary according to certain threshold values of water consumption; *Two-part tariff*: Usually this pricing method involves a volumetric cost marginal pricing rule and fixed annual charge by irrigation area; *Betterment levy*: Water fees are based on the increase in land value from irrigation provision and are charged per unit of area; *Water markets*: Their participants may trade water rights at a particular price during specific periods of time or trade water quantities at a price that is charged on a volumetric or flow basis.

The derived demand and supply, as well as prices were presented and discussed in this paper as the main elements of the theoretical background of water pricing policies based on the work of Tsur and Dinar (1997), Tsur (2000; 2005), Dinar (2000), Dinar and Maria-Saleth (2005), and Dinar and Mody (2004). In addition to irrigation water pricing, other considerations in promoting more efficient water policies should be considered, such as the role of water markets, the use of water saving technologies, and the integrated management of ground and surface water (Caswell and Zilberman, 1985).

The impacts of economic policy on the water sector are frequently assessed using a hydro-economic model structure (Ward, 2009). In order to have a broad and systemic analysis, mathematical programming models have been largely used, because their structure is well suited to dealing with the economic problem of making the best use of limited resources. The economic agents are perceived as optimisers, and the basic elements of the neoclassical micro-economic theory can be easily considered, as well as those of other economic theories, such as the new institutional transaction cost theory (Buysse *et al*., 2007).

Recently, renewed interest in mathematical programming applied to the agricultural sector has been observed (Heckelei and Britz, 2005). The Positive Mathematical Programming initially proposed by Howitt (1995) for calibrating models is greatly responsible for this renewed interest in mathematical programming models.

2.2. The Positive Mathematical Programming Model

The original PMP version by Howitt (1995) is applied in two phases. First, a linear model with calibration constraints is built to predict the dual values of resources and constraints. Second, these dual values are used to calculate calibration parameters which represent the marginal cost coefficients of a convex cost function, and are incorporated in the non-linear term of a profit function in a maximisation program with linear constraints. The general idea is to use the dual values of the calibrated model to specify additional non-linear terms of an objective function that allows reproduction of the observed situation without constraints (Heckelei and Britz, 2005; De Frahan *et al*., 2007).

The PMP model for Odivelas irrigation scheme was developed like the original version of Howitt (1995), considering in the first phase the specification of a linear model constrained to the reference situation (base year = 2008), and in the second phase specification of a quadratic model without calibration constraints. The linear programming model was established as follows:

$$\max_{l} \pi = gm'l,$$

$$s.t \qquad Al \leq b \ [\lambda], \ \ l \leq l^0 + \varepsilon \ [\rho], \ \ l \geq 0 \qquad (1)$$

Where π is the short-term profit function, which corresponds to the farm's gross margin, gm and l are $n \times 1$ vectors of unitary gross margins per activity and non-negative variable of land allocation to crops, respectively; A is the $m \times n$ matrix of unitary resource requirements, b is the $m \times 1$ vector of the availability of resources, such as fixed resources (land) and variable resources (chemicals and services, labour and water), and λ is the $m \times 1$ vector of the corresponding shadow prices; l^0 and ρ are $n \times 1$ vectors of observed crop areas in the reference situation (base year) and the corresponding dual values of calibration constraints; and ε is a small number that is introduced in calibration constraints to prevent problems of linear dependence.

Once the vector ρ_i is determined, the second phase of the PMP approach begins with specification of a non-linear variable cost function $C^v(l^0)$, in which the marginal cost of activities is equal to the sum of a cost c that is known from the firm's accounts and the unknown marginal cost ρ:

$$MC^v = \frac{\partial C^v(l^0)}{\partial l} = d + Ql^0 = c + \rho$$

Where d and Q are the $n \times 1$ vector and the $n \times n$ symmetric positive definite matrix of coefficients of the linear and quadratic terms of the variable cost function, respectively. For simplicity, the diagonal elements of Q were calculated according to the standard procedure for specifying the cost function $\left(q_{jj} = \frac{\rho_j}{l_j^0}\right)$, and then introduced in the following quadratic model that reproduces the reference situation:

$$\max_{l} \pi = gm'l, -\frac{1}{2} l'Ql$$
$$s.t \qquad Al \leq b \ [\lambda], \quad l \geq 0 \qquad (2)$$

2.3. The Econometric Mathematical Programming Model

The PMP approach as presented above has some important limitations. It requires zero degrees of freedom in the calibration constraints, which is very demanding in data or puts restrictions on the flexibility of the model's functional form. Another limitation is that different procedures for obtaining calibration parameters lead to significant differences in simulation behaviour (Heckelei and Britz, 2005).

