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Toward Sustainable Water Resources Management in the Tunisian Citrus Sector: Impact of Pricing Policies on Water Resources Reallocation

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Abstract: This study aims to analyse Tunisian farmers' ability to pay (ATP) in a citrus area and propose a penalising price strategy based on the block-pricing process to decrease over-irrigation without affecting farmers' incomes. The methodology is based on the residual imputation approach to determine farmers' ATP, a stochastic production frontier to estimate the technical efficiency to determine optimal water irrigation quantity and calculation of the price elasticity of demand for an effective penalty and the Gini index before and after penalisation to study equity improvement. A survey was carried out on a sample of 147 citrus farms in the Nabeul Governorate, Northeastern Tunisia. The technical efficiency analysis confirms that an optimal quantity of 5000 m^3/ha guarantees the maximisation of yields and profits. Above this quantity, the amount of overused water could be penalised without significantly affecting farmers' incomes. Results also reveal that water overconsumption represents 28% of available resources and the ATP varies according to technical efficiency. Therefore, the proposed penalty system could reduce water overconsumption by 44.56% without deteriorating agricultural welfare. To improve water management as well as farmers' welfare, this study recommends an increase in the technical efficiency level of farms to optimise all production factors for any implemented pricing policy.

Keywords: water value; ability to pay; residual imputation approach; stochastic production frontier; overconsumption penalties; equitable reallocation; Tunisia

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1. Introduction

The assessment of water resources in Tunisia shows a growing water deficit; indeed, available water in surface and groundwater per year and per capita was 420 m^3 in 2013, which is considered below the threshold of absolute water scarcity [1]. Irrigation uses 83% of distributed volumes and contributes 35% of agricultural production and 20% of agricultural exports. The irrigated area increased from 250,000 ha in 1990 to 450,470 ha in 2010 and the consequent increased water demand is difficult to satisfy. A report by the Ministry of the Environment [2], assessing climate change and hydraulic stress, concludes that Tunisia will suffer from more erosion, increased drought, higher temperatures as well as an increase in the salinity of water reserves. According to the same report, the tendency during the 20th century was a decrease in rainfall of 5% for the north, 8% for Cape Bon and the northeast and 10% for the extreme south. By 2030, conventional water resources in Tunisia will be reduced by 28% and surface water by 5%. According to Lasram et al.

[3], the increasing trend in maximum temperatures was 0.43 °C between 1973 and 2013, and there will be a further rise of 16% between 2050 and 2090.

Water management is highly dependent on climatic variation and peak periods, and is characterised by wastage, losses and/or repetitive breaks, an extension of irrigation beyond planned areas and inequities in the distribution of agricultural water; this observation reinforces the urgency of improving the allocation of water resources in order to allow better equity among the different users and to ensure water economy. In this context, many studies have proposed pricing as a tool for water demand management [4]. According to Feike and Henseler [35], pricing policies and quantitative policies (quota or deficit irrigation) are the most used mechanisms in demand management [6]. Theoretically, increasing the price of a resource creates incentives to improve the allocative efficiency of this resource and better manage it; indeed, there are arguments that volumetric policies are more efficient in reducing water consumption as well as in recovering the costs of the irrigation system [7].

Parween et al. [8] observed that low revenue collection is mainly due to the low rate of water taxes, no periodic revision and flaws in the current revenue collection mechanism across the states in India. Zamami et al. [9] revealed that a water-pricing policy can change the cropping pattern and also an irrigation system. Chaudhuri and Roy [10] supported the introduction of a volumetric water-pricing system and suggested employing automatic metering devices to charge for the actual volume of water used. There have been many studies on the impact of increased water pricing and other parameters on the conservation of water and water demand by farmers at different scales [11–15].

Nevertheless, the proposed strategies have a different impact on supply and demand. Marginal cost pricing (the case of volumetric pricing) allows efficient allocation that maximizes total surplus but can lead to a budget deficit for the water agency. Average cost pricing ensures a balanced budget for the water agency but results in a loss of efficiency, and farmers lose the most in welfare. Block pricing, or multiple rates (marginal cost pricing with multiple rates), results in a transfer of funds from agricultural water users to the supply agency, equilibrates the supply budget and allows resource-efficient allocation [16]. In addition, similar pricing policies may have different impacts under different conditions. The ability of farmers to respond to a pricing policy depends on their ability to adapt by changing technologies, soil type, reliability of water supply, water management institutions and prices of water, other inputs and substitute crops; therefore, any pricing policy needs to consider the direct and indirect impacts on income and farmers' welfare.

Below a certain threshold, water demand is almost inelastic. At this stage, the direct impact of the price increase is at the level of agricultural incomes that will decline following the transfer of private funds to the public sector; nevertheless, if this transfer of funds is used to improve the efficiency of the irrigation network, it leads to a better supply of water and an increase in rural welfare [17]. Thus, a pricing system that does not take into account the price elasticity of the demand for irrigation water and the optimal need of plants for water (an essential allocation for production) will have a negative impact on farm income without improving the efficiency of water use and reducing waste [18–21]; therefore, taking into account the conclusions of the studies on pricing policies and with the aim of presenting a strategy that can improve the irrigation water economy without deteriorating the agricultural welfare and that takes into account the price elasticity of demand and the essential water quantity to production, it is proposed to penalise, exclusively, over-consumption; this can readjust consumption to more equitable allocation of available resources, reduce waste of resources and increase efficiency while improving rural welfare. To determine the amounts over-consumed, we propose to use the stochastic production frontier. Dhehibi et al. [22] indicated a low technical efficiency of citrus farmers, who could potentially reduce water consumption by 47% to achieve the same yields.

