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# Irrigation Water Use Efficiency and Farm Size in Tunisian Agriculture: A Parametric Frontier Analysis Approach

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**Abstract:** In an economy such as Tunisia where resources are scarce and opportunities to use new technologies are limited, efficiency is a very important factor for productivity growth. Inefficiency studies indicate the potential to raise productivity by improving efficiency without necessarily developing new technologies or increasing the resource base. The objective of this study was to measure productive efficiency of irrigation water use based on the concept of technical efficiency and through comparing different sized farms in Tunisia. The proposed methodology was applied to a randomly selected sample of 144 citrus growing farms in the north of the country during 2003-2005 and differentiated by size (small, medium and large farms). A stochastic frontier production function, in which the non-negative technical inefficiency effects are assumed to be a function of farm-specific variables, is defined for cross section data on farms. The function is used to obtain farm-specific estimates of technical and irrigation water efficiency and to ascertain the effect of factors influencing irrigation water efficiency differentials across citrus growing farms. This study has revealed that small scale citrus farmers are not fully technically and irrigation water efficient and therefore there is potential for efficiency improvement, in both technical and irrigation aspects by addressing some important policy variables that negatively and positively influenced farmers' levels of efficiency. Another consistent result of this study is that medium size farms are the most efficient from a technical, irrigation and irrigation technical cost efficiencies point of view. Indeed, this study's most important contribution to the continuing debate over the relationship between efficiency and farm size is an affirmation of the inverse relationship in the case of citrus growing farms in Tunisia. Through this "lens", it is not surprise that medium size farms are the more efficient users of productions factors, especially water. A further rationale for these initial results, regarding increased technical water use efficiency with high quality agricultural practices, was the price premium for these farmers.This highlights the need for government policies, through extension activities, to set up professional training programs in advanced irrigation techniques. This could be effective, particularly if targeted at farmers with limited skills and would also stimulate innovation if decisions makers encouraged investment in irrigation equipment machinery by facilitating access to credit.

**Classification J.E.L:** C13 · Q12
**Key words:** Water Use Efficiency · Stochastic frontier production function · Farm sizes · Citrus farming · Tunisia

## INTRODUCTION

Accelerating agricultural growth remains one of the most important objectives policy makers face in less developed countries, where agricultural productivity is low, population growth rates are high and where the ability to import food is severely constrained [1]. As an arid country with limited water resources, Tunisia depends heavily on irrigated agriculture. The sector contributes 30-40 percent of the country's agricultural

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production and is highly important in some regions. In addition, irrigated farming contributes 10 percent of exports and provides 27 percent of jobs. The farming sector provides 90 percent of national needs of vegetables and 75 percent of local market needs in fruits [2]. However, abstraction for irrigation accounts for 83 percent of the available water resources, competing heavily with other uses. Tunisian water reserves are estimated at 4.7 billion $m^3$/year, of which 2.7 billion $m^3$ comes from annual rivers in the north, 0.7 billion $m^3$ from groundwater in the centre, the plains and the coastal area and approximately 1.3 billion $m^3$ from the deep groundwater table mainly in the south. Water resources are unevenly distributed across the country, with around 60 percent located in the north, 18 percent in the centre and 22 percent in the south. Water resources that have a salinity of less than 1.5 g/liter are distributed as follows: 72 percent of surface water resources, 8 percent of shallow groundwater and 20 percent of deep groundwater [2].

To conserve water resources and encourage demand management in the irrigation sector, a national water saving strategy was implemented. As part of the strategy, a number of reforms were introduced in the past few years, including the promotion of water users' associations, an increase in the price of irrigation water and the use of incentives to adopt new irrigation technologies at field level. The strategy also introduced a number of supporting actions such as strengthening applied research, improved agricultural marketing and better capacity building in the irrigation sector. The integrated strategy has resulted in a marked and sudden increase in national awareness of water scarcity and of the value of water in the country's economic development. Specific measures introduced by the new strategy included the creation of a legislative framework to promote water users' associations and financial incentives for water saving; a strengthened capacity in all water management sectors, including the management of water users' association supervision; training of trainers and improving farmers' awareness of the need to improve the irrigation practice; and an increase in water tariffs to reinforce users' participation in cost management and to provide incentives for the adoption of water saving techniques. Moreover, Tunisia's strategies aims at expanding irrigated areas, developing the methods and means of exploitation and increasing the production with a view to increase the value of Tunisia's agricultural production by 50 percent and to ensure the full exploitation of irrigated areas compared to 90 percent currently. Irrigated areas, which consume 80 percent of water resources, cover an area of approximately 405, 000 hectares accounting for 8 percent of the planted area (220, 000 hectares in public areas and 185 000 in private areas).

In Tunisia, small and medium-sized family farms dominate agriculture. According to Jouili [3], more than 89 percent of farms are smaller than 20 hectares and 54 percent of farms have less than 5 ha. In addition to the weakness of their land potential, these farms face a multitude of natural constraints (low and erratic rainfall, poor fertility of the majority of soils, etc.). From the early 80s, with the introduction of the Structural Adjustment Program (SAP), the conditions of production and trade on small farms have radically changed. In addition to the unfavorable trend of prices, these farms are increasingly excluded from credit, land and support services [3]. The ultimate consequence is a tendency of real incomes to decline, particularly sharply for small farms in the arid regions of the country. Faced with this degradation, small farms have developed mechanisms of adaptation or regulation allowing them to survive. Even so, all the indications suggested that the changes observed will lead the majority of these farmers to abandon their land [3]. However, the absence of any alternative for employment and stable income, in other activities, condemns many small farms to remain in poverty and insecurity. Given this, one of the important economic arguments in favor of the equitable distribution of farmland is that smaller farms are more productive. A large portion of the economic development literature is devoted to this topic, with arguments going both for and against the notion that smaller farms are more productive than medium and large farms.

