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Groundwater pricing for farms and water user association sustainability

H. Abdelhafidh[1] · **M. S. Bachta**[2]

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Abstract Tunisia has invested heavily in irrigation schemes to secure water supply. The management of irrigation systems has been denied to local water user associations (WUA). These WUAs are assimilated to a natural monopoly. They sell water to farmers at the unit operational cost (marginal production cost). Such a price does not allow for budgetary balance, which leads to a chronic deficit of these WUA. It also does not reflect the scarcity of the resource, a situation that contributed to irrigated area expansion, an increase in the agricultural water demand, and misallocation of the resource. Low cost recovery results in poor maintenance, infrastructure deterioration, and water distribution inefficiency. The purpose of this paper is two folds: (i) to propose an alternative price scheme which ensures cost recovery and water use efficiency and (ii) to examine the impact of this new price on the farms' surplus. To achieve this goal, we assumed that irrigation's water price increase will be necessary. A field survey of 75 farmers in the center of Tunisia was conducted to estimate the irrigation water demand function. We also used the data collected on 36 WUAs in the region to estimate the irrigation water production cost function using the OLS method for both demand and cost functions, and the peak and the non-peak irrigated demand functions (i.e., summer and winter). The methodology consisted of maximizing social surplus to derive optimal prices for both seasons. The main results show that an increase in price in the range of 11 to 15 % in the winter and 50 to 75 % in the summer results in 11 % decrease of the annual quantity consumed and in a 2 % increase in the social surplus.

Keywords Water pricing · Tunisia · Ground water · Budgetary balance · Farms' surplus

Introduction

Tunisia has invested heavily in irrigation schemes to increase agriculture water supply and to secure agricultural production and farms' livelihoods. The irrigation water management has been transferred from public entities to local user associations (WUA). Since then, the irrigation water demand is increasing due to the development of more water-intensive cash crops which areas are growing at a rapid pace with their demands. This development has resulted not only in increasing the quantity of water demanded but also in extending the period of peak water demand, which now stretches from April to September (Gana and Fouillen 2013).

WUA are facing severe financial difficulties, related to unpaid water bills (the rate of collection of water bills does not exceed 40 % of the total volumes supplied to farmers). This situation has created a negative impact on the ability to maintain distribution channels and water supply of the members (Gana and Fouillen 2013). In fact, the WUAs set the price at the marginal-cost exclusively (operational and maintenance cost or cost of water delivery). This method of pricing does not allow to cover the costs of investments that are quite high. The WUAs are considered to be natural monopolies and pricing at the operational cost which is considered by economists as pricing that enables optimal resource allocation (the one

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✉ H. Abdelhafidh
Abdelhafidhhassen@yahoo.fr

[1] Ecole supérieure d'Agriculture de Mograne, Université de Carthage, Carthage, Tunisia

[2] Institut National Agronomique de Tunis, Université de Carthage, Carthage, Tunisia

that maximizes social welfare). Lower cost recovery and poor maintenance caused infrastructure deterioration and low water distribution efficiency and irrigation performance (Easter and Liu 2005). The price on the base of operational cost is very small compared to the actual value of the resource and the full cost of supply (fixed and O&M cost). Indeed, this method of pricing does not reflect scarcity and does not meet users' efficiency.

The price of irrigation water that considers cost recovery (costs of capturing and delivering irrigation water, which is broken into fixed costs and variable costs or operational cost) becomes a major issue in resources allocation and well-being of farmers. The role of water pricing as an economic instrument for such allocation is critical to guide the farms to better usage and conservation of the resource and to choose appropriate institutional mechanisms. This ensures that water prices reflect on these costs and the empirical value of irrigation water (Dinar and Mody 2004).

For the implementation of a water pricing system, it is usually important to get a compromise between different regulatory objectives, which may be contradictory (Johansson et al. 2002). These objectives are of different natures and their relative weights vary according to the priorities of the various economic agents. Those most mentioned objectives both in economic literature and by those responsible for managing water resources are allocative efficiency (Garcia and Reynaud 2004), equity (Burt 2007; Elnaboulsi 2008), and coverage of certain administrative or operating costs (Easter and Liu 2005).

The purpose of this paper is two folds: (i) to propose an alternative price scheme which ensures cost recovery and water use efficiency and (ii) to examine the impact of this new price on the farms' surplus. To achieve this goal, we assumed that irrigation's water price increase will be necessary. The questions were: how and by how much the price will be increased? And what will be the impact of pricing reforms on farmers' surplus?