In order to obtain more realistic simulation behaviour, econometric mathematical programming (EMP) models are a valuable alternative to the traditional PMP approach (Buysse *et al.*, 2007). Heckelei and Wolff (2003) suggest a general alternative to the PMP based not on calibration, but on estimation of a programming model. In order to avoid some methodological problems, it directly employs the optimality conditions of a desired programming model to estimate simultaneously dual values of resources and calibration parameters, and the first phase of PMP is no longer necessary.

The basic principle of this approach can be illustrated by writing the programming model in its Lagrangian form:

$$\mathcal{L} = gm'l - \tfrac{1}{2} l'Ql + \lambda(b - ul)$$

Where land is the only fixed resource, the matrix A=u, and u is a $n \times 1$ summation vector of ones. The first order optimality conditions are the zeros of the gradients of l and λ:

$$\frac{\partial \mathcal{L}}{\partial l} = gm - Ql - \lambda u = 0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = b - ul = 0$$

Thus, the unknown parameters λ and Q of these Kuhn Tucker conditions can be estimated using some econometric criteria. In this case, as the number of observations available was lower than the number of parameters to be estimated with this being hence an ill-posed problem, we applied the Generalised Maximum Entropy (GME) approach (see Golan *et al.*, 1996). Like Heckelei and Wolff (2003), we incorporate some information concerning land elasticities out of the sample to have better estimates.

The simplified matrix structure of the GME model applied to the optimality conditions of the programming model is given by the following expressions:

$$max_{w_t, w^e, Q, l, \lambda} H(w_t, w^e) = -\textstyle\sum_{t=1}^{T} w_t' ln(w_t) - w^{e\prime} ln(w^e) \qquad (3)$$

$$s.t.$$

$$gm_t^0 - \lambda_t u - Q(l_t^0 - \varepsilon_t) = 0, \qquad u'(l_t^0 - \varepsilon_t) = b_t^0 \qquad (4)$$

$$\varepsilon_t = Vw_t = \textstyle\sum_{s=1}^{2} \sigma_{jts} w_{jts} \qquad (5)$$

$$diag[E] = V^e w^e = diag\left[(Q^{-1} - Q^{-1}u(u'Q^{-1}u)^{-1}uQ^{-1})\left(\frac{\overline{gm^0}}{\overline{l^0}}\right)\right] \qquad (6)$$

$$Q = LL', and\ L = 0\ \forall\ i > j \qquad (7)$$

$$\textstyle\sum_{s=1}^{2} w_{jts} = 1, \quad \sum_{s=1}^{2} w_{js}^{e} = 1 \qquad (8)$$

Where H is the Entropy variable; w_t and w^e are the probabilities with respect to estimates of the error (ε_t) and elasticity (E); gm_t^0 and l_t^0 are known vectors of crop gross margin and crop level in each observation t, respectively; λ is the estimate of fixed resource (land) shadow price; Q is the symmetric positive definite matrix of crop marginal cost coefficients; and V and V^e are the known matrix of error and elasticity support values, respectively.

Equation (3) represents the maximisation of joint entropy of the error and elasticity probability estimates. The first set of constraints (4) concerns the first order conditions of optimality. Equations (5) and (6) allow calculation of the values of error (ε_t) and elasticities (E). Variable cost function must be non-decreasing, and to meet the suitable curvature, the positive definiteness of Q is based on a Cholesky factorisation, which is present in equation (7). Finally, we have the set of equations (8), which assure that the sum of error and elasticity probabilities are equal to one.

The stochastic errors of each observation (ε_t) have zero mean and a standard deviation of σ_{jts}. To apply the GME approach, it was necessary to carry out re-parameterisation of the error term as expected values of a probability distribution (Vw_t). This is calculated based on known values of standard deviation, which are spread by two support points (the $n \times n \times 2$ V matrix). Incorporation of out of sample information through the use of priors on elasticities allows us to obtain more accurate estimates for the Q matrix. As for the error estimates, the elasticities (E) also have to be re-parameterised as the expected values of a probability distribution (w^e). In this case, for the central value of prior elasticities two support points were also considered and the values of standard deviations are bounded in the $n \times n \times 2$ V^e matrix.