The research question developed in this original paper addresses the relationship between farm size and efficiency. We want to address whether productive efficiency of water irrigation is higher or lower in small farms. We use the methodology proposed by Karagiannis *et al.* [4] that uses the concept of input-specific technical efficiency applying to a comparative analysis of the productivity of water use efficiency between small, medium and large citrus farms. This methodology is a non- radial, input-oriented measure of input specific technical efficiency. It has an economic rather than an engineering meaning and it is defined as the ratio of the minimum feasible water use to observed water use, conditional on production technology and observed levels of output and other inputs used. It provides information on how much water use could be lowered without altering the output produced and the quantities of other inputs used on-farm. The remainder of this paper is organized as follows. In section 2, we present a general overview of the Tunisian citrus fruit sector. The methodological framework with a special emphasis on the measurement of technical and irrigation water efficiency measurement is presented in section 3. Data descriptions as well as the variables used in the empirical model are presented in section 4. Section 5 presents the empirical results and discussions. Section 6 provides concluding remarks and implications derived from the empirical findings.

**The Tunisian Citrus Fruit Sector: An Overview:** Citrus trees are mainly grown in the North-Eastern part of Tunisia in the Cap Bon peninsula, where the environmental conditions are quite suitable. In Tunisia the commercial production of citrus fruits began 85 years ago. In 1918 French companies, with a view to discontinue imports of Spanish oranges, introduced the habit of citrus consumption in Tunisia and specifically in the Cap Bon area.The favorable conditions in this area enhanced citrus production, especially during the first decades. The *Maltaise* orange remains the dominant variety in the citrus sector. It represents more than a third of the total citrus orchard and it contributes about 55 percent to the citrus production [5]; in parallel the Tunisian orchard citrus shows other varieties with considerable value: Clementine, Tangerines, Lemons, Sweet Oranges, Navel Oranges, Oranges Valencia, etc. [5]. With a good quality recognized universally, the citrus fruit remains a tradition in Tunisia and this sector plays a significant role in the socio-economic life, given that it satisfies the demand of fruits during six months of the year and contributes an area of 0.3 percent of the total cropping area; about 3.4 percent of total fruit crop area; more than 9.45 percent of fruit production value; a source of income for more than 18 000 households. In addition, the sector is a source of 3 million working days/year, with 15 percent of the permanent agricultural labor and almost 51 percent of the occasional agricultural labor. It also has multiplier effects on the citrus commodity chain such as packaging and trading for the domestic and international markets [2]. Despite Tunisia's tradition in citrus production, the citrus sub-sector is still facing problems at production and marketing levels and particularly at technical and efficiency levels.Several reasons explain this situation. First, the increasing competition in the world citrus fruit market has hit Tunisian farmers in terms of structural and organizational problems that historically characterized the Tunisian citrus fruit sector. Furthermore, despite the small size, many farms are also fragmented with multiple plots of land, with evident implications on their ability to operate under efficient conditions.

International competition, small farms and other factors have all contributed in the last few years to Tunisian's declining competitiveness and efficiency in the European citrus fruit market. Structural constraints such as political instability also seem to negatively affect the performance of the Tunisian sector and inhibit economic development of citrus farming. The analysis of efficiency together with an estimation of technical efficiency can offer us more information about the nature of these problems. If significant technical and/or water use inefficiency were found, this would indicate that small farms are not suitable for maintaining an efficient citrus sector since these structural problems prevent farm expansion and the rational use of technical inputs, especially water.

## Methodological Framework

**Stochastic Frontier Production Function Approach:** Since the stochastic production frontier model was first and nearly simultaneously, published by Meeusen and van den Broeck [6] and Aigner *et al.* [7], there has been considerable research to extend the model and explore exogenous influences on producer performance [8-10]. Early empirical contributions investigating the role of exogenous variables in explaining inefficiency effects adopted a two-stage formulation, which suffered from a serious econometric problem[1]. Kumbhakar *et al.* [11], Reifschneider and Stevenson [12], Huang and Liu [13] and Johansson [14] proposed stochastic production models that simultaneously estimate the parameters of both the stochastic frontier and the inefficiency functions. While, the formulated models differ somewhat in the specification of the second error component, they all used a cross section data. Battese and Coelli [15] formulated a stochastic frontier production model similar to that of Huang and Liu [13] and specified for panel data.

In this study, we adopt the Battese and Coelli [15] model but specified for a cross section data context. The model consists of two equations (1) and (2). The first equation specifies the stochastic frontier production functionthat describes random shocks, not directly attributable to the producer or the underlying technology,

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[1] In the first stage of this formulation, the stochastic frontier model is estimated and residuals are decomposed using the Jondrow *et al.* [16] technique. The estimated inefficiency scores are then regressed, in a second stage, against the exogenous variables contradicting the assumption of identically distributed inefficiency of the first stage.

affecting the output. The second equation, which describesthe effects of technical inefficiency, has a systematic component $\delta' z_i$ associated with the exogenous variables and a random component $\varepsilon_i$:

$$LnY_i = Lnf(x_i;\ \beta) + v_i - u_i \tag{1}$$

$$u_i = \delta' z_i + \varepsilon_i \tag{2}$$

where $Y_i$ denotes the production of the $i^{th}$ firm; $x_i$ is a vector of input quantities of the $i^{th}$ firm and $\beta$ is a vector of unknown parameters to be estimated. The non-negativity condition on $u_i$ is modelled as $\varepsilon_i \sim N\ (0,\ \sigma_\varepsilon^2)$ with the distribution of $\varepsilon_i$ being bounded below by the truncation point $-\delta'\ z_i$. Finally, $v_i$ are assumed to be independent and identically distributed $N\ (0,\ \sigma_v^2)$ random errors, independent of the $u_i$.

