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Measuring Irrigation Water Efficiency with a Stochastic Production Frontier: An Application for Citrus Producing Farms in Tunisia

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Abstract

The objective of this paper is to propose an alternative measure of irrigation water efficiency based on the concept of input- specific technical efficiency, which contracts with measures previously used in the literature. The proposed methodology is applied to a randomly selected sample of 144 citrus growing farms located in Nabeul (Tunisia). A stochastic production frontier approach, based on Battese and Coelli's (1995) inefficiency effect model, is used to obtain farm-specific estimates of technical and irrigation water efficiency. In addition, a second-stage regression approach is used to identify the factors influencing irrigation water efficiency differentials across citrus growing farms. Results indicate that technical efficiency ranges from a minimum of 12.9% to a maximum of 90.7% with an average estimate of 67.7%. This suggests that citrus producers may increase their production by as much as 32.3% through more efficient use of production inputs. Further, mean irrigation water efficiency is found to be 53%, which is much lower than technical efficiency and also exhibits greater variability ranging from 1.6% to 98.87%. The 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 47.0% less of irrigation water. Moreover, the estimated mean irrigation water technical cost efficiency is found to be 70.81% indicating a potential decrease of 29.19% in total cost by adjusting irrigation water to its efficient level. In addition, the vast majority of farms have achieved irrigation water technical cost efficiency greater than 90% (71% of farms). Finally, the analysis of the sources of efficiency differentials among farmers showed that farmer's age, farm's size, education level, agricultural training, the share of productive trees and the water disposable perception tend to affect positively the degree of both technical and irrigation water efficiency.

Keywords; Citrus, Efficiency, Tunisia, Water,

Introduction

Irrigation water is becoming an increasingly scare resource for the agricultural sector in many regions and countries. A common ground in past policy schemes was the development of adequate irrigation infrastructure to guarantee the supply of irrigation water as the demand for agricultural products was increasing. However, these expansionary policies have resulted in a massive use of irrigation water at a heavily subsidized cost and physical scarcity. Water scarcity has become an increasing social and economic concern for policy makers and competitive water users. Particularly, agriculture is becoming the sector to which policy makers are pointing out at the core of the water problem.

Taking into account the limited water resources and the disparity between supply and demand often generated in conditions of dryness, Tunisia has engaged over the last three decades in a dynamic program of water mobilization. Agriculture remains as the biggest water consuming sector (more than 80% of the total demand) and accounts for approximately 12% of the GDP. The industrial sector and the tourism retain 5% and 1% of water resources, respectively. The service of water-drinking represents 11% in rural area; the service rate reached 80 % in 2000, whereas it did not exceed 38% in 1990.

Irrigated agriculture represents 35% of the output value derived from the agricultural sector, 20% of exports and 27% of agricultural employment (Ministry of Agriculture and Water Resources, 2003). Irrigated perimeters, contribute to 95% of the vegetable production, 70% of fruits and 30% of the dairy output. The average efficiency of the irrigation networks is relatively weak. It is estimated approximately 50% (Bachta and Ghersi, 2004).

The objective of this paper is to propose an alternative measure of irrigation water efficiency based on the concept of input- specific technical efficiency, which contracts with measures previously used in the literature. The proposed measure 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 decreased without altering the output produced and the quantities of other input used.

The remainder of this paper is organized as follows. In section 2, we present the methodological framework paying special attention to the measurement of irrigation water efficiency in the empirical model as well as explaining the efficiency differentials. In the same section, we describe also statistical data and variables used in the model. Section 3 presents the empirical results and discussions and section 4 concludes with some remarks on policy implications.

