To what extent corruption and free-riding behavior affect technical and water use efficiency of small-scale irrigated farms

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Abstract

This paper examines irrigation management within the Tunisian Water Users Association (WUA) in Nadhour, a public irrigated area in central Tunisia. How well 14 WUAs operated was evaluated based on surveys and related interviews. The methodology of this study consisted of two main steps: (i) an estimation of the technical efficiency scores of 90 smallholder farmers and the sub-vector of WUE (Water Use Efficiency) using a nonparametric DEA model, and (ii) a regression of a Tobit model to test the hypothesis regarding explanatory variables of differentiated technical efficiency scores. The investigation showed an average technical efficiency of 70.8% and WUE of 64.8%. It highlighted the water turn, state of infrastructure, water supply shortage, corruption and free-riding behaviors as factors tightly correlated with a farm's productivity. This suggests that there is potential to improve production efficiency by implementing targeted programs and rules for inefficient farmers. The findings of this study show that it is important to fight corruption in the water sector by increased government oversight, reformed regulations that stimulate performance, and increased accountability towards citizens through greater participation in decision making.

Keywords: *Water Users Association, Corruption, Free rider, Technical efficiency, Tobit model, Public irrigated area.*

1. Introduction

Growing water scarcity in many countries has put pressure on irrigation systems, as the main consumptive user, to release water for other uses and improve performance (Malano *et al.*, 2004). Currently in Tunisia, water resources are facing both ever-growing demand and greater numbers and types of crises and challenges. Often shortages due to a lack of water resources but to governance failures, such as institutional fragmentation, lack of coordinated decision-making, corruption, and deficiency of transparency and accountability, thus resulting in a shortage of access to water. Governance systems are rarely able to prevent corruption which provides incentives for unethical or even illegal behavior.

In recent decades, the Tunisian government has undertaken massive reforms to address rural poverty and inequalities. It has adopted ambitious new water legislation that promotes equity, sustainability, representativity, and efficiency by decen-

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tralizing water management. This led to empowering users by allowing them to manage irrigation water through associations (Bachta and Zaïbet, 2006). Since then, irrigation water management was handed over to local Water Users Associations (WUAs) to allocate. However, transferring control over resources from state to local organizations does not necessarily lead to greater participation and empowerment of all stakeholders. While there may be many ways of identifying groups that are frequently marginalized, this may widely affect farms' productivity. Most WUAs are in crisis and offer poor service to their members. Thus, these associations have failed to achieve their primary goal and objective: managing water resources equitably, efficiently, and sustainably (Abdelhafidh and Bachta, 2016; Mahdhi *et al.*, 2011; Chemak and Dhehibi, 2010; Belloumi and Salah Matoussi, 2007; Dhehibi *et al.*, 2007; Albouchi *et al.*, 2003).

Improving efficiency and irrigation water productivity has become the core concern of Tunisian's policy makers through the "Water for life" strategy, an ambitious goal of improving conservation, efficiency and productivity of water use. Assessing water use inefficiency in the irrigation sector is essential to be able to use water more wisely and sustainably.

This paper focuses specifically on the situation of various smallholding irrigation systems located in Nadhour in central Tunisia. These small farms face numerous technical and social constraints and have been the subject of several studies of irrigation systems in Tunisia (Abdelhafidh and Bachta, 2016; Albouchi *et al.*, 2003; Mahdhi *et al.*, 2011; Belloumi and Salah Matoussi, 2007; Chemak and Dhehibi, 2010; Dhehibi *et al.* 2007; Frija *et al.*, 2017). However, none of the studies have yet examined the effects of corruption and free-riding behavior on these farms or their implication on the productivity of farmers who are members of WUAs.

Within this perspective, the primary aim of this study is to develop objective estimates of the technical efficiency of 90 irrigated farms in central Tunisia based on the input-output relationship originally suggested by Farrell (1957). The second objective is to analyze the determinants of technical and water use efficiency with an emphasis on corruption and free-riding behavior.