The parameters of the stochastic frontier production function in (1) and the model for technical inefficiency effects in (2) may simultaneously be estimated by the maximum likelihood method. The technical efficiency of production for the $i^{th}$ farm can be defined as follows:

$$Te_i = \exp(-\ u_i) = \exp(-\ \delta'\ z_i - \varepsilon_i) \tag{3}$$

A predictor for which is provided by its conditional expectation[2]:

$$E\left[\exp\left\{-u_i\right\}\middle|\ (v_i - u_i)\right] = \left[\exp\left\{-\mu_{*i} + \frac{1}{2}\sigma_*^2\right\}\right] \cdot \left[\frac{\Phi\left[(\mu_{*i}/\sigma_*) - \sigma_*\right]}{\Phi(\mu_{*i}/\sigma_*)}\right] \tag{4}$$

where,

$$\mu_{*i} = \frac{\sigma_v^2(\delta' z_i) - \sigma_u^2(\varepsilon_i)}{\sigma_v^2 + \sigma_u^2} \tag{5}$$

$$\sigma_*^2 = \frac{\sigma_v^2\ \sigma_u^2}{\sigma_v^2 + \sigma_u^2} \tag{6}$$

**Measuring Irrigation Water Use Efficiency: Theoretical Model:** In order to achieve the outlined objectives, in this paper we have applied the methodology developed by Karagiannis *et al.* [4] for a cross section data from survey conducted into the principal Tunisian citrus sector production called *Nabeul* (North of Tunisia). According to Karagiannis *et al.* [4], the methodological framework of technology is described by the following stochastic production frontier function:

$$Y_i = f\ (X_i,\ W_i;\ a)\ \exp\ (\varepsilon_i \equiv v_i - u_i) \tag{7}$$

where $i = 1,2,....,N$ refers to farms, $Y$ is the quantity of output produced, $X$ is a vector of input quantities used, $W$ is irrigation water, a is the vector of the parameters to be estimated and $\varepsilon_i$ is a composed error term consisting of a symmetric and normally distributed error term, $v_i$, respecting those factors that cannot be controlled by farmers (i.e., weather effects, diseases, etc.).

According to Kumbhakar and Lovell [17], farm specific estimates of output-oriented technical efficiency are obtained as $TE_i^0 = \exp\ (-u_i)$, while farm-specific estimates of input oriented technical efficiency are derived by equation (7) with $Y_i = f\ (v_i X_i,\ v_i W_i;\ \alpha)\ \exp\ (v_i)$ and solving for $TE_i^1 = v_i$ [18, 19]. Thus, $TE_i^0$ is greater, equal, or less than $TE_i^1$ whenever returns to scale are decreasing, constant, or increasing, respectively [20].

The above measures of efficiency are incapable of identifying the efficient use of individual inputs. For this reason, the proposed irrigation water efficiency measure is based on the notion of input specific technical efficiency [21]. Specially, it is defined as the ratio of minimum feasible to observed levels of outputs and input. Thus, irrigation water efficiency is an input-oriented, single-factor measure of technical efficiency defined as:

$$IE^1 = [\min\ \{\lambda : f\ (X,\ \lambda\ W;\ a) \geq y\ \}] \rightarrow (0,\ 1) \tag{8}$$

Irrigation water efficiency, as defined in (8), has an input-conserving interpretation, which however cannot be converted into a cost saving measure due to its non-radial nature. This means that irrigation water efficiency measure is based on the non-radial notion of input-specific technical efficiency, which is defined as the minimum feasible to observed use of irrigation water given the production technology and the observed levels of the output and all other inputs [21]. The proposed measure of irrigation water efficiency is illustrated in Fig. 1 [4].

Let the i^th inefficient farmer producing output $Y_0$ by using $x_1$ of all other inputs and $w_1$ units of irrigation water. Then $TE_i^1 = OB\ /OA$ and $IE_i^1 = x_1\ C/\ x_1\ A = w_2\ /\ w_1$. The proposed irrigation water efficiency measure

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[2] For the derivation of the likelihood function, its partial derivatives with respect to the parameters of the model and an expression for the predictor of technical efficiency see Battese and Coelli [22].

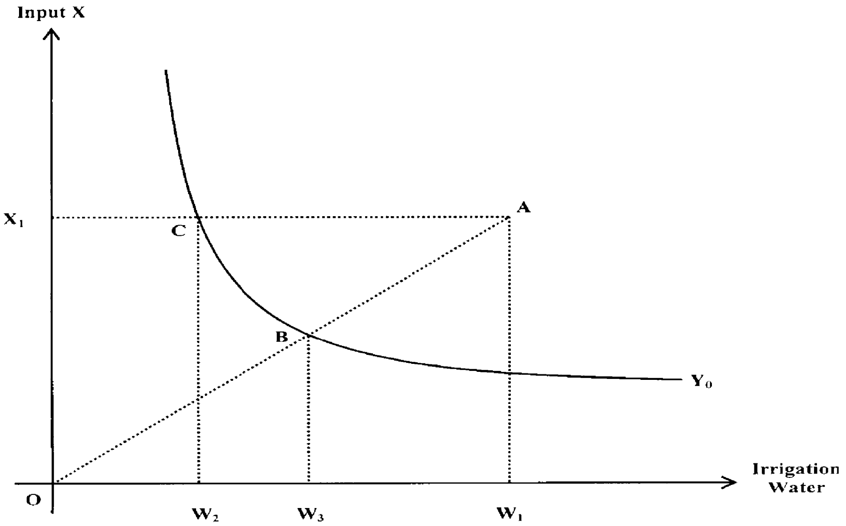

Fig. 1: Proposed measure of irrigation water efficiency [4].

determines both the minimum feasible water use ($w_2$) and the maximum possible reduction in water use ($w_1 - w_2$) that still permits the production of $Y_0$ units of output with unaltered use of all other inputs.