Methodological Framework

Measuring Irrigation Water Efficiency

Let technology be described by the following stochastic production frontier function (Karagiannis *et al.,* 2003):

$$y_i = f(x_i, w_i,; a) \exp (\varepsilon_i \equiv v_i - u_i) \qquad (1)$$

Where $i = 1,2,....,N$ refers to farms, $y \in R_+$ is the quantity of output produced, $x \in R_+^m$ is a vector of input quantities used, w is irrigation water, and ε_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), measurement errors and left-out explanatory variables, and a one-sided non-negative error term, $0 \leq u_i$, reflecting the shortfall of farm's output from its production frontier, due to the existence of technical inefficiency. Then, farm specific estimates of output-oriented technical efficiency are obtained as $TE_i^{\ 0} = \exp(-u_i)$ (Kumbhakar and Lovell, 2000), while farm-specific estimates of input oriented technical efficiency are derived by equation (1) with $y_i = f(v_i x_i , v_i w_i ; \alpha) \exp (v_i)$ and solving for $TE_i^{\ 1} = v_i$ (Atkinson and Cornwell, 1994; Reinhard *et al.,* 1999). Given strict monotonicity, both measures result in the same ranking but in different magnitude of efficiency scores. $TE_i^{\ 0}$ is greater, equal, or less than $TE_i^{\ 1}$ whenever returns to scale are decreasing, constant, or increasing, respectively (Fâre and Lovell, 1978).

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 non-radial notion of input specific technical efficiency (Kopp, 1981). 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:

$$IE^1 = [\min \{\lambda : f (x, \lambda w ; a) \geq y \}] \rightarrow (0, 1) \quad (2)$$

Irrigation water efficiency, as defined in (2), has an input-conserving interpretation, which however cannot be converted into a cost saving measure due to its non radial nature (Kopp, 1981). The proposed measure of irrigation water efficiency is illustrated in figure 1 (Karagiannis *et al.,* 2003).

Let the ith 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 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 the 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 ith farm technically efficient, is ($w_1 - w_3$). From figure 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 (Akridge, 1989).

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., $u_i = 0$, (1) may be rewritten as:

$$y_i = f (x_i, w_i^E; a) \exp (u_i) \qquad (3)$$

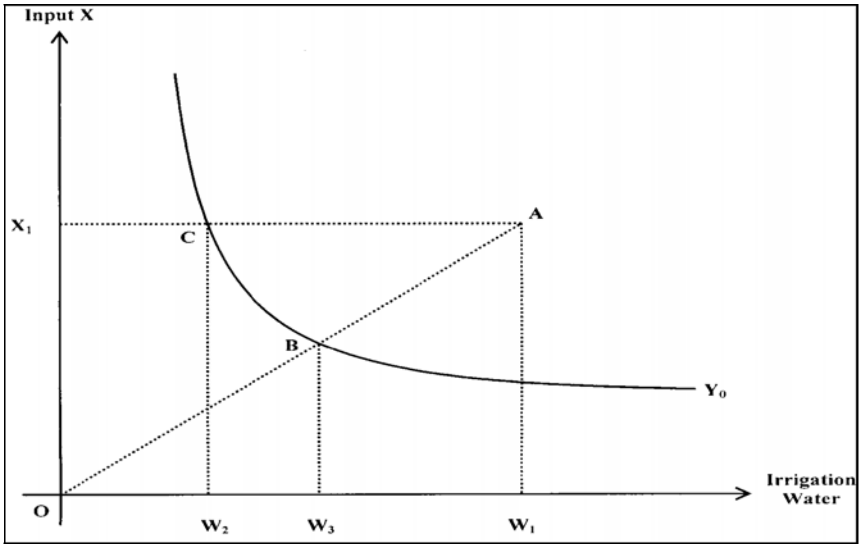

Fig. 1. Schematic measure of irrigation water efficiency

Wehere; $w_i^E = w_2$ (Reinhard *et al.,* 1999). Then, a measure of $IE_i^{\,1}$ can be obtained by equating (1) with (3) 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 (Kopp, 1981). 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 (1989), farm-specific estimates of $ITCE_i$ may be obtained as:

$$ITCE_i = S_{wi}\, IE_i^I + \sum_{j=1}^{J} S_{ji} \tag{4}$$

Where S_{wi} and S_{ji} are the ith farm's observed input cost shares for irrigation water and the jth input, respectively. Given that $0 < IE_i^{\,I} \leq 1$ and $S_{wi}\, IE_i^I + \sum_{j=1}^{J} S_{ji} = 1$ 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 (Kopp, 1981).