Conceptual framework

Designing efficient water rates is a crucial issue for water utilities and local water users associations. The first objective of a water utility pricing scheme is to generate revenues covering costs. But pricing method must also achieve two other functions: A pricing rate has to allocate costs among users, and it has to provide incentives for an efficient use of water (Garcia and Reynaud 2004). Applying these criteria to determine the best rate structure is a challenging task. First, some of the criteria may directly conflict and require a trade-offs. An example of such trade-off is the balance revenue stability and efficiency of the price. Moreover, since high capital investments are involved with water service, a significant share of expenses are fixed costs that do not vary with the quantity of water consumed. This makes the allocation of costs among users a more demanding task.

First best water pricing

The literature on public sector pricing prescribes the different pricing for a variety of circumstances. In the simplest formulation, maximizing social welfare leads a public utility to use marginal-cost pricing (MCP). Maximizing aggregate net surplus leads to the well-known price equal to social marginal-cost rule:

$$P = \frac{\partial C(Q)}{\partial Q} + \lambda \tag{1}$$

Where Q is the volume produced by the water utility, C(Q), with $C' > 0$ and $C'' > 0$. is the cost function. and λ is the marginal shadow price of water. This shadow price is positive when water is scarce or when water withdrawals have environmental impacts. If the price does not reflect the social marginal-cost, consumers do not receive appropriate information about the societal cost of a marginal increase in demand.

MCP has received a number of criticisms and therefore raises many practical difficulties (Garcia and Reynaud 2004). First, the absence of a budget constraint does not provide appropriate incentives for managers to reduce costs . This is one of the reasons why average cost pricing (ACP) has been imposed on many regulated industries. Second, MCP does not reveal whether it is worth incurring the fixed costs (Coaes 1946). One of the criticisms of MCP is related to the distortion implied by this deficit that has to be covered by a subsidization. In the absence of lump-sum transfers, the benevolent authority must resort to distortionary taxes (Garcia and Reynaud 2004). Therefore, optimal pricing in the presence of a cost of public funds (the marginal-cost of public funds measures the loss incurred by society in raising additional revenues to finance government spending) requires the price to diverge from the marginal-cost. An alternative solution is to use a second best price.

Second best pricing

First best pricing is to set all prices equal to marginal-cost. However, for a monopoly, MCP can result in a firm losing money. If the firm cannot be subsidized, the price must be raised above the marginal-cost until profit rises to zero. In one product and one market situation, the requirement of zero profit is sufficient to determine the second best price: Price is necessarily equal to average cost when profit is zero. Consequently, the second best price for one good and one market is the average cost (Kenneth 1991).

Certainly, it is more favorable to the community in terms of well-being than the solution that maximizes profit monopoly, but it violates the conditions of optimal allocation of the resource. The dead-weight loss caused depends on the price elasticity of demand for the service in question and does not encourage the firm to minimize the total cost and the efficient resource use.

In a second best world, where the budget of the water utility must be balanced, an alternative to average cost pricing is "Ramsey–Boiteux" pricing. It is a type of discriminatory pricing that is charging different prices from one market to another in order to generate maximum revenues in a market where the price elasticity of demand is the lowest.

$$\frac{P-C'(Q)}{P}=\frac{\mu}{1+\mu}\cdot\frac{1}{\varepsilon} \tag{2}$$

Where ε is the price elasticity of the water demand and $\mu/(1+\mu)$ is a term reflecting the cost of the budget constraint. Ramsey–Boiteux pricing ensures the maximal economic welfare under a budget constraint. Implementing this pricing, however, requires a perfect knowledge of marginal-cost and price elasticity.

The empirical model

WUAs' primary mission is the distribution of water to members of the associations. This activity usually requires very capitalistic technologies which put its producer in a monopoly or quasi-monopoly situation. This situation justifies the intervention of the state to prevent the producer that can increase its profit by extracting the pension that lavishes its monopoly position. The adopted pricing is that which can cover operating expenses (operational and maintenance cost). This mode does not reflect the scarcity of the resource. We assumed that there are N members of the WUA. The annual demand for irrigated water is divided into two independents demands: summer demand and winter demand.

$$q_{in}=q_{1n}+q_{2n} \tag{3}$$

Where

$n=1\ldots\ldots.N$

$i=(1.2)$ and 1 is the peak of demand in summer; 2 is the peak-off demand in winter.

The global water derived demand that face the WUA:

$$Q(p)=\sum\nolimits_1^N q_{1n}+\sum\nolimits_1^N q_{2n} \tag{4}$$

i.e.,

$$Q(p)=Q_1(p)+Q_2(p). \tag{5}$$

Where P is the price of the water

Let $Q_{\mathrm{i}}(P)$: the seasonal demand function and $P(Q_{\mathrm{i}})$ is the inverse seasonal demand function.

Let $C(Q)=C$ (Q1, Q2): the production cost function of irrigation water.