On the other hand, according to the $TE_i^1$ measure, the maximum possible reduction in water use, required to make the i<sup>th</sup> farm technically efficient, is ($w_1 - w_3$). From Fig. 1, it is clear that the former ($w_1 - w_2$) will always be greater than the latter ($w_1 - w_3$). Consequently, the maximum possible reduction in water use suggested by $IE_i^1$ should be considered as an upper bound [23]. Conceptually, measurement of $Ie_i^1$ requires an estimate for the quantity ($w_2$), which is not observed. Nevertheless, using $IE_i^1 = w_2 / w_1$ it can easily be seen that $w_2 = w_1 . IE_i^1$. By substituting this into (1) and by noticing that point C in Figure 1 lies on the frontier, i.e., $u_i = 0$, (7) may be rewritten as:

$$Y_i = f(X_i, w_i^E; a) \exp(u_i) \tag{9}$$

where $w_i^E = w_2$ [19]. Then, a measure of $IE_i^1$ can be obtained by equating (7) with (9) and by using the econometrically estimated parameters α.

Since $IE_i^1$ is a non-radial efficiency measure that does not have a direct cost-saving interpretation, the single-factor technical cost efficiency measure could instead be used to evaluate the potential cost savings accruing to more effective management of a single factor [21]. Then, irrigation water technical cost efficiency, $ITCE_i$, could be defined as the potential cost savings from adjusting irrigation water to a technically efficient level while holding all other inputs at observed levels.

Following Akridge [23], farm-specific estimates of $ITCE_i$ may be obtained as:

$$ITCE_i = S_{wi} IE_i^I + \sum_{j=1}^{J} S_{ji} \tag{10}$$

where $S_{wi}$ and $S_{ji}$ are the ith farm's observed input cost shares for irrigation water and the j<sup>th</sup> input, respectively. Given that $0 < IE_i^1 \leq 1$ and $S_{wi} IE_i^I + \sum_{j=1}^{J} S_{ji}$ for all i, $0 < ITCE_i \leq 1$.

However, cost saving will vary with factor prices and relatively inefficient water use in a physical sense can be relatively efficient in a cost sense and vice versa [21].

**Measuring Irrigation Water Use Efficiency: Empirical Model:** Approximate the unknown production frontier (7) by the following *Cobb-Douglas*specification:

$$\text{In } y_i = \alpha_0 + \sum_{j=1}^{J} \alpha_j \text{In } x_{ji} + \alpha_w \text{In } w_i + v_i - u_i \tag{11}$$

Using the Battese and Coelli's [15] inefficiency effect model, the one sided error term is specified as:

$$U_i + g(Z_i; \delta) + W_i \tag{12}$$

where Z is a vector of variables used to explain efficiency differentials among farmers, δ is a vector of parameters to be estimated (including an intercept term) and $W_i$ is an *iid*. The model (11) and (12) can be estimated econometrically in a single stage using ML techniques and the frontier (version 4.1) computer package developed by [24]. The variance parameters of the likelihood function are estimated in term of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{\sigma^2}$, where the γ parameter has a value between zero and one.

Using the estimated parameters and variances, farm-specific estimates of $TE_i^0$ are obtained as:

$$TE_i^0 = E\{\exp(-u_i/\varepsilon_i)\} = \exp\left[(-\mu_i^0 + 0.5G_0^2)\left(\frac{\left[\left(\mu_i^0/G_0\right) - G_0\right]}{\phi\left(\mu_i^0/G_0\right)}\right)\right] \tag{13}$$

where:

$$\mu_i^0 = \frac{G_v^2\mu_i - G_u^2\varepsilon_i}{G_v^2 + G_u^2}, G_0^2 = \frac{G_u^2 G_v^2}{G_u^2 + G_v^2}$$

Φ is the cumulative density function of the standard normal random variable and E is the expectation operator.

On the other hand, farm specific estimates of $IE_i^1$ are derived by using (9) and the following relations developed by Reinhard *et al.* [19] and applied for the *Cobb-Douglas*specification case (11):

$$IE_i^I = \exp\left[\left\{-\xi_i \pm \left(\sqrt{\xi_i^2 - 2\alpha_{ww}u_i}\right)\right\}/\alpha_{ww}\right] \tag{14}$$

where;

$$\xi_i = \frac{\partial \text{In} y_i}{\partial \text{In} w_i} = \alpha_w + \sum_{j=1}^{J} \alpha_{jw} + \text{In}\, x_{ji} + \alpha_{ww}\, \text{In}\, w_i$$

**Data Description and Variables Definitions:** A cross section data of 144 Tunisian citrus producing farms covering the 2002-2003; 2003-2004 and 2004-2005 periods were collected from surveys conducted in two provinces of *Nabeul* governorate in Tunisia (Table 1). These two provinces are the most important citrus production areas, representing 1.7 percent of national agricultural land, contributing 80 percent of national citrus production and more than 90 percent of citrus exports.

The selected sample comprises 32 farms of size lower than 1 ha (22.22 percent of the sample), 58 of size ranging between 1 and 2 ha (40.27 percent) and 54 of size greater than 2 ha (37.50 percent). Citrus productive citrus trees add up to 105921, from which 8.63 percent were less than 5 years, 8.49 percent were between 5 and 10 years, 19.23 percent were between 10 and 20 years and 63.6 percent were older than 20 years. The density of plantation is about 270 trees/ha on average. The production of citrus during 2002/2003, 2003/2004 and 2004/2005 was 2390.7 metric tonnes per year, on average, corresponding to 67.7kg/tree or 18.3MT/ha.

Table 1: Distribution of citrus farms surveyed by delegation and by land area

| | Private Farms | | | |
|---|---|---|---|---|
| Zone of localization | < 1Ha | 1 - 2 ha | > 2ha | Total |
| Beni Khalled | 20 | 31 | 19 | 70 |
| Menzel Bouzelfa | 12 | 27 | 35 | 74 |
| Total Nabeul | 32 | 58 | 54 | 144 |

Source: Own elaboration from citrus producing farms in Tunisia.