2. Water resource: scarce and unevenly distributed

Water resources in Tunisia are characterized by scarcity and the pronounced unevenness of surface and groundwater distribution which result from climate and geography. Tunisia receives 230 mm/year of rainfall on average, the equivalent of 36 billion cubic meters. However, this volume varies from year to year depending on drought conditions.

Between the Mediterranean Sea in the north and the Sahara Desert in the south, the climate of Tunisia fluctuates widely. Consequently, this makes rainfall both scarce and unequally distributed spatially and over time. Annual precipitation varies from 594 mm on average in the north to 289 mm in the center, to only about 150 mm in the south. The ratio between the highest observed values of precipitation and the lowest varies from 4.4 in the north to 15.8 in the south, illustrating the temporal irregularity and variability of rainfall (Benabdallah, 2007). Surface water resources are estimated at 2,700 million m^3 per year distributed over three natural areas distinguished by their climatic and hydrological conditions. The north provides relatively regular contributions of 2,190 million m^3, representing 82% of the total surface water potential while covering only 16% of the country. The central region, making up 22% of the country's area, is characterized by irregular resources. It provides 12% of the total surface water potential. The southern part of the country, which accounts for approximately 62% of the total area, is the poorest in surface water. It provides very irregular resources at 190 million m^3, only 7% of the country's total surface water potential. Water quality also varies across the country with 82% of the water resources in the north considered good quality, 48% considered so in the center, and only 3% in the south. The groundwater resource is estimated at 2,125 million m^3, 745 million m^3 of which is confined within 212 shallow aquifers and the rest in 267 deep aquifers, 50% of them non-renewable. It is estimated that 650 million m^3 of this resource, located mainly in the south, is non-renewable. Groundwater is also characterized by unequal distribution and variable quality regarding salinity. While the north has 55% of the shallow groundwater resources, the center has only 30% and the south 15%. However, the south has more of the deep groundwater resources at 58% whereas the north and center only have 18% and 24%, respectively. The treated wastewater resource is estimated at 120 million m^3 that is still misallocated. Currently, about 8,000 hectares are being used as orchards and for livestock feed. With expanded urban and land development, the volume of treated wastewater used is expected to grow to 450 million m^3 in 2030, the equivalent of 10% of the total conventional resources of the country, making it possible to irrigate 100,000 hectares (Ministry of Agriculture, 2010).

Agriculture, which accounts for approximately 12% of the GDP, is the largest consumer of water (80%) from the available resources. Today, about 450 thousand hectares (9% of useable agricultural land) are irrigated in Tunisia (Ministry of Agriculture, 2010). The volume of water used for irrigation is estimated at 2,100 million m^3, with average consumption per hectare of approximately 5,500 m^3/year. Consumption reaches 20,000 m^3/hectare/year in the southern oases whereas is about 4,000 m^3/hectare/year in the north. Irrigation supports 35% of total agricultural production, 22% of export crops and 26% of agricultural employment (Mahdhi *et al.*, 2014). In addition, the demand for water for domestic, touristic, and industrial purposes continues to increase. Drinking water demand was estimated at 400 million m^3 and 150 million m^3 for industry and tourism, respectively (Chahed *et al.*, 2014).

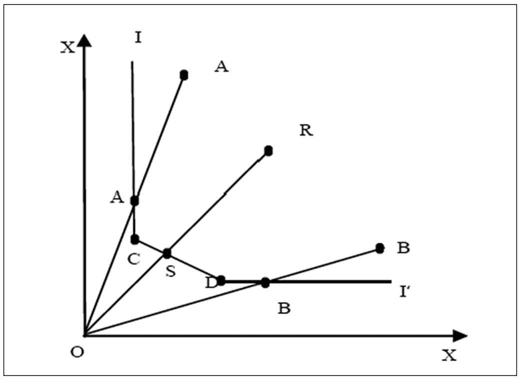
Conflict between various water users will become more and more acute in the future. There will be pressure on the agricultural irrigation sector to transfer water to the urban, industrial, and tourist sectors. The agricultural sector will need to compensate for the water shortage by boosting water conservation efforts and water efficiency programs. In recent decades, concerns regarding the efficient use of water resources in the country have increased. These concerns have been addressed particularly by transferring government water management systems to water user associations (Mahdhi *et al.*, 2014; Abdelhafidh and Bachta, 2016; Abdelhafidh and Bachta, 2017). WUAs were created with government financing to handle the smallholding irrigation systems. They are responsible for collecting both water usage and service-related fees such as those related to infrastructure maintenance.