$C_{\mathrm{mi}}(Q_i)=\frac{\partial C(Q_i)}{\partial Q_i}$: the marginal production cost of irrigation water.

$R(Q)=\sum_1^2 p_i\,Q_i$: the total revenue function.

The optimal allocation of resources is achieved by maximizing the surplus of users. It is assumed that the WUA maximizes the social welfare subject to budget balance constraint. The problem is as follow:

$$Max\int_0^{Qi}P_i.d(Q_i)-C(Q) \tag{6}$$

Subject to

$$\sum_1^2 P_i.Qi=C(Q)$$

The lagrangian function is as follows:

$$L=\int_0^{Qi}P_i.d(Q_i)-C(Q)+\lambda\left[\sum\nolimits_1^2 P_i\ .Q_i-C(Q)\right. \tag{7}$$

The first order conditions are as follows:

$$\frac{dL}{dQ_i}=P_i-C_m+\lambda\left(P_i+\frac{d(P_i)}{d\,(Q)}\ .Q_i-C_m\right)=0 \tag{8}$$

$$(P_i-C_m)=-\lambda\left(P_i+\frac{d(P_i)}{d\,(Q)}\ .Q_i-C_m\right) \tag{9}$$

$$(P_i-C_m)=-\lambda\,(P_i-C_m)-\lambda\,\frac{d(P_i)}{d\,(Q)}\ .Q_i \tag{10}$$

$$(1+\lambda).(P_i-C_m)=-\lambda\,\frac{d(P_i)}{d\,(Q)}\ .Q_i \tag{11}$$

We divided by P_{i} the two terms of Eq. (11) and we obtain the following:

$$(1+\lambda).\,\frac{(P_i-C_m)}{P_i}=-\lambda\,\frac{d(P_i)}{d\,(Q)}\cdot\frac{Q_i}{P_i} \tag{12}$$

$$\frac{(P_i-C_m)}{P_i}=\frac{-\lambda}{(1+\lambda)}\cdot\frac{1}{\varepsilon_i} \tag{13}$$

Where

$\varepsilon_i=\frac{d(Q_i)}{d(P_i)}\cdot\frac{P_i}{Q_i}$: price elasticity of water demand.

The Eq. (13) states that the "mark-up" varies inversely to the price elasticity of water demand. The proportionality coefficient is a function of λ which represents the social marginal utility of improving the revenue or also the opportunity cost of public funds (imposed by an additional monetary unit of public expenditure).

So the WUA prices above the production marginal-cost to ensure a balanced budget and to give a signal to consumers to recognize the scarcity reduce demand (Oum and Tretheway 1988) and encourage farms to improve water value.

To this end, WUA cost and demand functions are estimated on a panel of WUAs located at Nadhour. Cost and demand functions are estimated to simulate Ramsey–Boiteux prices by equalizing total cost to total revenue. Finally, welfare changes from reforming water pricing are computed.

Study area and data

Study area

This research was conducted at the Nadhour region that is located at the southern part of the governorate of Zaghouan in the center of Tunisia. It is characterized by a semi-arid climate. The average annual rainfall is 400 mm. The agricultural area of Nadhour is around 38,200 ha. Nadhour region accounts about 1925 farms, 60 % of them with an area less than 5 ha and 28 % with a farm size ranging from 5 to 10 ha. The irrigated systems were installed since 1980, and the irrigated area is about 3050 ha. Most irrigated areas are planted with summer crop (watermelon, pepper, melon, season tomato…). The water resources are about 14 millions m^3. Two thirds of these resources are groundwater. Water demand management is ensured by 34 WUAs. These WUAs ensure the sale of water to users and networks maintenance. The pricing method most used is the volumetric pricing. The irrigation water rate varies from 0.085 to 0.13 TD/m^3.

The problem of water availability usually arises during peak periods corresponding to the months of May, June, July, August, and September. The different types of irrigation currently practiced are as follows:

> Sprinkler irrigation: It is used in wheat, barley, and summer forages.
>
> Drip irrigation: This system is very widespread in vegetable crops. The government provides subsidy covering up to 60 % of the investment cost.

Data is collected through a survey on 75 farmers representing 38 % of the total number of members from 6 WUAs during 2011. The perimeters areas range from 50 to 70 ha. These WUAs are marked by a low rate of exploitation. The latter is between 40 % at the perimeters Chaalil Sud and Naffet and 67 % at the perimeter Nadhour 2. The applied price is based on the calculation of operating costs incurred by the WUA to pump and distribute irrigation water to different members. These expenses mainly cover the costs of energy, labor, and maintenance. It forms the operational cost of irrigation water pumped and distributed. This rate covers operational costs with a slight margin of no more than 0.01 TD/m^3. It varies from one to another WUA. The lowest rate is recorded at the WUA Zwagha 2 which is 0.09 TD/m^3 against a rate of 0.13 TD/m^3 at the WUA Chaalil Sud. The average price at the level of 6 WUAs is approximately 0.103 TD/m^3 (Table 1).