2. Theoretical Framework

The theoretical method deals with the following: determining technical efficiency, crop optimal and essential quantity, the ability to pay (ATP) and elasticity price for water irrigation demand; this may lead to a water overconsumption penalisation, without decreasing agricultural welfare, and can be used for any crop with respect to relative specificity: soil quality, climate, and use of other inputs.

The ATP, via the residual value method, is what an individual can give in order to benefit from a good and/or service and is determined by isolating the contribution of water in the total value based on the profitability of irrigated land. The price elasticity of demand is a measure of quantities of variation of a product demanded in response to variation of its price. Finally, the Gini index is a statistical measure allowing analysis of the disparities and inequalities of wealth distribution within a population; therefore, to estimate equity improvement, for our sample, after reallocation of over-consumed resource quantities, we use the Gini index for the current and post-penalisation situations. Initially, farmers, suffering from inequity in water allocation, generate very low yields and benefits. The penalised reduced quantities will be reallocated to this sub-sample. Thus:

- On the perfect equality line, Gini index = 0, perfect wealth repartition (benefits in our case). If Gini coefficient = 1, non-existent equality;
- Lorenz curve presents the current situation: observed values concentration;
- Surface A: the surface between the perfect equality line and Lorenz curve;
- Surface B: surface below Lorenz curve;
- Gini Index (GI): surface A/(surface A + surface B).

Tang et al. [23] and Garcia et al. [24], proposed improving water use efficiency given increased resource scarcity. We aim to quantify the efficient optimal water irrigation amount that corresponds to the needs of the crop and guarantees the optimisation of yields, profits and surplus (as indicators of farmers' welfare) via the stochastic production function. Then, we estimate the ATP according to the residual imputation technique. By comparing the ATP to the current price of water, as well as the profits and surplus, we can analyse the present situation and detect the incidence of inequitable agricultural water distribution on resource valuation and incomes.

The analysis of the demand curve and price elasticity will allow us to propose penalties for overconsumption that would provide incentives for citrus farmers to save water resources and perform better allocation, and to subsequently analyse the impact of the penalisation on farmers' surpluses and profits. In fact, the residual value represents the maximum amount that the producer will be willing and able to pay for water while covering its costs [25,26].

According to this definition, it can be assumed that penalizing overconsumption, with an amount less than or equal to the ATP according to the determined price elasticity, will cause a water demand decrease, and reduce waste of the resource; indeed, a penalty system, exclusively on water overconsumption, will allow efficient and adjusted consumption of available resources [27–30]; and thus, to overcome the problems raised by the literature on determination of price elasticity and the negative pricing system on agricultural impact and welfare, we propose the following: (i) for price elasticity, a pricing system that considers and can act on the elastic segment of the demand curve and (ii) concerning the negative impacts of pricing on agricultural income and welfare, we consider the necessary and optimal water quantity for production, which maximizes the productivity of agricultural water via the estimation of technical efficiency [31]. Theoretically, this quantity allows the farmer to be on the frontier of production (assuming the optimal use of the other inputs); therefore, penalizing overconsumption above this amount ensures optimal income by reducing costs and water waste.

In the agricultural sector, the stochastic frontier is preferred for estimating technical efficiency. The most common measure of technical efficiency is the ratio of observed production to potential production frontier:

$$E_i = q_i/\exp(x_i\beta + v_i) = \exp(x_i\beta + v_i - u_i)/\exp(x_i\beta + v_i) = \exp(-u_i) \quad (1)$$

where E_i is the efficiency of the nth cell of the grid; q_i is observed production at the nth cell of the grid; v_i is a random error term due to statistical noise which can be positive or negative with an average of 0, and u_i is a non-negative variable representing the effect of the inefficiency of production and is independent of v_i.

Thus, E_i determines the production of the nth cell of the grid that could be obtained if it were completely efficient under the same production conditions and with the same inputs; E_i has a range of 0–1, representing inefficiency and total efficiency, respectively [32].

The parameters of the estimated function are evaluated by the likelihood maximisation method. The model follows:

$$\ln(\text{yield})_i = \beta_0 \ln(a) + \beta_1 \ln(\text{Q water})_i + \beta_2 \ln(\text{inputs1})_i + \beta_3 \ln(\text{inputs2})_i + \beta_4 \ln(\text{labor})_i + \varepsilon_i \quad (2)$$

where A is a constant; yield is farm citrus production in t/ha; $\varepsilon_i = v_i - u_i$; v_i is a random error term; u_i is an error term representing the inefficiency of the producer by zone; and inputs used in the production process are classified into three groups: Q water is irrigation water consumption per m^3/ha, inputs1 are defined as the values of production inputs such as fertiliser and pesticide, etc. in Tunisian Dinars (TND). Inputs2 are defined as the quantities of nitrogen, phosphate etc. consumed in kg/ha, and labour is family and occasional measured in working days/ha.

3. Empirical Model

3.1. ATP Using Residual Value Method

The ATP is what an individual is willing to give in order to benefit from goods, a service, or the benefits of a project [33]. The fundamental economic concepts for the ATP comprise the demand function and the consumer's surplus, as well as the production function and producer's surplus. The difference between the actual price and the ATP is the surplus; thus, the value that individuals attach to a rare non-tariffed resource and the services it provides may be estimated through the concept of ATP [34].