Table 2: Summary statisticsof the variables used in the empirical model for citrus producing farms in Tunisia

| Notation | Variables | Total Sample | Small Farms < 1ha | Medium Farms 1 - 2 ha | Large Farms > 2ha |
|---|---|---|---|---|---|
| P | Production (in kg) | 48946.19 (55063.21) | 12533.55 (6955.44) | 23715.04 (12010.9) | 84777.025(65048.06) |
| S | Area (in ha) | 2.68 (3.08) | 0.546 (0.171) | 1.22 (0.24) | 4.76 (3.61) |
| L | Labour (in Working Days) | 428.44 (364.9) | 174.70 (75.9) | 288.02 (82.05) | 672.85 (435.7) |
| CI | Chemical Inputs (in TD) | 1937.83 (2491.7) | 465.54 (415.4) | 882.89 (478.3) | 3562.78 (3083.2) |
| IW | Irrigation Water (in $m^3$) | 1127.382 (1367.350) | 327.833 (217.536) | 503.632 (163.73) | 1966.61 (1680.2) |
| OC | Other Costs (in TD) | 631.77 (1206.5) | 177.16 (149.2) | 331.20 (262.07) | 1135.78 (1695.2) |
| AF | Age of Farmer (in years) | 55.88 (10.6) | 56.75 (10.5) | 53.40 (10.3) | 57.04 (11.01) |
| SFL | Share of Family Labour (in %) | 0.68 (0.4) | 0.70 (0.3) | 0.65 (0.4) | 0.68 (0.4) |
| SPT | Share of Productive Trees (in %) | 0.86 (0.19) | 0.80 (0.18) | 0.75 (0.22) | 0.82 (0.18) |

Notes: (1): 1TD = 0.7US $ (average 2011).(2): Standard deviations are in parentheses.

Source: Own elaboration from citrus growing farms in Tunisia.

As we posed at the outset, the dependent variable is the total annual citrus production measured in kg. The aggregate inputs considered in the analysis are: (1) land, measured in hectares; (2) total labour measured in working days; (3) chemical inputs measured in Tunisian Dinars; (4) irrigation water measured in $m^3$; and (5) other costs, comprising the rest of inputs used in producing citrus (mechanisation, etc.) measured in Tunisian Dinars. Summary statistics of these variables are given in Table 2.

## RESULTS AND DISCUSSION

**Production Structure:** The estimated parameters of the *Cobb-Douglas* stochastic production frontier for the different farms sizes are presented in Table 3. This parameters represent percentage change in the dependent variable as a result of percentage change in the independent variables and as such show the relative importance of these variables to citrus output on Tunisian farms. From this table it appears that all the parameters ($\alpha_i$) have the anticipated positive sign and magnitude. On the other hand, the ratio of farm specific to total variability, $\gamma$, is positive and statistically significant at the 5 percent level for small and large farms. The value of 0.81 (for total sample) indicates that output oriented technical efficiency is important in explaining the total variability of output produced. The remaining portion (0.19) is due to factors outside the control of farmers (weather, diseases, etc.). Whereas, output technical efficiency is not important on explaining the volatility of output produced in the case of medium farms ($\gamma$ is positive but not statistically significant).

Average estimates of production elasticities and returns to scale for the whole sample and for the different sizes (small, medium and large) are also presented in Table 3 for the region of study under consideration. For the whole sample, estimated production elasticities of all five inputs are positive. They indicate that in *Nabeul* region land (S) is the foremost important input followed by irrigation water (IW) and chemical inputs (CI), while labour (L) has the lowest point estimate, which on average were found to be 0.03. In economics terms, this latter means that holding all other inputs constant, a 1 percent reduction in irrigation water requires a sacrifice of 0.33 percent of marketable output. On the other hand, the hypothesis of constant returns to scale is rejected at the 5 percent level of significance and returns to scale were found to be increasing (1.16). The same magnitude was found in the case of small and medium farms with the only difference that returns to scale was decreasing for medium farms.

A direct comparison of the estimated elasticitiesshows the close difference between small, medium and large farms in terms of intercepts, labour input and returns to scale. Whereas, some similarities are outlined for the importance of water irrigation weight (the relative coefficient is positive and statistically significant for all farm sizes) which was greater for the small farms.

A shadow price of irrigation water may be computed by using the mean values of the relevant variables reported in Table 3 and the estimated production elasticity of irrigation water for the whole sample and differentiated by farm sizes. By combining these figures we find that a reduction of 1 $m^3$ of irrigation water would "cost" approximately 1.4 kilograms in terms of foregone quantities and 0.611 Tunisian Dinars in terms of foregone revenue for the whole sample.

For small farms, medium and large farms, a reduction of a 1 $m^3$ of irrigation water would "cost" approximately 1.261, 1.367 and 1.379 kilograms in terms of foregone quantities and 0.538, 0.583 and 0.589 Tunisian Dinars in terms of foregone revenue, respectively. This in turn implies that the shadow price of irrigation water is equal to 0.538 Tunisian Dinars per $m^3$ for the small farms, 0.583 for the mediums farms and 0.589 Dinars for the largest ones, a value that is much higher than the market price charged in *Nabeul* region, which varies between 0.09 and 0.1 Tunisian Dinars per $m^3$ [25]. This shadow price should be considered as the upper bound of the true shadow assumption that all other inputs are held constant at their observed levels, which might not be palatable for greater changes in the quantity of irrigation water.

**Technical and Irrigation Water Efficiency:** From the above analysis, it appears that there is a similarity in the cost of 1 $m^3$ of irrigation among the different sizes. Indeed, the shadow price is not the adequate indicator on water use efficiency between farm sizes.

Given this, in a second step, we estimate technical efficiency ($TE_i$), irrigation efficiency ($IE_i$) and irrigation water technical cost efficiency ($ITCE_i$) for the whole sample and disaggregated by size of farms in order to address the relationship between farm size and efficiency. Results for the three farm types are presented in Table 4.