Water consumption per irrigated hectare is estimated by the total consumption of perimeter / (the total area of the perimeter × exploitation rate). It is an average of 4082 m^3. This varies according to the perimeters. It is noted that the lower consumption is recorded at the WUA Nadhour 2 which is 3458 m^3/ha against that recorded the highest consumption level recorded at WUA Chaalil Sud which amounts to 6000 m^3/ha. This disparity show a close correlation between the consumption and exploitation rate that is closely linked with the intensification rate.

Farms characterization and structure

The aim of past agricultural policies was to motivate farm managers to adopt irrigation to improve farms' income. The average size of farms surveyed is 3.5 ha with a minimum of 0.8 and a maximum of 23 ha. However, 70 % of farms have areas below average. The number of plots ranges from 1 to 3, with an average of 1.6 plots/farms and average area of 2.1 ha/plot.

Land use

The analysis of land use at the perimeters subject of our investigation shows that the irrigated areas main crops are watermelon ranging between 21 % at Zouagha 2 to 57 % at Naffet, followed by tomato that varies from 10 to 40 %. Pepper comes third, where it occupies between 12 and 37 % of cultivated land.

The importance of cereals is also variable from one perimeter to another where it does not exceed 10 % in areas at Zwagha1 and Nadour 2 to 23 and 48 %, respectively, in the perimeters Nadhour 3 and Chaalil Sud.

For the legumes and despite their importance in crop rotations, they are virtually absent in the existing farming systems since they do not appear in the perimeters of Zwagha1 and Chaalil Sud and do not exceed 12 % at the perimeter of Nadhour 2.

The analysis of the cropping calendar shows that crops grown in summer are the long cycle and spread over the whole season and more these crops are very demanding in water which increase the water demand for irrigation. Indeed, during summer that stretches from April to September, farmers grow watermelon, tomato, pepper, and cucumber which are all high

Table 1 WUA characterization

WUA	I	II	III	IV	V	VI	Total
Members number	19	14	18	33	35	40	183
Perimeter area	50	70	50	60	70	50	380
Average area/farm	2.6	5	2.8	1.8	2.0	1.25	2.08
Exploitation rate (%)	50	57	40	67	63	40	53
Water price	0.1	0.09	0.13	0.12	0.1	0.1	0.103
Flow	15	45	15	20	25	25	24
Consumption/ha	5000	4261	6000	3458	3900	3600	4082
No. of investigated farmers	8	10	11	15	11	20	75
% of total number of members	42	71	61	45	31	50	38

I Zwagha 1, *II* Zwagha 2, *III* Chaalil Sud, *IV* Nadhour 2, *V* Nadhour 3, *VI* Naffet

water consumption crops (Table 2). The increase in demand leads to conflicts between farmers both for the water turn and the amount requested.

Estimation of demand and cost functions

Demand functions

Several methods of estimating demand functions have been proposed and used. Chembezi (1990) identifies both direct and indirect estimation approaches. Indirect approaches include demand functions derived from agronomic response functions. Direct methods include the estimation of demand functions directly from observed market data on consumption and input prices and the price or quantity of agricultural production. For the purposes of this study, the method of direct approach will be used to estimate water demand function associated with irrigated production in the area of Nadhour.

Table 2 Mean water consumption/crop/ha

Season	Crops	Mean water consumption (m^3/ha)	Area (ha)
Summer	Tomato	3800	450
	Pepper	5110	150
	Watermelon	3650	300
	Melon	3500	50
	Cucumber	3300	70
Winter	Bean	600	50
	Pea	350	30
	Durum wheat	200	20
	Barley	180	20
	Back season tomato	3100	50
	Back season pepper	2970	30
	Back season cucumber	2950	20
	Back season potato	2600	350

A regression analysis technique was used to estimate the values of model parameters, and ordinary least squares method was applied. The parameters of the demand function were estimated using the econometric method on panel data, and SPSS software was used.

The economic model

The economic model used to determine the relationship between the various inputs and outputs in agriculture is the model of the production function. In agriculture, inputs consist of land, labor, and capital which are the basic factors of production. The simplified form of the production function of these factors is given by:

$$Y = f(\mathrm{Xi}) \tag{14}$$

Where Y is the output which is a function of inputs Xi: the land (T), capital (K), and labor (L) used to produce a maximum amount. A production function can be defined as a mathematical equation exhibiting the maximum amount of output that can be achieved from a given set of inputs.