After estimating the values of w_t, w^e, ε_t, Q and λ, the values of Q were incorporated into the programming model defined in (2), and which was used to simulate alternative water pricing policies in Odivelas irrigation scheme.

3. Results and discussion

Before doing the water pricing policy simulations, the data observed in Odivelas irrigation scheme were compared with results of PMP and EMP models, concerning the land allocation to crops, the variable resources used (water, labour and materials and services), and the land dual value.

3.1. PMP and EMP models

As expected, the PMP model reproduces exactly the observed situation (Table 1). The EMP model also reflects coherently the observed situation, but with some differences, as shown by the Percentage of Absolute Deviation (PAD). The land allocation to olive trees (1.6%) and other irrigated crops (4.4%), the total land used (0%) and the variable input use (6.8%) fit very well the observed data. Results concerning land allocation to maize (19.8%), horticulture

(20.5%) and fruit (20.5%) present some important deviations, but are in general very acceptable. The land allocation to rice (100%) and the land dual value (48 euros/ha) are the poorest results.

Table 1 - *Observed data in Odivelas area and PMP and EMP model results*

	Observed	Models		
	Data	PMP	EMP	PAD
Crops (ha):				
Olive trees	5085	5085	5002	1.6%
Maize	1135	1135	1360	19.8%
Horticulture	404	404	321	20.5%
Rice	308	308	-	100.0%
Fruit	331	331	399	20.5%
Other irrigated crops	1379	1379	1319	4.4%
Dry crops	1358	1358	1599	17.7%
Irrigated area (ha)	8642	8642	8401	2.8%
Total land used (ha)	10000	10000	10000	0.0%
Water consumption (1000 m3)	23558	23558	20106	14.7%
Labour (UTA 1900 h)	256	256	262	2.4%
Materials and services (1000 Euros)	4757	4757	4432	6.8%
Land dual value (Euros/ha)	93	93.0	48.3	48.1%

Sources: ABORO 2008 and PMP and EMP model results.

Figure 1 presents the derived water demand in Odivelas irrigation scheme estimated with the PMP model and with the EMP model.

Figure 1 - *Derived water demand curve estimated with PMP and EMP models.*

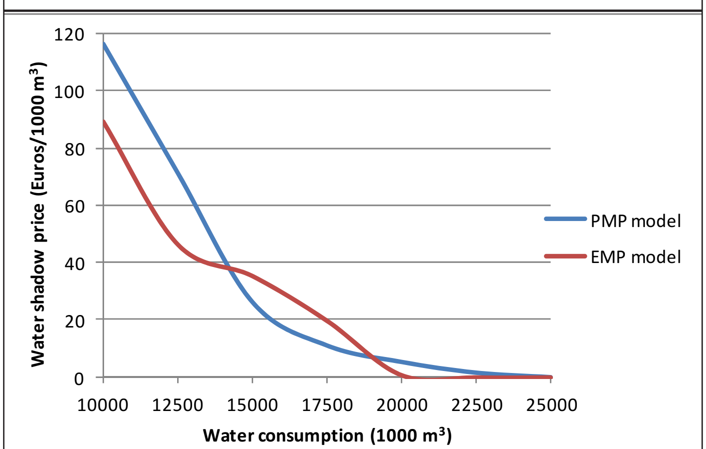
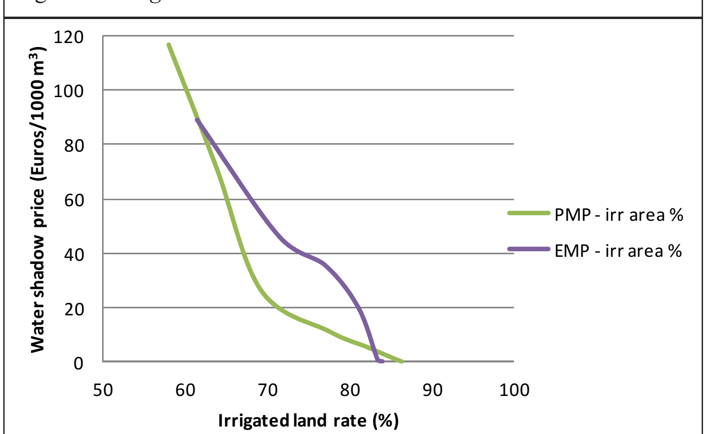