3. Theoretical framework

According to economic theory, the concept of efficiency refers to the Pareto optimum. The first studies of technical efficiency of producers were carried out by Koopmans (1951) and Debreu (1951). According to Koopmans, efficiency in Paretian logic is as follows: if it is technologically impossible to increase an output and/or reduce an input without simultaneously reducing at least one other output and/or increasing at least one other input, the production plan chosen by the farm is technically efficient. The concept of productive efficiency was taken onby Farrell (1957). A farm is technically efficient if it produces a maximum output given the level of input usage and technology. Thus, the production possibility frontier is associated with the maximum level of output given a quantity of inputs, or the minimum number of inputs required to produce a given level of output. Technical inefficiency is attributed to a failure of the farm to produce the frontier level of output, given the quantities of inputs (Kumbhakar, 1994).

In Figure 1, it is assumed that there are two inputs (X_1 and X_2) used by a firm to produce a single output (Y) with the assumption of constant returns to scale. The II' curve represents the isoquant of fully efficient farms and could be used to measure TE. If the firm employs a quantity of inputs at point R to produce one unit of output, the technical inefficiency of that farm could be measured by the distance RS. This is the proportion by which the use of inputs could be reduced without a decrease in output. This is expressed in percentage terms by the ratio SR/OR, which stands for the percentage by which all inputs need to be reduced to gain a technically efficient production level. The TE of a farm is measured by the ratio: TE= OS/OR. If a firm has a TE equal to 1, it is technically efficient. The firm is technically inefficient if its TE value is

Figure 1 - Technical efficiency, radial adjustment, and slack identified.



less than 1. At point S, the firm could gain full technical efficiency because point S lies within the efficient production indifference curve.

The efficiency measures proposed by Farrell assume that the production function of a fully efficient DMU is known. However, it is generally unknown in practice, and relative efficiencies must be measured from the sample data available. Two approaches are used to estimate relative efficiency indices: the parametric or Stochastic Frontier production Approach (SFA) and the nonparametric or Data Envelopment Analysis approach (DEA) (Coelli, 1996). The SFA assumes a functional relationship between outputs and inputs and uses statistical techniques to estimate parameters for the function. It incorporates an error composed of two additive components: (i) a symmetric component that accounts for statistical noise associated with data measurement errors and (ii) a non-negative component that measures inefficiency in production (Coelli, 1996). The stochastic model specification of SFA also allows for hypothesis testing. The disadvantage of SFA is that it imposes specific assumptions on both the functional form of the frontier and the distribution of the error term.

In contrast, DEA uses linear programming methods to construct a piece wise frontier of the data, because it is nonparametric. DEA does not require any assumptions be made about functional form or distribution type. It is thus less sensitive to misspecification than SFA. However, the deterministic nature of DEA means all deviations from the frontier are attributed to inefficiency. It is therefore subject to statistical noise resulting from data measurement errors (Coelli, 1996). We chose the DEA approach in this study since it imposes no a priori parametric restrictions on the underlying technology (Chavas and Aliber, 1993; Fletschner and Zepeda, 2002; Wu and Prato, 2006).

4. Methodology

4.1. *Measuring efficiency*

As noted above, we intend to apply the DEA technique to measure the technical efficiency of farmers who are WUA members in the study area. In DEA, Technical Efficiency (TE) can be viewed from two perspectives. First, input-oriented TE focuses on the possibility of reducing inputs to produce given output levels. Second, output-oriented TE considers the possible expansion of outputs for a given set of input quantities. A measure of TE for a DMU can be defined as:

$$\theta^{\text{output}} = \frac{\text{actualoutput}}{\text{Maximumpossibleoutput}} \quad \text{in an output-oriented context, or} \qquad (1)$$

$$\theta^{\text{input}} = \frac{\text{Minimuminputpossible}}{\text{Actualinput}} \quad \text{in an input-oriented context} \qquad (2)$$

To quantify a measurement of TE, we need to find out the divergence between actual production and production on the boundary of the feasible production set. This set summarizes all technological possibilities of transforming inputs into outputs that are available to the organization. A DMU is technically inefficient if production occurs within the interior of this production set.