To apply the residual imputation method, we proceed from the production function to measure the irrigation water economic value by presuming that producers can predict the optimal production function and the prices of the outputs and inputs other than water; thus, we aim to estimate the value of irrigation water and identify inefficiencies in its use and management at the microeconomic level. Farmers' behaviour can be explained in different ways; nevertheless, in our analysis, we focus on profit maximisation in a competitive environment—the farmer will continue to use inputs until the marginal income of an additional unit equals its marginal cost [345]. The economic value of a non-tariffed good, such as water, is determined by isolating the contribution of water in the total value [36].

The determination of ATP via the residual imputation method is, therefore, based on the profitability of irrigated land as the basis for water pricing. It is assumed that all markets are competitive except for water and that the value of the final product equalises the opportunity cost of all inputs [35,37]. In our study, the ATP was calculated for the following: the input average values for the entire sample [25], the sub-sample whose water consumption is less than the optimal quantity, the sub-sample whose consumption is equal to the optimal quantity, the sub-sample whose consumption is greater than the optimal quantity and for the most efficient farms. From the ATP for these samples, the current surpluses, benefits, and profits generated per m^3 used are estimated for each sample. Then, by varying the price for the overconsumption of water, the impacts of this variation on the surpluses, profits and water allocation are re-estimated (See Appendix A).

3.2. Analysis of the Demand Curve and Price Elasticity

The price elasticity of demand can vary according to the different demand curve segments [12,18] and the price elasticity of irrigation water demand has been estimated for different countries. A meta-analysis of 24 studies published in the United States between 1963 and 2004 shows an average price elasticity of −0.48 [38]. Jeder et al. [39] estimated that increasing the price by more than 17% is not effective on water consumption against a decline in farm income. The main reason for water demand inelasticity is that the current price is low [40].

Huang et al. [19] found a gap between water price and its value, which is measured as the increase in farm income for an additional unit of available water. In countries such as China, the United States, India, Spain and Tunisia, irrigation water prices are lower than economic returns for various crops and, in such cases, farmers will not react to any increase in the water price as long as the level of water value is not reached. In this case, unless the price of water reaches the level of economic profitability, in the short run, farmers will use all available water.

Therefore, irrigation water prices must be significantly increased to induce significant water savings. In regions where policymakers are considering a pricing policy, the relevant question is how much the price of water has to be raised to reach the expected level of water-saving. To determine this, policymakers need to understand both the price elasticity of water demand and the value of water. Another key component is progressive pricing—a relatively low water price up to a certain amount (i.e., a quota) and then a much higher price for any quantity exceeding the quota [21].

Thus, we estimate that determining the optimal quantity, the economic value of water via the ATP and the price elasticity of water demand is crucial to an effective water-pricing policy. The price elasticity has been estimated as follows:

$$\ln Q = \ln a + \beta \ln P \tag{3}$$

where Q is the quantity of water consumed in m^3/ha, P is the cost of m^3 in TND, β is elasticity and a is the standardisation constant. A great advantage of the log–log specification is that the estimated coefficients can be interpreted as elasticities (the "constant elasticity model" or elasticity of y with respect to x):

$$(\partial y/\partial x) \times (x/y) = (\partial y/y)/(\partial x/x) = [\partial(\ln(y))]/[\partial(\ln(x))] = \beta \tag{4}$$

Since $[\partial(\ln(y))]/\partial y = 1/y$, thus, $\partial y/y = \partial[\ln(y)]$.

Like the standardised coefficients, the coefficients of a log–log model can be compared across the independent variables, since elasticity is expressed in the same units (i.e., in terms of percentage deviations of y and x).

3.3. Study Area and Data Collection

The study is based on the analysis of survey results. A three-stage sampling procedure was implemented to select a representative sample of the farmers for the survey. In the first stage, Nabeul Governorate was purposely selected based on the production status of citrus in comparison with the rest of the governorates. In the second stage, two delegations—namely, Bny khaled and Menzel Bouzelfa—were purposely selected based on the number of citrus producers and the irrigated water problem. Finally, simple random sampling was employed and a total of 147 respondents were selected randomly from the selected two delegations. The survey was performed during the 2019–2020 cropping season (Figure 1). The citrus activity consumes irrigation water during the peak period (summer); this generates an important competition between agricultural/urban users and intra-agricultural users whose water consumption amounts vary according to their expertise, the water source distance (hence the choice of two delegations, the delegation of Menzel Bouzelfa is closer than Bny Khalled, which would allow us to compare) and local water management (e.g., water distribution time, the duration of access to the resource and number of irrigations); thus, this context reinforces the economic value of water and hence the need to value it and improve its distribution to ensure better equity in its allocation. The choice of the Nabeul Governorate is justified by its importance in constituting more than one-third of national citrus production [41]. We collected data on farm characteristics (e.g., area, number of feet, surface and underground water sources, salinity and energy sources), citrus farmers (e.g., age, sex, education, tenure, activity, specialisation, diversification, family situation, knowledge and training), farming system (e.g., mechanisation, labor, production assets, investment in inputs) and production.

However, to assure the reliability and validity of our research, which is essentially to ensure that our data are sound and replicable, and the results are accurate, two factors have been considered:

1. We selected Nabeul Governorate for this study; this is justified by the importance of this region in two issues: Agricultural water over-consumption and use, and its high contribution to the national production of citrus; in fact, it is constituting more than one-third of national citrus production.
2. The selected sample is representative, and it is considered statistically significant. In addition, we tried to collect all relevant data such as farm characteristics (e.g., area, number of feet, surface and underground water sources, salinity and energy sources), citrus farmers (e.g., age, sex, education, tenure, activity, specialisation, diversification, family situation, knowledge and training), farming system (e.g., mechanisation and labor capital investment in inputs) and production.