Figure 2 - *Irrigated land rate estimated with PMP and EMP models.*



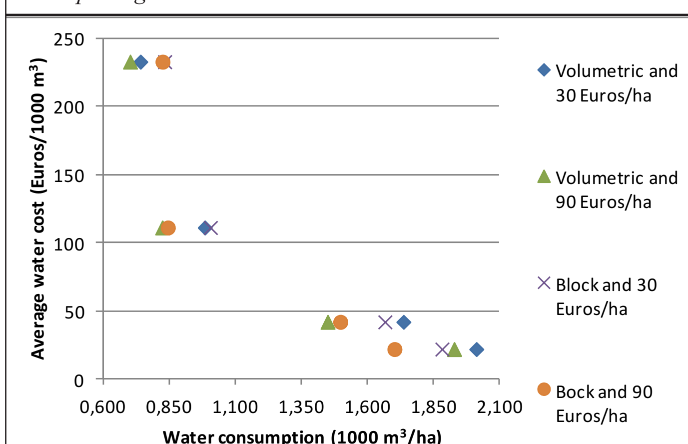
The PMP model has a smoother behaviour pattern than the EMP model. However, this regular pattern also reveals a limited capacity of the PMP model to simulate substitution between crops as the water constraint becomes stronger. This result is even clearer when we observe the evolution of irrigated land as a function of the water shadow price in Figure 2. Although the demand curve obtained with the EMP is less smooth than with the PMP model, it fits farmers' behaviour better with regard to policy changes.

3.2. Water pricing policies

The water pricing policy simulations were based on a two-part tariff approach considering two alternative pricing schemes, the volumetric and block tariff. Both pricing schemes were simulated for the critical average water costs of 22 Euros/1,000 m^3, 42 Euros/1,000 m^3, 111.3 Euros/1,000 m^3, and 233.1 Euros/1,000 m^3. In the volumetric tariff, water is charged directly by consumption in Euros/1,000 m^3. In the block tariff, the water rights are divided into three equal parts, the first being charged at 50% of the water average cost, the second part at 100% and the third part at 150%. In addition, increases in the irrigation fixed rate charged in euros/ha were also considered: for both pricing schemes: 30 Euros/ha; 60 Euros/ha; and 90 Euros/ha.

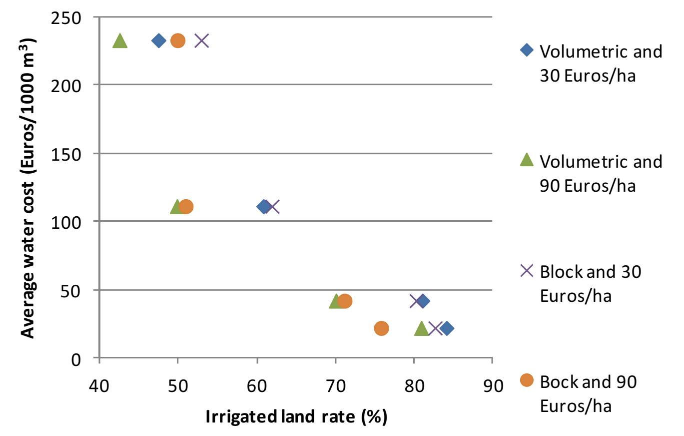
Assessment of water pricing policy was made in terms of its impacts on water consumption, irrigated land rate, farm profit, recovery of water cost and total welfare, using the EMP model, which fits better farmers' behaviour. Figures 3 to 7 show the respective results for the simulation of the two alternative pricing schemes considering different levels of water average cost (AV) and the maximum and minimum level of the fixed irrigation rate (30 and 90 Euros/ha).