4.1.1. *Technical efficiency on farms*

Under the nonparametric approach (DEA), to estimate the production frontier, we consider the "input-oriented" model according to Coelli (1996). In this model, we have: n farms (i=1.… …n) each producing M outputs y_{mn} (m=1.…M) using K different inputs x_{kn}(k=1.…..K), each farm becoming the reference unit. For the i^{th} farm, we have vectors x_i (K*1) and y_i (M*1). Therefore, for the entire data set, we have a K*N input matrix X and M*N output matrix Y. Technical efficiency (TE) is measured by solving the CCR model initially proposed by Charnes *et al.* (1978). The CCR model is indicated in Eq. (3):

$$\begin{aligned} &\mathrm{Sc} \\ &-y_i + Y\lambda \geq 0 \\ &\boldsymbol{\theta x_i - X\lambda \geq 0} \\ &\lambda \geq 0 \end{aligned} \qquad (3)$$

Where θ_i is a variable representing the efficiency of the Reference Farm i and hence the percentage of reduction to which each input must be subjected to reach the production frontier λ is a vector of (k*1) elements representing the influence of each farm in determining the efficiency of the i^th^ farm.

4.1.2. *Measuring water use efficiency at farm level*

The economic approach to defining and measuring Water Use Efficiency (WUE) is based on the concept of input specific technical efficiency (Kaneko *et al.*, 2004). Thus, water use at farm level is used in combination with other inputs (land, labor, fertilizers, etc.) to estimate a production frontier which represents optimal allowance of the inputs used. This methodology aims to assess farmers' managerial capability to implement technological processes (Karagiannis *et al.*, 2003).

Using the notion of sub-vector efficiency proposed by Färe *et al.* (1994), the technical sub-vector efficiency for the variable input k is determined for each farm i by solving the following programming problem (Eq. (4):

$$\begin{aligned} &\mathrm{Min}_{\theta.\lambda}\theta^k \\ &\mathrm{Sc} \\ &-y_i + Y\lambda \geq 0 \\ &\boldsymbol{\theta^k x_i^k - X^k\lambda \geq 0} \\ &\boldsymbol{x_i^{n-k} - X^{n-k}\lambda \geq 0} \\ &\lambda \geq 0 \end{aligned} \qquad (4)$$

where θ_k is the input k sub-vector technical efficiency score for farm i. The terms x_i^{n-k} and X^{n-k} in the third constraint refer to x_i and X with the k^th^ input (column) excluded whereas in the second constraint, the terms x_i^k and X^k include only the k^th^ input. Other variables are defined identically as in Eq. (3).

4.2. *Tobit model*

The present study uses the Tobit regression to analyze the effect of factors on explaining TE. This approach has been used widely in efficiency literature (Speelman *et al.*, 2008; Abdelhafidh *et al.*, 2018; Chebil *et al.*, 2015). The values of the dependent variable lie in the interval (0-1). The censored Tobit model can then be used to get a consistent estimation. The Tobit regression used in our study is specified as follows:

$$\theta_i = \begin{cases} \theta_i^* \text{if } 0 < \theta_i^* < 1 \\ 0 \text{ if } \theta_i^* \leq 0 \\ 1 \text{ if } \theta_i^* \geq 1 \end{cases} \qquad (5)$$

Where θ_i are technical efficiency scores used as dependent variables. θ^*: is the value of an artificial variable (unobservable) that is related to explanatory variables (X_i) in the following relationship:

$$\theta_i^* = x_i\,\beta^* + \varepsilon_i \qquad (6)$$

Where: ε_i is the error term and β are parameters to be estimated.

The estimation of the Tobit model is based on the maximum likelihood procedure. For Tobit estimates to be consistent, residuals must be normally distributed (Holden, 2004).