Figure 1. Study area. Source: Institut de Recherche sur le Maghreb Contemporain (2022).

4. Results and Discussion

In this section, we deal with the following. (1) Determining the average optimal quantity from the technical efficiency scores. (2) Current situation analysis: distribution of water consumption, ATP and benefits. (3) The impact of price policy on water demand considering the price elasticity. (4) Simulating the following scenarios: (i) penalisation and reallocation of overused water; (ii) penalisation, reallocation of overused water and technical efficiency improvement; and (iii) maximised technical efficiency. In the last part of this section, we compare these scenarios in terms of water consumption, average yields, benefits and relative technical efficiency scores. The Lorenz curves allow us to analyse the resource reallocation impact and the improvement of the efficiency of the distribution of the benefits.

4.1. Determination of Water Optimal Quantity, Yield, ATP and Technical Efficiency

Through the determination of the stochastic production frontier and the technical efficiency scores, the optimal quantities of water are estimated to ensure the potential yield. To do this, production and water consumption volumes are analysed for farms with an efficiency score of 0.8–1. Table 1 and Figure 2 show that the optimal yields and the best scores correspond to a volume of 5000 m^3/ha. Above this volume, the revenues and technical efficiency scores decrease; therefore, penalising over-consumed volumes will push farmers to readjust their quantity without deteriorating their welfare. The graph comparing the technical efficiency scores, the water quantities per ha and the ATP (Figure 3), reinforces this hypothesis: with 5000 m^3/ha, farmers should be able to generate the best ATP and irrigation water use.

Table 1. Descriptive statistics of water used quantities, yields and ability to pay (ATP) for the most efficient farms (efficiency scores ≥ 0.8).

Descriptive Statistics	Water Quantity (m^3/ha)	Yield (t/ha)	ATP (TND/m^3)
Number of farmers with technical score ≥ 0.8 (ET)	24	24	24
Mean	4935	48	3.246
Standard deviation	1840	9	1.123
Minimum	2000	34	0.862
Maximum	9990	70	5.467
Percentiles% scores ET 25	3680	40	2.664
Percentiles% scores ET 50	4900	47	3.212
Percentiles% scores ET 75	5880	56	3.901

Source: Own elaboration based on model results (2022).

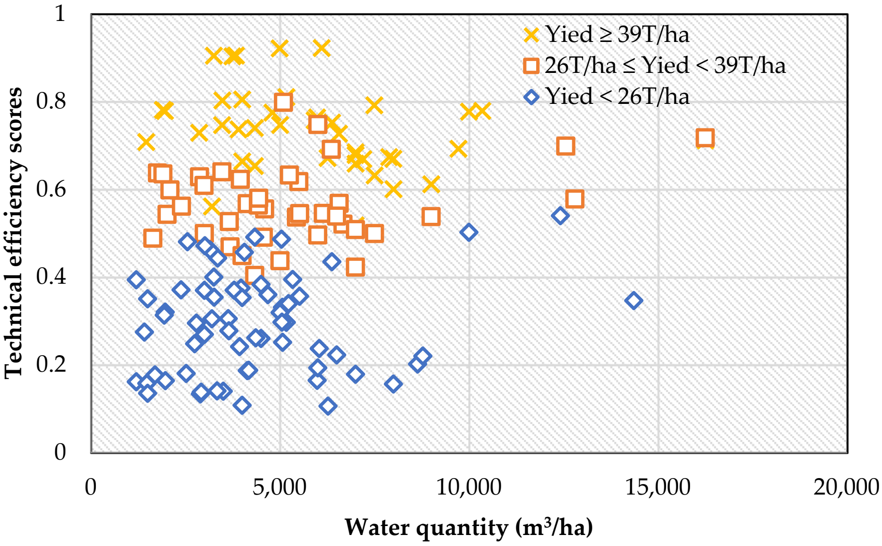

Figure 2. Technical efficiency scores per quantity of water consumed and average yields. Source: Own elaboration based on model results (2022).

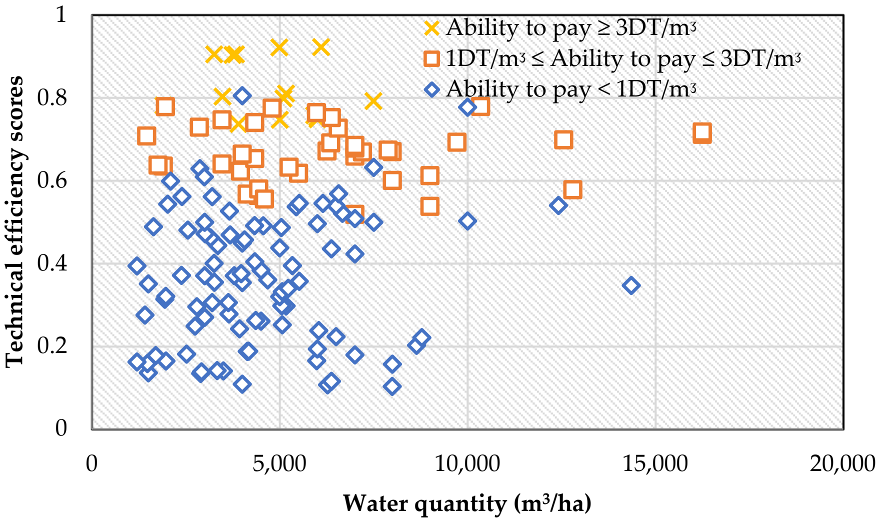

Figure 3. Technical efficiency scores per quantity of water consumed and ability to pay. Source: Own elaboration based on model results (2022).