Column 2 shows the mean, maximum and minimum irrigation efficiency for the three categories of farms in addition to the whole sample. The estimated mean irrigated efficiency for the whole sample ranges from a minimum of 1.6 percent to a maximum of 98.87 percent with an average estimate of 53 percent. Whereas, the estimated mean irrigated efficiency was 52.02 percent, 55.63 percent

Table 3: Production elasticities estimates and returns to scale of the frontier model of a sample of Tunisian citrus producing farms

| | Estimates | | | |
|---|---|---|---|---|
| Parameters | Small (<1 ha) | Medium (1-2 ha) | Large (>2 ha) | Total Sample |
| Stochastic Frontier Model | | | | |
| Intercept | 0.72** | 0.064 | 0.64** | 0.43** |
| Ln(S) | 0.69** | 0.41* | 0.22* | 0.34** |
| Ln(L) | -0.054 | -0.12 | 0.42* | 0.03 |
| Ln(CI) | 0.11* | 0.22** | -0.098 | 0.22** |
| Ln(IW) | 0.37** | 0.29** | 0.32** | 0.33** |
| Ln(OC) | 0.036 | -0.02 | 0.067 | 0.24 |
| Returns to Scale | 1,152 | 0,78 | 0,929 | 1,16 |
| Variance Parameters | | | | |
| $\sigma^2$ | 0.32* | 0.16 | 0.63** | 0.38** |
| $\gamma$ | 0.79** | 0.17 | 0.99** | 0.81** |
| Log-Likelihood | -15.51 | -24.96 | -99.20 | -79.46 |
| N | 32 | 58 | 54 | 144 |

Source: Own elaboration from citrus growing farms in Tunisia.

Notes: ***, ** and * indicate significance at the 1, 5 and 10 percent level respectively.

Table 4: Efficiency ratings for Tunisian citrus producing farms

| Efficiency (%) | IE | TE | ITCE |
|---|---|---|---|
| | Total Sample (N=144) | | |
| Mean Efficiency | 53.00 | 67.73 | 70.81 |
| Min. Efficiency | 1.6 | 12.82 | 70.21 |
| Max. Efficiency | 98.87 | 90.69 | 99.90 |
| | Small Farms (N=32) | | |
| Mean Efficiency | 52.06 | 68.01 | 91.09 |
| Min. Efficiency | 9.41 | 32.77 | 75.54 |
| Max. Efficiency | 99.05 | 86.61 | 99.90 |
| | Medium Farms (N=58) | | |
| Mean Efficiency | 55.63 | 70.57 | 92.86 |
| Min. Efficiency | 1.59 | 12.82 | 79.17 |
| Max. Efficiency | 98.87 | 90.69 | 99.85 |
| | Large Farms (N=54) | | |
| Mean Efficiency | 52.30 | 64.51 | 91.37 |
| Min. Efficiency | 2.94 | 29.24 | 70.21 |
| Max. Efficiency | 93.28 | 90.52 | 99.59 |

Source: Own elaboration from citrus growing farms in Tunisia.

and 52.3 for the small, medium and large farms, respectively. Given this, it appears that the maximum value was found for the medium farms. This results means that estimated mean irrigation water efficiency implies that the observed quantity of marketable citrus could have been maintained by using the observed values of other inputs while using 44.37 percent less irrigation water. This means that medium farmers can achieve significant savings in water use by improving the utilisation of irrigation systems and by utilizing more advanced irrigation technologies with respect to small and large farmers. This result was confirmed by Chemak *et al.* [26] using data envelopment analysis (DEA) method.

Column 3 represents the technical efficiency (TE) results obtained for the small, medium and large farms. Empirical findings show that mean technical efficiency for the whole sample is found to be 67.73 percent, which is much higher than irrigation efficiency and also exhibits greater variability, ranging from 12.82 percent to 90.69 percent. As similar to column 2, empirical results confirm that medium farms present the highest technical efficiency with an average output-oriented technical efficiency estimate of 70.57 percent, rangingfrom a minimum of 12.82 percent to a maximum of 90.69 percent. This result means that a 29.43 percent increase in production is possible with the present state of technology and unchanged input uses, if technical inefficiency is completely removed. Thus, improving technical efficiency of medium farms will result in significant increases in the farmer's revenue and profit.

Moreover, cost savings that could be achieved by adjusting irrigation water to its efficient level, would be small since its outlays constitute a small proportion of total cost. For this reason, the estimated mean $ITCE_i$ is much higher than $IE_i$ for the different sizes. Results from column 4 (Table 4) showed that the estimated mean irrigation water technical cost efficiency is found to be 70.81 percent (91.01 percent for small farms; 92.86 percent for medium farms and 91.37 percent for large farms) indicating a potential decrease of 29.19 percent (19 percent, 7 percent and 8 percent, respectively for small, medium and large farms) in total cost by adjusting irrigation water to its efficient level. In addition, the vast majority of farms have achieved irrigation and irrigation water technical cost efficiency greater than 90 percent (92.86 percent for medium farms) which correspond to the 71 percent of farms. Thus, even though irrigation water is used least efficiently in a technical sense, it offers only few potential cost savings if it is adjusted to its technically efficient level.

**Explaining Drivers of Technical and Irrigation Efficiency Differentials:** The last step of the analysis discusses the sources of technical and irrigation efficiency differentials among farmers. In this fact, one of the advantages of Battese and Coelli [15] model is that it allows measurement of technical efficiency (TE) and examination of its differentials among farmers to be done with a single stage estimation procedure.

The commonly applied two stage estimation procedure has been recognised as one that is inconsistent with the assumption of identically distributed inefficiency effects in the stochastic frontier, which is necessary in the maximum *likelihood* (ML) estimation [12, 11, 15]. However, the two stage estimation procedure can be used with no problem for identifying the factors influencing irrigation water efficiency differentials across farms as irrigation efficiency (IE) is calculated from the parameter estimates and the estimated one sided error component of the stochastic production frontier in (7). The relevant second stage regression model has the following form:

$$\text{Ln}\, IE_i = h\,(z_i, \delta) + e_i \tag{15}$$

where h (*) is deterministic Kernel of the regression model, $\delta$ is the vector of the parameters to be estimated and $e_i$ is an *iid* random variable with zero mean and constant variance. The above model is estimated with standard *OLS*.