5. Data and empirical procedures

5.1. *Study area*

The research was conducted in fourteen Irrigated Public Areas (IPA) in the Nadhour region of the Zaghouan governorate located in central Tunisia. The Nadhour IPA is facing growing problems of water scarcity. It is located in the semi-arid bioclimatic region with moderate winters. The average rainfall in the area is 400 mm/year with high annual variability and significant evapo-transpiration. The agricultural area of Nadhour is around 38,200 ha shared by about 1,925 farmers; 60% of the farm area is less than 5 ha and 28% ranges from 5 to 10 ha. The irrigated systems were installed in 1980 covering an area of about 3,050 ha. Most irrigated areas are devoted to summer crops such as watermelon, pepper, melon, and seasonal tomato. The average annual volume of withdrawal water is about 14 million m^3. Two-thirds of this resource is groundwater. Demand is managed by 34 WUAs. These WUAs sell water to users and ensure network maintenance. The volumetric pricing method is the most often used.

5.2. *Data collection*

Data is gathered through direct survey of 90 farmers, 17% of the total number of members of 14 WUAs in 2018. The irrigated areas range from 25 ha at Maidher Sud to 160 ha at Souar. These WUAs are marked by a low rate of user participation with an average of 52% ranging from 15% at the perimeter of Souar to 94% at the perimeter of Zouagha 2. This low participation rate indicates that various concerns plague farmers, including technical, financial, and governance issues.

5.3. *Variables*

The data includes farm production, input use, and socioeconomic characteristics. Inputs included in the analysis are presented in Table 2: cropped land area (ha) and crop-specific inputs (mechanization expenses, hired and family labor and fertilizers, pesticide expenses, and irrigation water fees in monetary units).

The variables used to explain the fluctuation of technical efficiency and WUE scores obtained using the Tobit model are presented in Table 3. The WUA is made up of many members who are supposed to collectively share and manage the same resource. This organization constitutes a form of institutional arrangement for water resource management. The success, or failure, of this arrangement will be reflected by the active participation of the WUA's members.

Table 1 - WUAs characteristics.

WUAs	*Schemes area (ha)*	*Number of members*	*Active members*	*Participation rate*	*Number of farms interviewed*
Maidher Nord (I)	80	64	34	53%	10
Maidher Sud (II)	25	42	36	86%	6
Chbaana 1 (III)	32	33	15	45%	5
Nadhour 3 (IV)	70	38	26	68%	6
Zouagha 1 (V)	50	21	13	62%	5
Zouagha 2 (VI)	70	16	15	94%	6
Sidi Abedelkader (VII)	120	67	45	67%	12
ChaalilSud (VIII)	50	21	7	33%	6
Souar (IX)	160	54	8	15%	5
Zbidine (X)	47	37	7	19%	5
Bouaarara (XI)	35	43	35	81%	6
Sidi Saleh (XII)	44	39	14	36%	6
Hnayniya (XIII)	60	36	20	56%	5
Saadine (XIV)	40	20	11	55%	7
Total	883	531	275	52%	90

Table2 - Summary statistics of the variables used in the DEA analysis.

Variables		*Average*	*S.D.*	*Max*	*Min*
Output	Gross Production value (TND)	15,493	15,679	89,400	800
Inputs	Cropped Area (ha)	3.07	2.26	13	0.5
	Mechanization expenses(TND)	984	835	4,600	60
	Seed expenses (TND)	1,744	2,117	14,850	60
	Fertilizer expenses (TND)	2,491	2,656	13,800	26
	Pesticide expenses (TND)	1,524	1,743	11,150	60
	Irrigation water fees(TND)	1,878	2,117	16,100	50
	Labor expenses (TND)	1,851	2,306	13,250	300

The WUA's performance is in turn supposed to affect farms' economic efficiency. The most important factors that can affect farms and WUE efficiency are:

- Breakdown time: A quantitative variable indicating the cumulative number of days of breakdowns.
- Water Turn: This variable is expressed as number of days. Water turn is the main constraint to the farmer who must juggle needs of crops, types of equipment, and time allowed for irrigation. This specific variable can be the main constraint to agronomic optimization of crop needs and explain the water shortage as well. It is essentially a function of the drilling flow, the number of WUA members, and the irrigated area served by the WUA. The water turn explains a form of the WUA's technical performance. When network efficiency is high, water demand will be better satisfied, thus reducing both water turn and potentially conflict surrounding water sharing.
- Supply shortage: This is a dummy variable. It is equal to 1 if the farmer suffers from insufficient water supply to make the desired cultural choice and zero if not.
- Reluctance: The aim of establishing WUAs is to promote a participatory decision-making process to efficiently manage water resources. Therefore, a lack of transparency between executive committees and farmers will lead to reluctance to participate in the general meeting which may affect the efficiency of water management.
- Payment terms: The number of days allowed to the farmer to pay any fees or expenses incurred from irrigation water consumed. This reduces a farmer's working capital requirements, allowing him to pay other more pressing expenses first.
- Corruption: For a non-member farmer to benefit from the WUA services, he must first send a written request to the regional agricultural commissioner, including approval from the head of the WUA in question, attesting that there is an excess of water for the crops grown in the area and that extending the network will have no negative effect on the needs of those crops grown within the perimeters. After receiving approval, the requesting farmer can benefit from the WUA services. However, the problem of the water turn and irrigation time remains. It is for this reason that corruption is often resorted to as a tool: (i) to have temporary approval from the head of the WUA, (ii) to adjust the turn and irrigation water volume to meet his needs. As a result, large users can drain water with impunity, depriving smallholders of essential resources for their own needs, placing them in difficulty because of the intense competition for water, and hence negatively affecting the WUA members' performance.
- Free-riding: Rational self-interested individuals will act to achieve their personal rather than group interests and have an incentive to free-ride if they can (Olson, 1971). In this paper, the "Free-riding variable" is measured by the number of members with

Table 3 - Definition and expected effects of explanatory variables.

Variables	*Definitions*	*Expected effects*
Breakdown time	Number of days of the water network was broken down	-
Water turn	Water turn in number of days	-
Supply shortage	Insufficient water supply (1= yes; 0 = no)	-
Reluctance	Reluctance of farmers to participate in the general assembly (1= yes; 0 = no)	-
Payment terms	Number of days allowed for farmers to pay water fees	+
Corruption	If the executive committee members receive bribes from a WUA non-member to provide irrigation water (1= yes; 0 = no)	-
Theft of water	Water stolen by the executive committee members (1= yes; 0 = no)	-
Free-riding	Number of members with free-riding behavior	-

free-riding practices (extending the irrigated area outside the perimeter or allowing an unauthorized connection by a non-WUA member). These practices increase when there is a lack of willingness to apply sanctions, especially where powerful farmers are concerned, thus encouraging free-riding. Moreover, the resource will be shared with larger groups or over a larger area, making the problem of free-riding more pervasive and giving individuals a higher incentive to shirk responsibility.

6. Results and discussion

6.1. *Efficiency score results*

DEA models were estimated using the DEAP 2.0 program (Coelli, 1996). The measurements of technical efficiency estimated using the DEA approach are presented in Table 4 along with frequency distribution.

The estimated mean of input-oriented technical efficiency under the CRS assumption for the sample of irrigating farms was 70.8%. This implies that the sample irrigating farms could reduce their inputs by 29.2% on average given the current state of technology and unchanged outputs. Technical efficiency ranges from 21 to 100%. 20% of the farms have an efficiency less than or equal to 50%; 55% have an efficiency between 50% and 90%; and 26% of farms have a technical efficiency greater than 90%. Thus, improving technical efficiency will significantly increase farmers' revenue and profit.

The WUE estimation results are presented in Table 5. The sub-vector efficiencies for water demonstrates even larger inefficiencies. Average water efficiency is found to be 65.8%. This is much lower than technical efficiency and also exhibits greater variability, ranging from 13% to 100%. The estimated mean irrigation water use efficiency implies that the outputs observed could have been maintained through

Table 4 - Frequency distribution of Technical Efficiency.