4.2. Water Consumption, ATP, Benefits and Surplus

The analysis of the current situation shows that farmers who over-consume water represent 52.1% of the overall sample (Table 2); this sub-sample consumes 68.2% of available water resources and creates only 58.8% of total production. With an average yield of 33 t/ha, these farmers remain far from the average yield of efficient exploitation (i.e., 48 t/ha). In contrast, the farmers whose consumption is equal to the optimal quantity constitute 3.4% of the sample, consume 3.2% of the available water resources and produce 4.4% of the total production. Furthermore, 44.5% of the sample do not profit from a sufficient quantity to produce high yields. Indeed, the average water consumed is 3396 m^3/ha, representing 28.5% of total available resources; this current situation reflects wastage, low productivity of irrigation water for the first sub-sample and inequitable water distribution. In fact, the available water resources would allow each farm to benefit from 5297 m^3/ha and generate better yields, particularly if this allocation is accompanied by technical efficiency increase and improved cultural practices. In addition, this situation leads to an inequitable agricultural welfare indicator, very low or even negative, for the sub-sample whose consumption is less than 5000 m^3/ha. The sample characterised by water overconsumption certainly has good welfare indicators but is lower than the potential optimum as the result of water resource wasting; therefore, to persuade them to readjust their water consumption and improve their technical efficiency, it is proposed to penalise over-consumed quantities using the price elasticity of demand. The first impact of this penalisation is to decrease this sub-sample's income but considering the ATP in determining the penalty would allow proposing lower prices than the ATP.

Table 2. Description of the ability to pay (ATP), benefit, water quantity (Q water) and yields.

Water < 5000 m^3/ha	ATP (TND/m^3)	Benefit (TND/ha)	Q Water (m^3/ha)	Yield (t/ha)
Number of farms	65	65	65	65
Mean	−0.76	164	3396	24.73
Std deviation	2.83	8870	941	13.64
Sum	−11.68	10,676	220,738	1607
% Total number	44.50	44.50	44.50	44.50
% Total sum	14.80	2.000	28.50	36.80

Water = 5000 m³/ha	ATP (TND/m³)	Benefits (TND/ha)	Q Water (m³/ha)	Yield (t/ha)
Exploitations number	5	5	5	5
Mean	2.39	11,424	5000	38.400
Std deviation	1.51	7764	0.000	12.116
Sum	11.95	57,120	25,000	192.000
% Total number	3.40	3.400	3.4	3.4
% Total sum	15.20	10.700	3.2	4.4
Water > 5000 m³/ha	**ATP (TND/m³)**	**Benefits (TND/ha)**	**Q Water (m³/ha)**	**Yield (t/ha)**
Exploitations number	76	76	76	76
Mean	1.03	6108	6942	33.79
Std deviation	1.27	8240	1835	11.69
Sum	78.40	464,264	527,576	2568
% Total sum	52.10	52.10	52.10	52.10
% Total number	99.70	87.30	68.20	58.50
Global Sample	**ATP (TND/m³)**	**Benefits (TND/ha)**	**Q Water (m³/ha)**	**Yield (t/ha)**
Exploitations number	146	146	146	146
Mean	0.54	3644	5297	29.91
Std deviation	2.22	9067	2274	13.39
Sum	78.68	532,042	777,314	4367
% Total number	100	100	100	100
% Total sum	100	100	100	100

Note: The sample and subsamples with consumption >5000 m³, equal to 5000 m³ and <5000 m³. Source: Own elaboration based on model results (2022).

4.3. Price Elasticity of Irrigation Water Demands and the Impact of Pricing Policy

The analysis of the demand reaction giving the m³ cost variation shows that demand is inelastic below a defined threshold (quantity lower than 5000 m³/ha and cost of m³) lower than 0.15 TND/m³) (Table 3). The price increase would not affect agricultural water use but only reduce citrus farmers' welfare (price = 0.136 TND/m³); however, for a price of 0.15–0.3 TND/m³ and from 6000 m³/ha, there is a relative price of elasticity of demand. Thus, a 1% price increase may result in a 0.712% water consumption reduction. By considering this segment, we analyse the impact of penalties of 0.136, 0.2 and 0.3 TND/m³. From this last price, we find that an inelastic segment of the water demand curve, with further increases in price, no longer leads to resource-saving. The calculation of the ATP in advance (1.031 TND/m³), allows us to determine the room for manoeuvre in the price proposal, so citrus farmers remain able to generate positive profits.

Table 3. The different segments of the irrigation water demand curve and price elasticity.

Segments of Demand Curve	Demand Price Elasticity
Total sample	−0.0571 **
cm³ > 0.15 TND/m³	−0.0903 *
cm³ > 0.15 TND/m³ and Q water > 5000 m³/ha	−0.0492 **
0.15 TND/m³ ≤ cm³ ≤ 0.3 TND/m³ and Q water > 6000 m³/ha	−0.7122 **
cm³ > 0.3 TND/m³	−0.0281

Note: * Significant level at 10% and ** significance level at 0.05%. Source: Own elaboration based on model results (2022).

Table 4 summarises the proposed prices and impacts on water distribution and agricultural welfare. A penalty of 0.136 TND/m^3 for quantities exceeding 5000 m^3/ha is an increase of 0.036 TND/m^3 compared to the current price (0.1 TND/m^3); therefore, this penalty is considered ineffective. A penalty of 0.2 TND/m^3 leads to a reduction in overconsumption of water by 18.25%, which would allow the sub-sample, whose consumption is less than 5000 m^3/ha, to benefit from 3810 m^3/ha (an average increase of 414 m^3/ha) but remains below the optimum quantity. When penalising overconsumption at 0.3 TND/m^3 and considering the price elasticity of agricultural water demand, the quantity wasted could be reduced by 44.56%, allowing an average increase in the quantity of 1013 m^3/ha and consumption would be augmented from 3810 to 4409 m^3/ha (Table 4).