Empirical Model

Let the unknown production frontier (1) be approximated by the following *translog* specification:

$$\ln y_i = \alpha_0 + \sum_{j=1}^{J} \alpha_j \ln x_{ji} + \frac{1}{2}\left(\sum_{j=1}^{J}\sum_{k=1}^{J} \alpha_{jk} \ln x_{ji} \ln x_{ki}\right) + \alpha_w \ln w_i + \frac{1}{2}\left(\alpha_{ww} \ln w_i^2 + \sum_{j=1}^{J} \alpha_{jw} \ln x_{ji} \ln w_i\right) + v_i - u_i \tag{5}$$

Using the Battese and Coelli's (1995) inefficiency effect model, the one-sided error term is specified as:

$$u_i + g(z_i;\ \delta) + w_i \tag{6}$$

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 random variable with zero mean and variance defined by the truncation of the normal distribution such that $w_i \geq -[g(z_i;\ \delta)]$. The model (5) and (6) can be estimated econometrically in a single stage using ML techniques and the frontier (version 4.1) computer package developed by Coelli (1992). 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:

$$TE_i^0 = E\{\exp(-u_i/\varepsilon_i)\} = \exp\left[\left(-\mu_i^0 + 0.5\,G_0^2\right)\left(\frac{\phi[(\mu_i^0/G_0) - G_0]}{\phi(\mu_i^0/G_0)}\right)\right] \tag{7}$$

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 (3) and the following relations developed by Reinhard *et al.,* (1999) for the translog specification (5):

$$IE_i^I = \exp\left[\left\{-\xi_i \pm \left(\sqrt{\xi_i^2 - 2\alpha_{ww}u_i}\right)\right\}/\alpha_{ww}\right] \tag{8}$$

Where,

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

Given weak monotonicity, a technical efficient farm is also irrigation water efficient and thus, only the positive root of (8) is used.

Explaining Efficiency Differentials

One of the advantages of Battese and Coelli (1995) model is that allows measurement of TE_i^0

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 ML estimation (Reifschneider and Stevenson, 1991; Kumhakar *et al.,* 1991; Battese and Coelli, 1995). However, the two stage estimation procedure can be used with no problem for identifying the factors influencing irrigation water efficiency differentials across farms as IE_i is calculated from the parameter estimates and the estimated one sided error component of the stochastic production frontier in (1), and it is not directly related to distributional assumptions. The relevant second stage regression model has the following form:

$$\text{Ln } IE_i = h(z_i, \delta) + e_i \tag{9}$$

Where h (*) is deterministic Kernel of the regression model, δ 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.

Table 1. Summary statistics of the variables used in the frontier model for citrus producing farms in Tunisia.

Notation	Variables	Mean	Standard Deviation	Min	Max
P	Production (in Kg)	47814.27	54577.96	2096.76	415129.1
S	Area (in Ha)	2.61	3.04	0.2	18,5
L	Labour (in Working Days)	428.44	364.93	46.5	2950.0
CI	Chemical Inputs (in TD)	1937.83	2491.76	0.00	14000.0
IW	Irrigation Water (in m^3)	97.90	121.83	0.00	900.00
OC	Other Costs (in TD)	631.77	1206.49	0.00	11300.00
AF	Age of Farmer (in years)	55.88	10.64	29.00	80.00
SFL	Share of Family Labour (in %)	0.68	0.36	0.00	1.00
SPT	Share of Productive Trees (in %)	0.86	0.19	0.00	1.00

Note: 1TD =0.65 Euros.
Source: Own elaboration from citrus growing farms in Tunisia

Data and Variables Definitions

A panel data of 144 Tunisian citrus producing farms covering the 2002-2003; 2003-2004 and 2004-2005 periods are collected from surveys conducted in 2 delegations of the governorate of Nabeul, Tunisia. The choice of this region is justified by its importance in the national citrus production, transformation and exports sector. Indeed, according to the Ministry of Agricultural statistics, this region represents 1.7% of national agricultural land; it contributes 80% for national citrus production and for more than 90% of national citrus exports.

As we posed at the outset, in the empirical analysis, the dependent variable is the total annual citrus production measured in Kg. 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 (TD); (4) irrigation water measured in m^3; and (5) other costs, comprising the rest of inputs used in producing citrus (mechanisation, etc.) and measured in Tunisian Dinars. Summary statistics of these variables is given in table 1.