Technical Efficiency (%)	*TE ≤50%*	*50%<TE≤70%*	*70%<TE≤90%*	*TE> 90%*	*Total*
Number of farms	18	25	24	23	90
%	20%	28%	27%	26%	100
Average	40%	60%	82%	98%	70.8%
Min	21%	52%	71%	90%	21%
Max	49%	69%	90%	100%	100%

Table 5 - Frequency distribution of WUE.

Technical efficiency (%)	*WUE ≤50%*	*50%<WUE≤70%*	*70%<WUE≤90%*	*WUE> 90%*	*Total*
Number of farms	28	18	21	23	90
%	31%	20%	23%	26%	100%
Average	35%	61%	81%	98%	65.8%
Min	13%	52%	70%	90%	13%
Max	49%	69%	90%	100%	100%

the observed values of other inputs while using 34.2% less irrigation water. This means that farmers can achieve significant savings in water use by improving the way they use the irrigation system and by using more advanced irrigation techniques.

Figure 2 gives a graphical representation of the cumulative efficiency distributions for the different measures. Again, it is clear that under constant returns to scale specification, 74% of farms are highly inefficient in the use of water compared to overall technical efficiency. It also showed that farms with a technical efficiency score greater than 90% are using water more efficiently. The interesting implication of these results is that there appears to be considerable scope for reducing water use. This means that if efficiency improves, it should be possible to reallocate a fraction of the water to other water demands without really reducing production or the role small-scale irrigation might play on rural development.

6.2. *Regression results*

The Tobit model was estimated using the econometric software STATA 10. The results of the two regressions identifying the characteristics that determine the technical and sub-vector efficiencies for water use are presented in Table 6. Concerning the individual variables, the results of the models with the CRS specification showed consistency. The results do not vary sharply between the two regressions. Only the variable payment terms have a positive effect on both efficiency scores but not significant for WUE. The variables characterizing WUA (breakdown time, water turn, supply scarcity, and reluctance) are all negatively correlated to TE and WUE.

According to Table 6, all explanatory variables have a statistically significant effect on TE except for reluctance. Regarding the sub-vector WUE efficiency, the variables supply shortage, reluctance, and payment terms are not statistically significant.

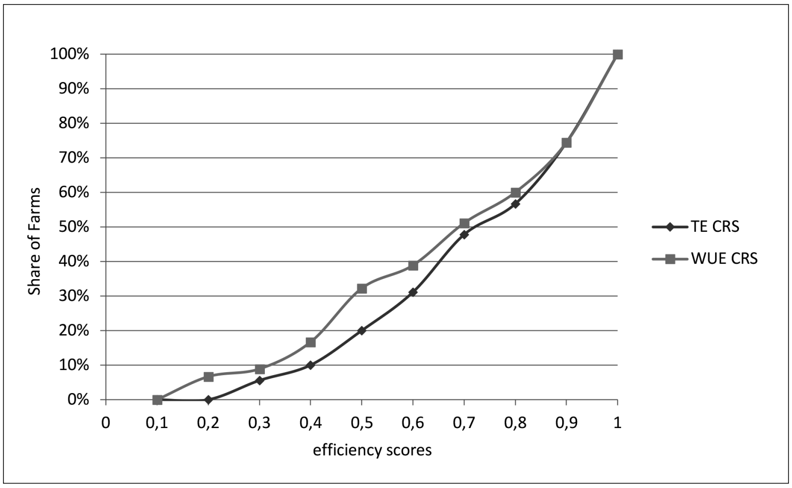


Figure 2 - Cumulative efficiency distribution for technical and sub-vector efficiency for water under CRS specification.

Table 6 - Tobit estimates of determinants of TE and WUE.