Table 4. Comparisons between different prices.

Impact on the Overused Water	No Impact	Reduction 18.25%	Reduction 44.56%
Q m^3/ha/exploitation with consumption >5000 m^3/ha	6942	6588	6075
Q m^3/ha/exploitation with consumption <5000 m^3/ha	3396	3810	4409
Impact on profit (TND/ha)	6038	5914	5720
Impact on profit (TND/m^3)	0.918	0.903	0.879
Impact on surplus (TND/ha)	3026	2964	2830
Impact on ATP (TND/m^3)	1.022	1.007	0.983

Note: Price: current, equal to cost on the inelastic segment, increased by 100% and 200% and their impact on the indicators of welfare for the sub-sample whose consumption is >5000 m^3/ha and water reallocation given the price elasticity of agricultural water demand. Source: Own elaboration based on model results (2022).

4.4. Wealth Assessment of Citrus Farmers: Gini Index (GI)

With the aim of assessing the wealth of citrus farmers, the following formula is used:

$$G = 1 - \sum_{k=o}^{n-1} (X_{k+1} - X_k)(Y_{k+1} + Y_k) \tag{5}$$

where X is the cumulative percentage of the population (farms) belonging to our sample, Y is the cumulative percentage of profits and n−1 is farms with profit y_i for i of n−1and $y_i \leq y_i + 1$.

The Gini index allows for analysing wealth distribution disparity in a given community (in our case, benefits for citrus farmers); the closer it is to 1, the greater the wealth inequality and conversely for Gini index = 0. We calculated this indicator for three situations (Table 5).

The current situation is characterised by the fact that 44.5% of our sample have access to only 28.5% of available water surface resources, generates an average yield of 24 t/ha, and have an average benefit of 164 TND/ha; this situation is described by a large wealth distribution inequality with Gini index = 0.644 (Table 5). The Lorenz curve shows that 40% of our sample does not have significant positive benefits. We can assume that inequitable water distribution is one of the reasons. In contrast, 15% of the sample receives 50% of the cumulated benefits. In the scenario in which there is a response to the penalisation, the water overuse is reduced by 44.56%, and this quantity is reallocated to the sub-sample damaged by the current water distribution; thus, the average quantity for this group (44.5%) will rise from 3396 to 4409 m^3/ha, and for the second group, the average amount of water will reduce from 6942 to 6075 m^3/ha.

Table 5. Gini index results.

Situation	Gini Index Value	% Sample	Water (m³/ha)	Average Yields (t/ha)	π (TND/ha)	ET Score
Initial before penalisation	0.664	44.5	3396	24.73	146	0.694
		55.5	6942	33.79	6108	0.609
Average values after penalisation and reallocation of reductions in over-consumed water	0.145	44.5	4409	32.61	6320	0.687
		55.5	6075	43.42	13,164	0.790
Optimised values, technical efficiency improvement after penalisation and reallocation of reductions in over-consumed water	0.094	44.5	4409	44.00	14,897	0.840
		55.5	6075	50.00	17,786	0.850
Perfect equality and technical efficiency maximised	0	100	5297	60.00	23,250	0.900

Source: Own elaboration based on model results (2022).

For our calculation and Lorenz curve estimation, we consider the average values of yields and benefits obtained from these quantities. In this scenario, the Gini index decreases to 0.145, showing that a better water reallocation can improve wealth distribution equality. In addition, the Lorenz curve shows that currently, 45% of the sample possess 30% of the accumulated benefits; however, after penalisation, if the same water reallocation is accompanied by technical efficiency maximisation for both groups, then the Gini coefficient becomes very low (0.094); this corroborates our conclusions: a penalisation can reduce distribution water inequity accompanied by optimisation of water and other input use and improve welfare for the whole sample and the equality of wealth distribution with the result that 50% of cumulated benefits are received by 55% of farmers (Figures 4–6).

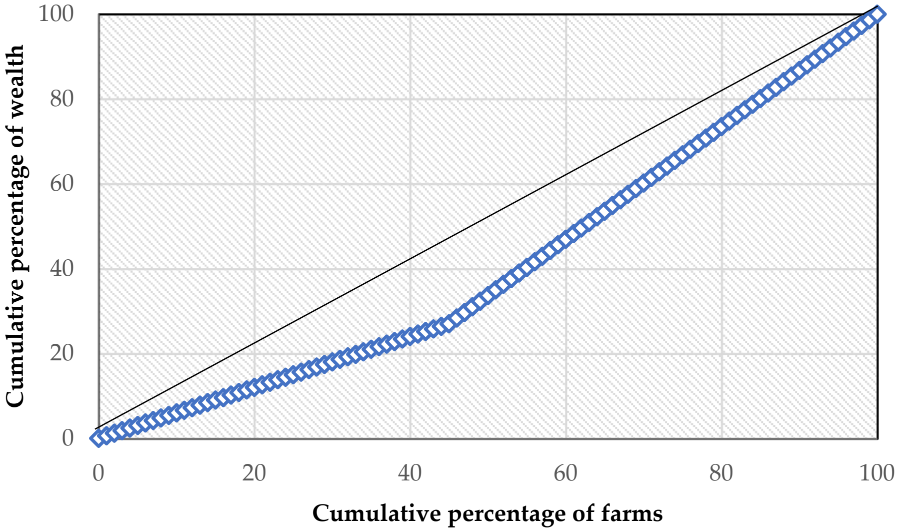

Figure 4. Lorenz curve for the current situation. Source: Own elaboration based on model results (2022).