The optimum demand for each factor, as a function of the input price and desired outputs, can be obtained using conditional factors demand function. The conditional demand functions are obtained using Shepard's lemma where the problem is to minimize costs. This is to maintain production at a certain level with the least expenditure of inputs (Sadeghi et al. 2010; Amos et al. 2014).

The Cobb–Douglas production function form is widely used in studies and researches. It can express the relationship between outputs and inputs used. This form is used because it is easy to convert it into linear regression where the coefficients represent the elasticities of the factors used.

The general mathematical form of the Cobb–Douglas production function is given by:

$$Y = A\prod_{i=1}^{n} X_{\mathrm{i}}^{\beta \mathrm{i}} \tag{15}$$

Where Y and X are respectively the production and inputs used. A and β_i are parameters to be estimated.

The empirical model of the seasonal demand for irrigation water

In this study, the function of the demand for irrigation water will be estimated using the Cobb–Douglas functional form and panel data econometric methods. It is assumed that, under the costs minimization, the water demand function in terms of the amount consumed depends on the water price P, capital factor (K) (expenditure on seed, treatment product, chemical fertilizers, mechanization costs), the land factor T (irrigated area), and the labor factor L (labor costs).

The demand function may be written as follows:

$$\mathrm{Ln}(Q) = \beta_0 - \beta_1 \ln(p) + \beta_2 \ln(T) + \beta_3 \ln(K) + \beta_4 \ln(L) + \varepsilon \qquad (16)$$

Where

Q: amount of water consumed per farm
β_i: parameters to be estimated
ε: error term

Cost function

In most countries, water distribution companies have a monopoly franchise to supply water in their areas of action and, therefore, rate regulation by a regulatory commission is necessary.

This raises the problem of determining the appropriate rates for the water delivery. On the one hand, prices should be high enough to ensure the viability of regulated company. However, prices that are set too high will bring about losses of welfare.

Because of the asymmetric information, the regulator does not know the real costs of the business. High cost may be due to the specific production situation of the business or simply because of its inefficiency. In this section, we try to shed light on the key variables of the total cost of groundwater produced by the WUAs.

Actually, the price of water charged to farmers includes operating and maintenance costs only. Therefore, the fees collected do not ensure the rehabilitation of networks put in place and infrastructure as they do not cover fixed costs which are high. Furthermore, the price does not include the opportunity cost of groundwater or the scarcity rent.

In addition to fixed and variable costs, other explanatory factors such as the network size and distribution efficiency can also influence the cost. The lager the perimeter size is the lager the distribution network is and therefore can generate efficiency losses.

The model of the water production total cost

For the specification of the cost model, we considered a water distribution entity with three inputs, labor (L, labor charges/m^3), capital (K, fixed costs related to investments), and energy (E, energy costs/m^3), which distributes one output (Q) to N users group size, which is a technical variable and can be defined, for example, by the perimeter area. The area of the perimeter can be regarded as a characteristic variable of the system and expresses the influence of the size on the total cost.

Assuming that the WUAs minimize their costs, the cost function can be written as follows:

$$\mathrm{CT} = C(\mathrm{Qd}.\ K.\ L.\ E.\ S) \qquad (17)$$

Where

CT: total cost of the distributed quantity
Qd: quantity distributed (demand m^3)
K: capital (fixed costs)
L: labor charges/m^3
E: energy expenses/m^3
T: the perimeter's area.

The estimate of the cost function (Eq. 17) requires specifying a functional form. We decided to use a Cobb–Douglas functional form, which, compared to the translog form, reduced significantly the number of explanatory variables in the cost model.

The Cobb–Douglas form of equation is as follows:

$$\mathrm{Ln}(\mathrm{CT}) = \alpha_0 + \alpha_i \mathrm{Ln}(X_i) \qquad (18)$$

Where $i = \mathrm{Qd}$; K; L; E; S.

It is assumed that the total cost is positively correlated to production factors (energy, labor, capital) and perimeter size.

Determination method of the Ramsey–Boiteux price

The Ramsey–Boiteux rule as described by Eq. (13) states that at Ramsey prices the elasticity of demand times the percent by which price exceeds marginal-cost is the same for all market or goods. Note that this equation holds at marginal costs setting. However, if marginal-cost pricing results in negative profit then prices must be raised according to Eq. (13) to allow the WUA to break even. To this end, Excel Solver was used. The Ramsey prices are determined by maximizing consumer surplus under the constraints of the budget balance of the WUA and Eq. (13) constraints.