Figure 3 - *Water consumption per hectare of irrigation according to water pricing scenario.*



The block tariff achieves the most efficient water allocation. When the farmer's water AC is below 50 Euros/1,000 m^3 this pricing scheme is clearly more efficient than the volumetric tariff. For a water AC of 22 euros/1,000 m^3 the water consumption under the block tariff is about 1,900

Figure 4 - *Irrigated land rate according to water pricing scenario.*



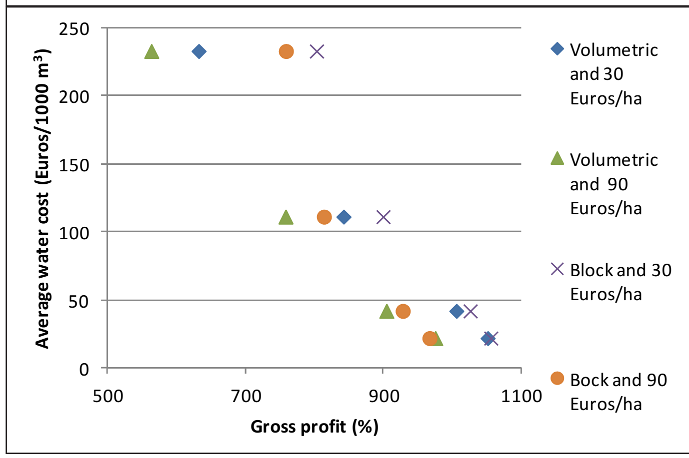
m^3/ha and under volumetric tariff more than 2,000 m^3, which means a water saving of at least 100 m^3/ha or 1,000 thousand m^3 for the whole area of Odivelas irrigation. If water AC rises to 42 Euros/1,000 m^3 the water saving under block tariff is about 50 m^3/ha or 500 thousand m^3 for all the irrigation area. However, for higher levels of water AC, the differences in allocation efficiency between the two pricing policies are much smaller. With respect to the fixed irrigation rate, as expected, results showed that this rate does not influence water consumption, because it does not directly affect famers' behaviour.

The increase in the fixed irrigation rate leads to a reduction in the irrigated area, which is proportional to the reduction occurring in water consumption. For water AC of 22 Euros/1,000, an increase in the irrigation rate from 30 Euros/ha to 90 Euros/ha leads to reducing the irrigated area by 8%. At higher levels of water AC, this reduction is even greater. Reductions in irrigated land rate due to increases in water AC or fixed irrigation rate can be mainly explained by reduction in areas of maize, horticulture and other irrigated crops. Under both pricing policies, areas of olive trees and fruits are the least sensitive to increases in water costs. This is related to the high returns these crops show for land and water resources.

As expected, farm profit decreases as the cost of water increases. The highest value of farm profit is obtained when water AC cost is 22 Euros/1,000 m^3 and the fixed irrigation rate is 30 Euros/ha. At this level of water cost, the farm profit is 1050 Euros/ha under both pricing policies studied. Increasing the water AC from 22 Euros/1,000 m^3 to 42, 111.3 and 233.1 Euros/1,000 m^3, reduces farm profit by 4%, 25% and 40%, respectively. The increase in the fixed irrigation rate from 30 to 90 Euros/ha reduces farm profit 7% to 11%. For the lower levels of water AC, the volumetric and block tariff provides similar levels of farm profit, but for higher levels of water AC profits are greater under block tariff than under volumetric tariff.

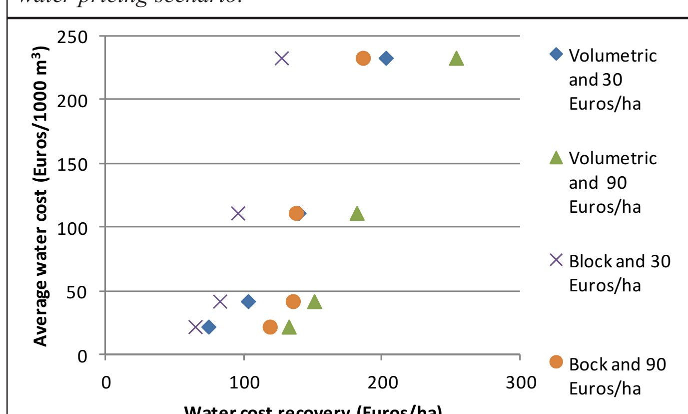
At the baseline level of water costs, that is, when the water AC is 22 Euros/1,000 m^3 and the fixed irrigation rate is 30 Euros/ha, the recovery of water cost with the volumetric tariff is 74 Euros/ha. If the water AC increases from 22 Euros/1,000 m^3 to 42, 111.3 and 233.1 Euros/1,000 m^3 the recovery of water cost can improve by 39%, 89% and 174%, respectively. Under a fixed irrigation rate of 90 Euros/ha, these growths in recovery of water cost are 14%, 38% and 92%, respectively. Only due to the increase in the fixed irrigation rate, we can expect a growth in recovery of water cost between 25% and 47%. Under the block tariff the recovery of water cost is lower than under volumetric tariff.