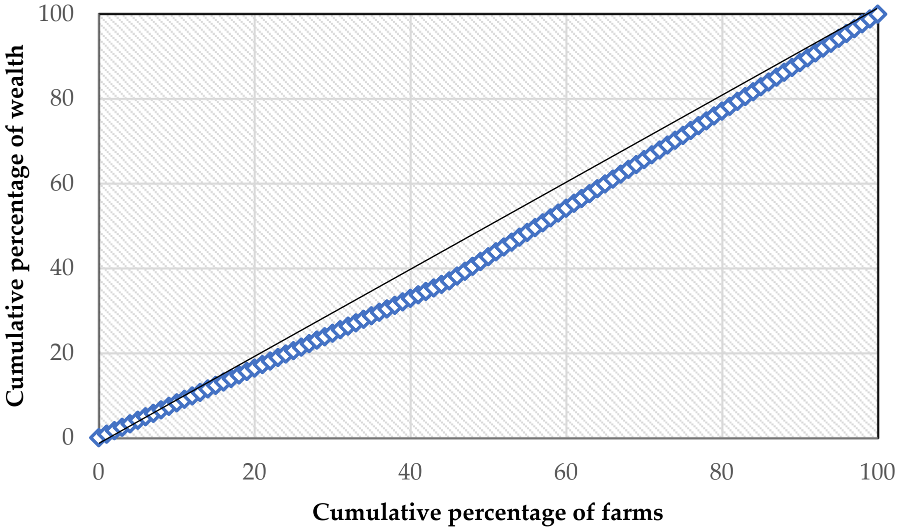

Figure 5. Lorenz curve for average values after penalisation and reallocation of reduced over-consumed water quantities. Source: Own elaboration based on model results (2022).

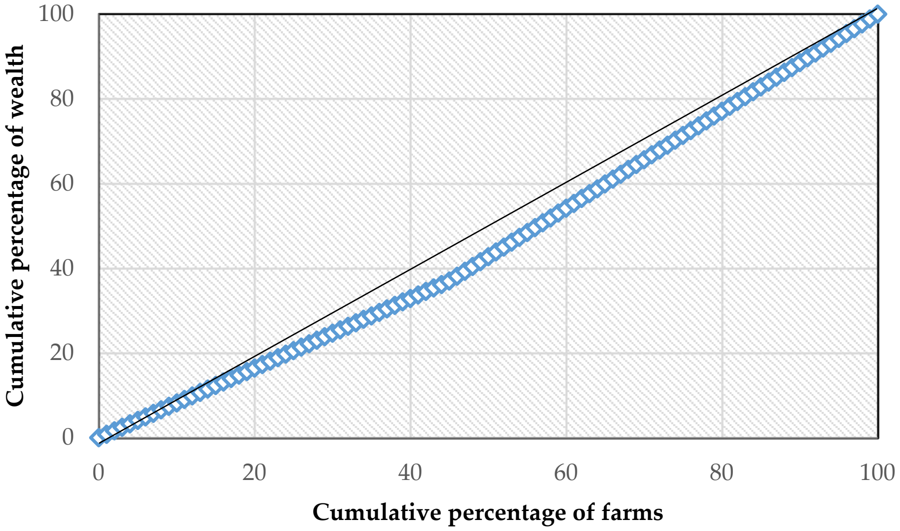

Figure 6. Lorenz curve for optimised values, technical efficiency improvement after penalisation and reallocation of reduced over-consumed water quantities. Source: Own elaboration based on model results (2022).

5. Concluding Remarks and Policy Implications

The purpose of this study is to analyse the Tunisian farmers' ATP in a citrus area and propose a penalising price strategy based on a block-pricing process to guarantee both water management and citrus sector sustainability. Our results show that the current price is far from its marginal value—the ATP. The penalty that would guarantee a perfect elasticity must be greater than the ATP, for any quantity above 5000 m^3/ha. When paying a price higher than the ATP, farmers begin suffering financial losses. Therefore, optimally, they will react by reducing their water consumption to 5000 m^3/ha and avoiding resource waste; however, such a price can be unrealistic, inapplicable and lead to significant discontent. The determination of crop water's optimal quantity is a crucial detail, requiring crop essential water needs and allowing the highest yields and benefits. From this amount, we can estimate wasted quantities and apply a pricing policy that does not deteriorate agricultural welfare.

Estimation of ATP, Gini coefficient, Lorenz curve, average profits and surplus allow us to analyse the current situation and the impact of inequitable actual water distribution on citrus farmers' welfare and also to propose a penalty that does not exceed their ATP and so allow them positive profits. In our study area, the penalisation of water overconsumption, accompanied by an adjustment of farmers' behaviour seems to improve water management and allow a better equity in its allocation and in wealth distribution; this is an incentive to save and reduce waste for sustainable irrigation water management. In addition, penalisation can improve agricultural welfare for the global sample if they respond to it correctly. Nevertheless, the degree of improvement also depends on the valuation of consumed water and its productivity with better yields. It is, therefore, essential to raise the technical efficiency level, to optimise input utilisation alongside any pricing policy. Until this well-developed volumetric system comes into practice, the existing system of assessment based on crop-wise irrigated areas must be rationalised and simplified. The concept of water as a free good needs to be replaced and revenue collection must be strict, which will inculcate a habit of paying water taxes among the farmers. The time has come to move from the vision of the national water policy to focus more on the action and make water everybody's concern. Nationally coherent water policy and proper plans for infrastructure development are required when resorting to any type of irrigation water-pricing mechanism in Tunisia.