Table 3 Descriptive statistics of the variables used in the seasonal water demand

Season	Summer				Winter			
Variables	Min	Max	Average	Standard error	Min	Max	Average	Standard error
Consumed quantity/farm *Q* (m^3)	500	16,758	5500	3262	113	12,500	2220	2759
Water price *P* (TD)	0.09	0.13	0.11	0.012	0.09	0.13	0.11	0.012
Irrigated area *T* (ha)	0.8	8	2.2	1.45	0.8	8	2.2	1.45
Capital *K* (TD)	197	9500	2737	1472	280	5200	1700	1480
Labor expenses *L* (TD)	0	2675	586	469	20	1400	306	356

Results and discussion

Seasonal demand

The data were collected from a survey of 75 irrigated farms in Nadhour region. The average consumption is 5500 m^3/farm in summer against 2220 in the winter. The minimum consumed amount was 113 m^3/farm in the winter against 500 m^3 in the summer. The maximum consumption per farm recorded rises to 16,758 in the summer against 12,500 m^3 in the winter. It is clear that the average summer demand is about 250 % higher than that of the winter. However, the prices charged for these two seasons' demand are the same. The average price is 0.11 TD/m^3, with a minimum of 0.090 TD/m^3 and maximum 0.130 TD/m^3 (Table 3).

The regression results are presented in Table 4 which shows that the determination coefficients are 90.7 and 99.5 %, respectively, for the consumed quantities in the summer and consumed quantities in the winter, indicating that 90.7 % of the variation of the summer demand and 99.5 % of the variation in the winter demand are explained by variations of selected explanatory variables. The values of Prob F indicate that the models are significant at the 1 % level.

According to the results, the coefficients of the price of irrigation water are −0.13 and −0593, respectively, for the summer and winter demands functions. These two values are less than one implying that the demand for irrigation water is inelastic.

However, we also note that the winter demand is more sensitive to price changes. Indeed, a 1 % increase in the price of irrigation water during winter causes a reduction in demand by 0.593 % against the summer demand which is more rigid to any change in the price of water where an increase of 1 % generates a reduction of the consumption by 0.13 %.

This negative correlation between changes in prices and demand for irrigation water is significant for winter demand at the 5 % threshold, while it is not for the summer demand. In fact, the value of the *t* test is of −0364.

Water demand is positively and significantly correlated with their irrigable area (*T*), during the summer. In contrast, the winter demand is negatively correlated to the land factor with a coefficient of −0.037. This correlation is moderately significant with a probability of 27 %. Similarly, the regression results show a strong positive correlation between the demand for irrigation water in the summer and capital. As for the winter demand, it is also positively correlated with capital but with a very low coefficient. These demands are also positively correlated with labor.

Table 4 Water demand model estimates

	Summer		Winter	
Variables	Coefficients	*t* test	Coefficients	*t* test
Constant	1.871	2.180	0.533	1.523
Ln(p)	−0.13	−364	−0.593	−3.469
Ln(T)	0.269	3.789	−0.037	−1.129
Ln(K)	0.653	9.801	0.0005	2.810
Ln(L)	0.153	1.757	0.998	46.608
R^2 (%)	90.7		99.5	
F statistic	112		1378	
Prob F	000		000	

The regressed cost function

The natural logarithm of variables was estimated using ordinary least squares (OLS) as specified above in the model.

Table 5 Cost function estimation

Variables	Coefficients	Standard error	*t* test	Signification
Constant	1.09	0.431	2.54	0.017
Ln(Qd)	0.1	0.019	5.07	000
Ln(S)	0.11	0.051	2.00	0.056
Ln(E)	0.031	0.043	0.49	0.628
Ln(L)	−0.028	0.023	−1.19	0.245
Ln(K)	0.88	0.038	20.51	000
R^2 (%)	95.81			
F	123.56			
Prob (F)	000			

Table 6 Ramsey–Boiteux pricing

WUA/season		Price at operational cost (TD)	Operational cost (TD)	Ramsey–Boiteux price: Pr-b (TD)	Mark-up (%)
I	Winter	0.1	0.096	0.11	13
	Summer	0.1	0.096	0.24	60
II	Winter	0.09	0.086	0.102	15
	Summer	0.09	0.086	0.34	75
III	Winter	0.13	0.12	0.135	11
	Summer	0.13	0.12	0.245	51
IV	Winter	0.12	0.11	0.125	12
	Summer	0.12	0.11	0.251	56
V	Winter	0.11	0.1	0.115	13
	Summer	0.11	0.1	0.246	55
VI	Winter	0.1	0.085	0.1	13
	Summer	0.1	0.085	0.219	61

The dependent variable is the natural log of the total production cost of the amount distributed: ln (CT).