Estimation results from the inefficiency effects model (equation 12) and the second stage regression (equation 15) have been estimated. The explanatory variables included in these models have been commonly used in estimating agricultural production frontiers for developing countries [27-29]. The sources of technical and irrigation efficiencies in citrus farms were examined by using seven explanatory variables (Table 5).

Estimation is carried out for the whole sample and for the different sizes (small, medium and large farms). In the case of the inefficiency effects model, it is important to indicate that a negative sign of the estimated parameter indicates a positive relationship between technical efficiency (or irrigation water efficiency) and the variable under consideration, while in the latter a positive sign depicts a negative relationship between irrigation water efficiency (or technical efficiency) and the corresponding variable.

Table 5: Explaining Technical and Irrigation Efficiency Differentials

| | Total Sample | | Small Farms | | Medium Farms | | Large Farms | |
|---|---|---|---|---|---|---|---|---|
| Parameters | TE | IE | TE | IE | TE | IE | TE | IE |
| $\delta_0$ (Intercept) | -0.30 (0.08) | 0.079 (0.16) | -0.36 (0.21) | -0.07 (0.12) | -0.1 (0.12) | -0.02 (0.15) | -0.51 (0.16) | 0.43 (0.38) |
| $\delta_{FS}$ | -0.009**(0.003) | -0.08** (0.006) | 0.15 (0.10) | -0.15** (0.06) | -0.04 (0.034) | -0.14** (0.04) | -0.016** (0.005) | -0.05** (0.012) |
| $\delta_{AG}$ | 0.0002 (0.0009) | -0.003* (0.001) | -0.001 (0.022) | -0.0013 (0.001) | -0.0007 (0.0012) | -0.00009 (0.001) | 0.002* (0.002) | -0.008* (0.004) |
| $\delta_{EDC}$ | -0.005 (0.012) | -0.009 (0.023) | 0.0018 (0.027) | 0.02 (0.016) | -0.005 (0.017) | 0.002 (0.022) | 0.006* (0.03) | -0.12* (0.064) |
| $\delta_{FT}$ | 0.036 (0.029) | 0.02 (0.055) | 0.033 (0.064) | - 0.09** (0.03) | 0.042 (0.04) | 0.01 (0.056) | 0.028 (0.05) | 0.12 (0.12) |
| $\delta_{FL}$ | -0.066** (0.03) | 0.03 (0.06) | -0.06 (0.093) | 0.02 (0.054) | -0.07* (0.04) | 0.0009 (0.05) | -0.033 (0.07) | -0.11 (0.16) |
| $\delta_{SPT}$ | 0.199** (0.05) | -0.05 (0.09) | 0.246** (0.102) | 0.07 (0.059) | 0.106* (0.06) | -0.056 (0.08) | 0.26 (0.11) | 0.07 (0.26) |
| $\delta_{WDP}$ | 0.016 (0.02) | 0.019 (0.04) | 0.006 (0.049) | -0.04* (0.028) | -0.019 (0.02) | 0.07** (0.03) | 0.07* (0.05) | -0.038 (0.11) |
| Econometric and Statistical Results | | | | | | | | |
| D.W | 1.85 | 1.79 | 2.50 | 2.28 | 2.13 | 2.13 | 2.01 | 1.59 |
| $R^2$ | 0.18 | 0.62 | 0.33 | 0.40 | 0.15 | 0.25 | 0.33 | 0.15 |
| F-statistic | 4.11 | 31.68 | 1.69 | 2.34 | 1.31 | 2.46 | 3.27 | 4.62 |
| N | 144 | 144 | 32 | 32 | 58 | 58 | 54 | 54 |

Source: Own elaboration from citrus growing farms in Tunisia.

Notes: * significance at 10 percent level; ** significance at 5 percent level. Standard errors are in parenthesis.

- FS: is the farm's size in hectares; AG is the farmer's age in years; EDC: is the level of schooling (1: illiterate; 2: primary level; 3: secondary level and 4: high school level); FT: is a dummy variable indicating farmer's followed training programs on conducting citrus plantation; FL: proportion of family labour; SPT: share of productive trees measured in percent and WDP: is a dummy variable indicating water disposable perception by farmers.

The estimated coefficient of farm size, with respect to technical and irrigation water efficiency had a negative sign and was both significant at 5 percent level for large farms. In addition, this coefficient was also negative, significant and with high values with respect to irrigation water efficiency for small and medium farms. That implies that farm size contributed negatively to irrigation water inefficiency. Farm size positively affected this efficiency where the smaller these farms, the more efficient they are.This result was confirmed by Edeh and Awoke [30] where they indicate that farmer's level of technical efficiency in Nigerian cassava farmers was significantly affected by level of education and farm size. While the education level had positive effect, farm size had negative effect on technical efficiency level of the farmer.

Regarding the estimated coefficient for age, empirical findings show that age had an impact only in technical and water efficiency of large farms (significant at 10 percent level). However, it contributed negatively to irrigation water inefficiency and positively to technical inefficiency, which may be because of the accumulated experiences that have been gathered over time. Therefore, the older the farmer the more irrigation water efficiency they display.

Education is a variable that is expected to sharpen managerial input and lead to a better assessment of the importance and complexities, of good decisions in farming. Education enhances the ability of farmers to see, decipher and make good use of information about production inputs, thus improving their efficient use. The coefficient of years of exposure to education was a determinant only for the large farms. The positive estimated coefficient was significantly different from 0 at 10 percent level with respect to technical efficiency. This implies that farmers' education reduced technical efficiency of the citrus farmers. This negative relationship technical efficiency and formal education can be attributed to the fact that higher educated farmers are involved in off-farm activities, such as business and thus rely on unsupervised, hired labor. In contrast, a significant positive relationship was found between irrigation water efficiency and education. Schooling helps farmers to use information and technology efficiently since a better educated farmer acquires more information on technology use, especially for water management.

For the analysis of the coefficient related to the farmer training (FT), a variable of particular interest to policy makers, empirical findings indicates that it affects only water irrigation efficiency for small farms. The negative and statistically significant at 5 percent level coefficient suggests that an increase in the training programs related to the irrigated agricultural contributes to higher water irrigation efficiency levels on these farms.