Figure 5 - *Farm gross profit per hectare of irrigation according to water pricing scenario.*



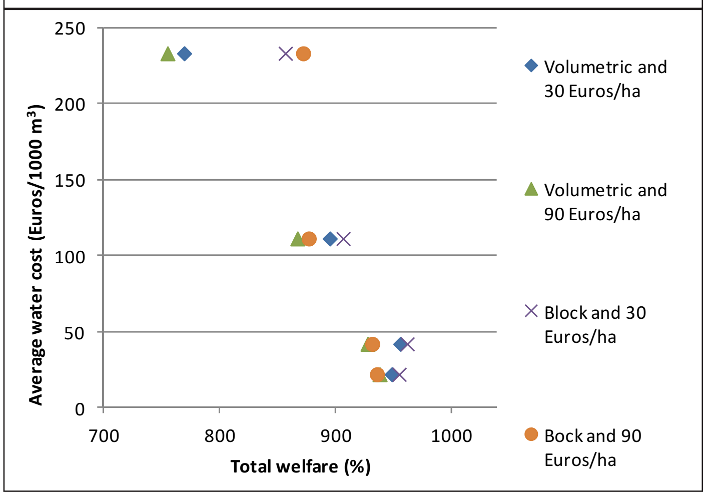
Noéme & Fragoso (2004) estimated a supplier cost in Odivelas irrigation of 479 Euros/ha, divided into a variable cost of 157 Euros/ha and a fixed cost of 322 Euros/ha. These values referring to 2008 at an inflation rate of 3%, are 539, 177 and 363 euros/ha, respectively. Comparing them with our model results we can observe that it is possible to recover the variable cost of the supplier under the volumetric tariff in situations where the water AC is 111.3 Euros/1,000 m^3 and 233.1 Euros/1,000 m^3. Under the block tariff, the variable cost of the supplier can only be recovered when the water AC is 233.1 euros/1,000 m^3 and the fixed irrigation rate is 90 euros/ha.

Figure 6 - *Water cost recovery per hectare of irrigation according to water pricing scenario.*



The total welfare was calculated considering farm profit as farmer surplus and supplier surplus obtained based on the supply variables cost estimated by Noéme & Fragoso (2004), the value of which was calculated to 2008 prices. The highest total welfare is obtained under the block tariff for a water AC of 42 Euros/1,000 m^3 and fixed irrigation rate of 30 Euros/ha. The second best value is achieved under the volumetric tariff for the same level of water cost. The increase in fixed irrigation rate from 30 euros/ha to 90 euros/ha has little impact in terms of total welfare level.

Figure 7 - *Total welfare per hectare of irrigation according to water pricing scenario.*



5. Conclusion

In this paper, the economic impacts of the two water pricing policies in the irrigation sector were assessed by exploring the relationship between the best water allocation and recovery of water cost with the main objective of finding the pricing scheme that allows the maximum total welfare. A methodological framework based on Positive Mathematical Programming and, as an alternative, on Econometric Mathematical Programming model was developed for the conditions of Odivelas irrigation in the Alentejo Region of southern Portugal.

Econometric Mathematical Programming model performs better than Positive Mathematical Programming capturing farmer response in terms of crop substitution to water availability and pricing policy changes.

The results allow us to conclude that under a two-part tariff approach the block pricing scheme may be better than the volumetric pricing scheme. The highest value of total welfare is achieved under the block tariff when the variable rate is 21, 42 and 63 Euros/1,000 m^3 in the first, second and third blocks of water rights, and the fixed irrigation rate is set at 30 Euros/ha. The second best level of total welfare is achieved with the volumetric tariff for the same level of fixed irrigation rate and when the variable rate is 42 Euros/1,000 m^3. Despite close proximity between the first and second best solutions, the block tariff achieves the best levels of total welfare in more simulations and particularly for the highest levels of tariffs.

These conclusions are in accordance with the results of other authors (Veettil et al., 2011). El Chami (2014) also demonstrates that the implementation of a two-part tariff approach can improve the governance of water policies and generate a sustainable development. D'Agostino at al. (2014), in a study made in the Apulia region in Italy reinforce the need to have efficient water management policies, above all to deal with climate change impacts.

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