The results of this estimation are presented in Table 5. The determination coefficient R^2 with a value of 95.81 % shows a strong correlation between the variability of the total cost and the variation of the explanatory variables chosen in the model. This correlation is significant, since the *F* statistic is significant at the 1 % level. Since the dependent variable and the explanatory variables are in natural logarithm, so the estimated coefficients represent the cost elasticities.

The coefficient of the distributed quantity is positive as it is 0.1 implying that an increase of distributed quantity by 1 % will increase the total cost of water by 0.1 %. This is significant at the 10 % level.

Similarly, elasticity cost for energy is positive showing a positive relationship between energy expenditure and total cost. Any time this relationship is not significant since the *t* test is low and does not exceed 0.49.

While the coefficient of capital input (K) indicates a strong positive correlation between the amount of investment and the total cost, this indicates that a variation of 10 % on invested capital leads to an increase of 8.8 % of the total cost. This correlation is significant at 1 % level since the value of *t* test is 20.51.

Contrary to what is expected, the elasticity cost of labor is negative indicating that a 1 % increase of these expenses resulted in a decreased total cost of 0.028 %. It is a small and insignificant correlation since the value of *t* test is −1.19. This can be explained by the fact that the labor expenses can improve network efficiency through the maintenance and monitoring.

The cost elasticity of the variable perimeter area revealing the size effect implies a significant positive correlation at the 5 % level. In fact an increase of 1 % of the perimeter of the area leads to an increase of the total cost by 0.11 %. Since, it is very interesting to optimize the allocation of the resource within the perimeter before any eventual extension to maximize the water value and to reduce the average cost.

This analysis allows us to deduce that the total cost of irrigation water is significantly influenced by the amount of initial investments and the size of the perimeter and the distributed quantity. For this purpose, to ensure the viability of these systems, it is recommended to take into account the real production costs of the resource in the rates setting paid by users to motivate them to a better resource allocation. Our objective was to determine a pricing system that ensures the viability and improvement of the financial performance of the WUAs which will allow them to have more autonomy and interventions at appropriate times if necessary and not exposing users to consecutive breaks of services rendered. The regularity of the services rendered by the WUAs gives more confidence to farmers on the regularity of supply and also allow them to make their inter seasons and inter annual choices more accurately.

Results of the second best pricing approach

After estimation of the seasonal demands functions and the total cost function of the irrigation water, we tried to determine the prices for each season which allows the achievement the annual balanced budget of the WUA. The results of the second best rate setting are presented in Tables 6, 7, 8, and 9. They indicate the economic and ecological effects of the passage

Table 7 Changes in farmers' surplus

Elements	I	II	III	IV	V	VI	Total
Initial total farms' surplus (TD)	181,083	180,002	112,648	189,038	223,859	141,962	1,028,592
Budget déficit (TD)	−16,790	−35,270	−7908	−17,456	−18,278	−9349	−105,051
Total farms surplus at R-b (TD)	165,415	155,907	104,406	174,599	206,023	132,100	938,450
Déficit budget R-b (TD)	0	0	0	0	0	0	0
Farms surplus variation (TD)	−15,667	−24,095	−8242	−14,439	−17,835	−9862	−90,140
Net variation	1123	11,175	−334	3017	443	−513	14,911

Table 8 Opportunity cost of public funds

WUA	I	II	III	IV	V	VI	Average
Λ	0.085	0.108	0.071	0.079	0.084	0.077	0.085

from current pricing method (operational costs slightly increased by a mark-up not exceeding 10 %) to Ramsey–Boiteux pricing method.

The Ramsey–Boitteux pricing (Pr-b)

Initially applied prices are uniform for two seasons and vary from 0.090 to 0.130 TD/m^3. The application of the Ramsey rule has led to a slight increase in water prices in winter (non-peak demand) compared to already applied prices. The relative differences of prices from marginal-costs for the winter season range from 11 % made at Chaalil Sud to 15 % made at Zwagha 2. Ramsey price in winter ranges from 0.100 to 0.135 TD/m^3. We also note that these prices have all increased from the current rate except for the Naffet WUA. For the summer season, where demand is inelastic with respect to that of the winter, the differences between price and marginal-costs are larger. Indeed, the average of these differences is 60 % and they range from 51 to 75 %. This variation depends on the realized budget deficit. In fact, the most important deficit is observed at perimeter Zwagha 2 which is 35,270 and the lowest is recorded at the Chaalil Sud WUA.

We note also that Ramsey–Boiteux prices are very low compared to the average cost from an individual well. In fact, the average cost from an individual well ranges from 0.37 to 0.49 TD/m^3 (Louhichi et al. 2000; Gabouj 2016). However, the farmers are not allowed to dig wells in the perimeter.