The proportion of family labor with respect to total labor positively affects the technical efficiency for medium farms. The negative and statistically significant at 10 percent level coefficient implies that an increase in the share of family labor could help these farmers to increase their technical efficiency.

On the other hand, the share of productive trees variable tends to affect negatively the degree of technical efficiency for small and medium farms since the corresponding parameters are positive and significant. This negative relationship can be attributed to the fact that only 75 percent of citrus trees are actually under production.

Finally, the farmer's water disposable perception (WDP) parameter was negative and significantly different from zero at 10 percent level with respect to water irrigation efficiency for small farms. This implies that small farmers have no problem to increase irrigation efficiency since water is disposable for these farmers. In contrast, this coefficient was to be positive and significant for the medium farms. This negative relationship between irrigation efficiency and water disposable perception indicates that the quantity of water is not sufficient for these farms; which suggests that, on average, medium farms could operate at higher efficiency levels than other farms given their irrigation technical cost efficiency.

**Concluding Remarks and Policy Implications:** This paper aims to assess the effect of farm size on technical and irrigation water efficiency for citrus growing farms in Tunisia. The proposed methodology was applied to a randomly selected sample of 144 citrus growing farms located in North Tunisiaand differentiated by size (small, medium and large farms). A stochastic production frontier approach, based on Battese and Coelli's [15] inefficiency effect model, was used to obtain farm-specific estimates of technical and irrigation water efficiency scores. In addition, this analysis was enhanced by the identification of the factors influencing irrigation water efficiency differentials across citrus growing farms on the basis on a second-stage regression approach.

This study has revealed that small scale citrus farmers are not fully technically and irrigation water efficient and therefore there is the possibility of efficiency improvement both in technical and irrigation water aspects by addressing some important policy variables that negatively and positively influenced farmers' levels of both efficiencies in the area. This finding is endorsed by Sharifabadi and Boshrabadi's [31] research on total factor productivity growth of pistachio production in Iran. They indicate that experience and firm size were both positively and the main determinants of efficiency.

Empirical results show that estimated production elasticities of all inputs are positive. They indicate that in this area, land is the foremost important input followed by irrigation water and chemical inputs, while labour has the lowest point estimate. On the other hand, the hypothesis of constant returns to scale is rejected at the 5 percent level of significance and returns to scale were found to be increasing (1.16).

Another consistent result of this study is that medium farms are the most efficient from technical, irrigation and irrigation technical cost efficiencies points of view. Empirical results confirm that medium farms present the highest technical efficiency with an average output-oriented technical efficiency estimate of 70.57 percent, ranges from a minimum of 12.82 percent to a maximum of 90.69 percent. This result means that a 29.43 percent increase in production is possible with the present state of technology and unchanged input uses, if technical inefficiency is completely removed. Thus, improving technical efficiency of medium farms will result in significant increases in the farmer revenue and profit.

Another important contribution is in terms of water irrigation efficiency – its mean estimate was the highest on medium farms, ranging from a minimum of 1.6 percent to a maximum of 98.87 percent with an average estimate of 55.63 percent. This implies that observed quantity of marketable citrus could have been maintained by using the observed values of other inputs while using 44.37 percent less irrigation water. This means that medium farmers can achieve significant savings in water use by improving the utilisation of irrigation system and by utilizing more advanced irrigation technologies with respect to small and large farmers.

In addition, for these farms, a reduction of a 1 $m^3$ of irrigation water would "cost" approximately 1.367 kilograms in terms of foregone quantities and 0.583 Tunisian Dinars in terms of foregone revenue, respectively. This in turn implies that the shadow price of irrigation water is equal to 0.583 Tunisian Dinars per $m^3$ for the medium farms, a value that is much higher than the market price charged in the study area, which varies between 0.09 and 0.1 Tunisian Dinars per $m^3$. This shadow price should be considered as the upper bound of the true shadow assumption that all other inputs are held constant at their observed levels, which might not be palatable for greater changes in the quantity of irrigation water.

Thus, cost savings that could be attained by adjusting irrigation water to its efficient level, would be small since its outlays constitute a small proportion of total cost. However, empirical results show that $ITCE_i$ is much higher than $IE_i$ for the different sizes. The estimated mean irrigation water technical cost efficiency is found to be 92.86 percent for medium farms indicating a potential decrease of 7 percent in total cost by adjusting irrigation water to its efficient level. Moreover, the majority of medium farms have achieved irrigation water technical cost efficiency greater than 92 percent. Thus, even though irrigation water is used least efficiently in a technical sense, it offers only few potential cost savings if it is adjusted to its technically efficient level for these farms.

The results of the inefficiency models reveal that farm size and farmer training (extension education) contributed significantly and positively to technical and water irrigation efficiency, while water disposable perception had a significant impact, but had an inverse relationship with water irrigation efficiency. A policy implication of the findings is that there is ample opportunity to increase the present level of efficiencies for citrus production in the study area, since extension education has a direct relationship with efficiency. Therefore, government policies should address ways of liberalizing access to extension services to meet the needs of the farmers.

Finally, this study's most important contribution to the continuing debate over the relationship between efficiency and farm size is an affirmation of the inverse relationship in the case of citrus growing farms in Tunisia. Through this lens, it is no surprise that medium farms are the more efficient users of productions factors, especially water.

Alternatively, one could imagine that those farmers who do engage in these practices are not doing so because of any improved input efficiency generated by good water management, but simply a mindset of sustainability that drives a motivation to reduce all inputs or to conserve water resources.

A further rationale for these initial results regarding increased technical water use efficiency with high quality agricultural practices is the price premium for these farmers. This highlights the need for government policies, through extension activities, to set up professional training programs in advanced irrigation techniques, which could be effective, particularly if targeted towards medium farmers with limited skills and in turn to stimulate decisions makers to encourage investment on irrigation equipment machinery by facilitating access to credit.

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