An efficient volumetric pricing system in the target area in particular, and in the Tunisian irrigated area in general, can be developed if a considerable investment is made in irrigation water supply infrastructure and the development of an operational plan which has a good balance between efficiency and equity objectives. Irrigation authorities must be willing to take on greater responsibility for irrigation system management. In all cases, these institutions and their functional policies need to address such socioeconomic concerns as a prerequisite if farmers are to accept price mechanisms for allocating remaining water to economic use; this will require a guaranteed mechanism for the regularity of the water supply to reduce farmer insecurity and also strengthen the extension system, support for farmers, training, awareness-raising, water scarcity awareness and improving the efficiency of citrus farmers.

Finally, it is worth noting that our study has some limitations where improvements can be undertaken in regard to future work. First, the risk associated with the stochastic production function and the ATP price was not considered in this research paper. The risk factor could be embedded in the error term, but it would be better to be considered as a separate factor linked to uncertainty in the water supply. Second, the wealth level is heterogenous and the analysis should go further to develop a set of representative farms for alternative levels of wealth; this could be possible through a set of different variables (farm size, the quantity of water used, water infrastructure capital, etc.) and with different penalisation regimes. Finally, considering larger sample size will certainly give more reliable results with greater precision and power.

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Appendix A

As displayed in the previous section, from the ATP for the selected samples, the current surpluses, benefits, and profits generated per m^3 used, are estimated for each sample. The framework consists of varying the price for the overconsumption of water. With this, we re-estimated the impacts of this variation on the surpluses, profits and water allocation. Thus, the estimated profit function is specified as follows:

$$\pi = RT - CT$$

$$\pi(Q) = RT(Q) - CT(Q)$$

where Q is water quantity consumed.

The producer's problem is to choose a level of production that maximizes their profit.

The first- and second-order conditions are applied as follows:

$$dp/dq = 0$$

$$d^2p/dq^2 < 0$$

Maximizing profit means producing until marginal revenue equals marginal cost. Nevertheless, firms operating in an imperfectly competitive environment often opt for a maximizing total revenue strategy.

By applying first- and second-order conditions:

$$dRT/dq = 0$$

$$d^2RT/dq^2 < 0$$

and assuming that firms are price takers (the price of water is fixed), the income and profit functions are derived as follows:

Total income:

$$RT(y) = y \times Py$$

The profit function:

$$\pi(y) = RT(y) - CT(y) = y \times Py - CT(y) \quad \text{(A1)}$$

where CT(y) is a long-term cost function including all costs including the cost of water: P(water) × Q(water).

The equation of y is expressed as follows:

$y = f(x_i)$: y (citrus yields in t/ha) according to all factors of production except water [Q(water)], and the profit function takes the following expression:

$$\pi = y \times Py - [\Sigma^{n}_{i=1} (x_i \times Px_i) + \{P(water) \times Q(water)\}] \quad \text{(A2)}$$

where Py is the selling price in Tunisian Dinar TND (1 TND = 0.35 USD) of a yield unit (TND/kg); x_i is a vector of other inputs, e.g., labor (number of days/year/ha), treatments and fertilizer (kg/ha) and land (TND/ha); Px_i is the market price of x_i, with the price of family labor considered by its opportunity cost and the price of land by its opportunity cost if it was rented; P(water) is water price in TND/m^3 and Q(water) is the quantity of water consumed in m^3/ha.

By deriving the profit function:

$$d\pi/dQ(water) = [Py \times \{df(y)/dQ(water)\}] - P(water) = 0 \quad (A3)$$

where df(y)/dQ(water) is the marginal product of water (P (water)) and Py × [df(y)/dQ(water)] is the value of the marginal product of water defined as the price of output multiplied by the physical productivity of water if all factors of production are exchanged in a competitive market.

Thus, because the value of the last used m^3 must equal its price:

$$P(water) \times Q(water) = y \times Py - (\Sigma^{n}_{i=1} x_i Px_i + \pi) \quad (A4)$$

The residual obtained after subtracting the costs (excluding water) from the total annual income is the gross margin and can be interpreted as the maximum amount the farmer can pay for water while covering all production costs.

$$P(water) = [y \times Py - (\Sigma^{n}_{i=1} x_i Px_i + \pi)]/Q(water) \quad (A5)$$

Thus, the ATP is given by:

$$P(water) = [(RTDkg/ha \times px/kg) - (C\ energy/ha + C\ work/ha + C\ nitrogen/ha + C\ potash/ha + C\ phosphate/ha + C\ treatment/ha + C\ manure/ha + C\ land)]/Q(water)/ha \quad (A6)$$

With QM the average water consumption for one hectare, the surplus is given by the following:

$$Average\ Sc = [(CAP - current\ water\ price) \times (QM)]/2 \quad (A7)$$

The benefits are estimated:

$$BN = RT - [C(water) + C(x_i)] \quad (A8)$$

The profits per m^3 in TND are calculated as follows:

$$Gross\ margin/m^3{:}\ BN = (RT - CT)/allocation\ (ha) \quad (A9)$$

The penalty concerns over-consumed quantities (greater than the optimal quantity), and the new cost of water would be:

$$CT'(water) = P \times Qop + P' \times Qexc \quad (A10)$$

where P is the current price of water in TND/m^3, P′ is the proposed penalty, Qop is the optimal quantity, Qexc is the over-consumed quantity and RTD is the initial average yield in t/ha.

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