The economic effects of Ramsey–Boiteux pricing: change in farmers' surplus

Increasing water prices often causes a decrease in farmers' surplus. The Ramsey rule minimizes this decrease. Indeed, the move from the current pricing method to the Ramsey–Boiteux pricing method allows comparison in terms of change of farmer surplus. Indeed, farms' surplus losses vary from −7 to −13 % and the average decrease is 8 % which is equivalent to −12,877 TD/WUA. On the opposite, the advantage of water price increase is the balanced budgets and zero deficits. The overall deficit realized is approximately 105,000 TD against an overall loss of the farmers' surplus of 90,000 TD which gives a ratio of gain/loss of 1.16. This means that gains exceed losses by 16 %.

Table 9 Water consumption variation

Elements	I		II		III		IV		V		VI		Total	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Demand at Cm	9690	115,450	22,400	146,440	4140	115,030	13,860	126,885	17,500	154,700	23,760	86,320	91,350	744,825
Total consumption (m^3)	125,140		168,840		119,170		140,745		172,200		110,080		836,175	
Demand R-b (m^3)	17,252	105,414	51,366	87,525	4809	68,945	33,948	104,157	44,078	123,452	24,874	79,880	176,327	569,373
Total demand R-b (m^3)	122,666		138,890		73,755		138,106		167,530		104,754		745,701	
Per season demand variation (%)	34	−6	129	−40	16	−40	145	−18	152	−20	152	−20	93	−24
Per year demand variation (%)	−2		−18		−38		−2		−3		−5		−11	

Opportunity cost of public funds

Any increase in price leads to a loss of unity than the unity of the social surplus and therefore a dead-weight of the social welfare. This dead-weight is expressed by λ. The prices obtained by the Ramsey–Boiteux rule are those that maximize social surplus under the balanced budget constraint of the WUA. In this interpretation, λ is a measure of the severity of the budget constraint. This is the marginal social surplus gain which can be achieved if we reduce the WUA revenue by one unit. Table 8 shows that this value varies from 7 % registered in Chaalil Sud to 10.8 % registered in Zwagha 2. The average value is 8.5 %.

The resource conservation

In addition to the economic effects of the passage from the marginal-cost pricing to the Ramsey–Boiteux pricing rule, ecological effects are recorded as a reduction of the water quantity consumed. Table 9 shows that the consumed quantity moved from 836,174 to 745,700 m^3 with an overall 11 % reduction. This decrease varies from one perimeter to another. There has been a significant decrease of 38 and 18 %, respectively, in Chaalil Sud and Zwagha 2 and small reductions of the order of 2 % in Zwagha 1 and 5 % in Naffet. In fact, this reduction is the result of increased winter consumption and a decrease in summer consumption. So winter demand recorded an increase of 93 % and moved from 91,350 to 176,327 m^3; this increase is variable depending on the perimeters. It ranges from 16 % in Chaalil Sud to 152 % in Nadhour 2 and Naffet.

The most important is the reduction of water consumption during peak periods. Summer demand accounted for 89 % of the overall demand in pricing at marginal-cost method and represented only 76 % in that Ramsey–Boiteux pricing marking a reduction of 24 % to move from 744,825 to 569,375 m^3. The majority of decreases are more than 18 % and may reach 40 % which are very important from an ecological and resource conservation viewpoint in a scarcity context.

Conclusion

Water management in Tunisia has been an ongoing major issue for policy makers. Management of medium and small-scale irrigation schemes is provided by local users associations. Most of these associations faced financial problems because of low irrigation water prices charged. These problems affect the sustainability of the WUAs and farm performance.

The purpose of this paper has been to identify a pricing system which allows the total cost recovery and improve the WUAs efficiency. To this end, seasonal irrigation water demand functions and production cost function were estimated.

Results show that peak demand function was less sensitive to price variation with an elasticity of −0.13. Then, the Ramsey–Boiteux rule was applied to both non-peak demand in winter and peak demand. The new water prices found are slightly increased in winter and more in summer, which allows the WUAs to break even against slight farms' surplus decrease. Therefore, the ratio of gain loss is 1.16 proving that gains exceed losses by 16 %. On the other hand, the overall water consumption loss of 11 % and peak demand decreased by 24 %. Consequently, this pricing system allows the WUAs to have their financial autonomy without being subsidized by the state and give resource scarcity signal to the farmers. Given an empirical assessment of the irrigation water value in 2012 in the study area, Abdelhafidh et al. (2014) show that the willingness to pay for the irrigation ground water varies from 0.6 to 1.1 TD/m^3 which indicates that the Ramsey–Boiteux pricing has a great chance to be accepted by the farms.

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