Variables	*Farm TE*		*WUE*	
	Coefficients	*T statistics*	*Coefficients*	*T statistics*
Breakdown time	-0.08*	-3.02	-0.15***	-1.66
Water Turn	-0.07*	-8.05	-0.09*	-2.95
Supplyshortage	-0.03***	-1.62	-0.6	-0.94
Reluctance	-0.02	-0.73	-0.008	-0.12
Payment terms	0.004*	2.63	0.004	0.74
Corruption	-0.04**	-2.07	-0.11***	-1.79
Water theft	-0.003***	-1.76	-0.008*	-1.73
Free-riding (illicit use of water)	-0.01*	-5.45	-0.016*	-2.85
Const.	1.18	16.5	1.42	6.08
LR ch(2)	299.72		152.34	
Prob>ch(2)	0		0	

*Notes: statistical significance levels: *1%; **5%; ***10%.*

The variables breakdown time and water turn strongly affect TE and they are statistically significant at 1%. These variables have the strongest negative influence on WUE and are statistically significant. The reason for this is because, if breakdown time increases by one day, WUE decreases by 15%; if water turn increases by one day, WUE decreases by 9%. This suggests that stakeholders should be involved in any attempt to reorganize irrigation systems and infrastructures due to their weighty social, economic, and environmental consequences. It can also be seen that when corruption, water theft, and free-riding occurred, TE was negatively affected but with low coefficients. On the other hand, the corruption variable has a strong effect on WUE; its coefficient of -0.11 indicates that WUE decreased by 11% when corruption took place. Corruption can distort the allocation of resources through rent-seeking behavior and maximizing individual interests. Bribes may be extorted by service providers in exchange for access to a water connection. As a result, corruption in water management may have a ruinous impact on food security. In places with little precipitation, low water tables, scarce access to water sources, or drought, water conservation becomes essential to agricultural production.

Given the presence of corruption, irrigation systems can be controlled by the rich and powerful. Spillages, leakage, and bad water management can lead to water shortages or contaminate irrigation water. Both of these situations can strain food security by causing crop failure in communities reliant on subsistence agriculture or by leading to a precipitous rise in local food prices for the urban poor. Fighting against illegal practices should raise accountability and transparency of the WUA. Increasing citizens' involvement can also curb corruption.

According to the model, farmers who feel that there is a shortage in supply see a negative impact on their TE which is statistically significant at 10%. This feeling also has a negative effect on WUE but not one that is significant. This means that when supply is reliable, access to irrigation water during the peak season enables farmers to be more efficient. Agronomic activities are done on time and higher yields are obtained at the end of the season.

The reluctance variable also has a negative effect on both TE and WUE but not to a significant degree. This finding should be carefully interpreted because this variable is used as an indicator to measure the level of farmer satisfaction with

WUA services and trust in the committee management. Clearly, those who are not satisfied or lack trust achieve lower efficiency.

7. Conclusion

The future increased climate change will result to a higher risk for both securing yield and farm income in Tunisia. In addition to these, the increasing food demand would make agriculture in a challenging and insecure environment. The water shortage is one of these challenges caused by the increasing risk of drought and over abstraction of the resource. In addition, failing practices in governance of irrigation water will have a significant impact on farmers' income. Understanding the factors affecting farmer productivity and WUE is crucial in irrigation water management. The main aim of this study is to determine the TE and WUE for improved irrigation water and to investigate factors responsible for their efficiency. The data envelopment analysis (DEA) approach was used to estimate the technical efficiency TE and WUE scores.

Results showed that the smallholder irrigation farmers fail to reach their overall technical efficiency levels when it concerns water use. This result implies that the improvement of WUE should be the first logical step to considerably increase the water availability for agriculture. In a second step, the examination of the factors affecting TE and WUE was conducted using a Tobit regression. Variables characterizing the WUAs (breakdown time, water turn, supply shortage) strongly impact with negative signs the TE. Their effect is more remarkable on the WUE which is conform to our expectations. The absolute values of the parameters vary from 0.008 to 0.6, these differences in coefficients values turn out to be particularly important in the case where managers and public decision-makers seek to design policies for improving the farms' technical efficiency and WUE. In addition to the coefficients values associated with the various explanatory variables, the design of policies to improve technical efficiency should take into account the socio-economic feasibility of the measures to be proposed. Based on our field knowledge and on the basis of discussions with a sample of managers and stakeholders, the implementation of a monitoring system to insure a trustful and transparent process appear to be a feasible solution; another solution is to empower water associations by giving them more prerogatives. Indeed, institutionalized sanctioning rules would result in a better management capacity. Further deeply researches on these institutional issues may give the clearest overview of water management challenges on public irrigated areas.

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