Results and Discussion

Production Structure

The estimated parameters of the *translog* stochastic production frontier are presented in table 2. From this table it appears that all the first-order parameters (α_i) have the anticipated (positive) sign and magnitude. On the other hand, the ratio of farm specific to total variability, γ, is positive and statistically significant at the 5% level. The value of 0.81 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 farmer (weather, diseases, etc.).

Average estimates of production elasticities and returns to scale for the region of study under consideration showed that production elasticities of all five inputs are positive. They indicate that in Nabeul region chemical inputs are the foremost important inputs followed by irrigation water (0.321), other costs (0.235) and land (0.133), while labour has the lowest point estimate, with an average standing at 0.117. In economics terms, this latter means that holding all other inputs constant, a 1% reduction in irrigation water requires a sacrifice of 0.298% of marketable output. On the other hand, the hypothesis of constant returns to scale is rejected at the 5% level of significance, and returns to scale were found to be increasing (1.106).

A shadow price of irrigation water may be computed by using the mean values of the relevant variables reported in table 1 and the estimated production elasticity of irrigation water. By combining these figures we find that a reduction of 0.979 m^3 of irrigation water would “cost” approximately 1.42486 kilograms in terms of forgone quantities and 0.5429 Tunisian Dinars in terms of forgone revenue. This in turn implies that the shadow price of irrigation water is equal to 0.546 Tunisian Dinars per m^3, a value that is much higher than the market price charged in Nabeul region, (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.

Technical and Irrigation Water Efficiency

Results for estimates of technical efficiency ($TE^0{}_i$), irrigation efficiency ($IE^1{}_i$), and irrigation water technical cost efficiency ($ITCE_i$) are showed in table 3 in the form of frequency distribution within a deciles range. The estimated mean output-oriented technical efficiency ranges from a minimum of 12.8% to a maximum of 90.7% with an average estimate of 67.7%. This result means that 32.3% 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 will result in significant increases in framer’s revenue and profit.

On the other hand, mean irrigation water efficiency is found to be 53%, which is much lower than technical efficiency and also exhibits greater variability ranging from 1.6% to 98.87%. The 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 47.0% less of irrigation water. This means that farmer’s can achieve significant savings in water use by improving the utilisation of irrigation system and by utilizing more advanced irrigation techniques.

Moreover, cost savings that could be attained by adjusting irrigation water to its efficient level, would be small since its outlays constitute a small proportion

Table 2: Parameter estimates and t-values of the frontier model of a sample of Tunisian citrus producing farms.

Parameters	Estimates	t-Student
Stochastic Frontier Model		
Cte	0.43	5.89**
Ln(S)	0.34	2.98**
Ln(L)	0.03	0.34
Ln(CI)	0.22	3.83**
Ln(IW)	0.33	3.39**
Ln(OC)	0.24	0.51
$Ln(S)^2$	-0.19	-3.91**
$Ln(L)^2$	0.16	2.43**
$Ln(CI)^2$	0.067	2.37**
$Ln(IW)^2$	-0.029	-0.54
$Ln(OC)^2$	-0.003	-0.029
Ln(S)*Ln(L)	0.98	3.87**
Ln(S)*Ln(CI)	-0.38	-2.52**
Ln(S)*Ln(IW)	0.002	1.12
Ln(S)*Ln(OC)	0.79	3.27**
Ln(L)*Ln(CI)	-0.07	-0.43
Ln(L)*Ln(IW)	0.017	2.95**
Ln(L)*Ln(OC)	-0.74	-3.38**
Ln(CI)*Ln(IW)	-0.08	2.25**
Ln(CI)*Ln(OC)	0.44	3.23**
Ln(IW)* Ln(OC)	0.065	4.21**
Variance Parameter		
σ^2	0.38	4.86**
γ	0.81	8.45**
Log-Likelihood	-79.46	

Notes: **: indicates significance at the 5% level; *: indicates significance at 10% level.

Table 3: Efficiency ratings of a sample of Tunisian citrus producing farms

Efficiency (%)	**IE^I**	**TE^O**	**ITCE**
N	**144**	**144**	**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

Source: Own elaboration from citrus growing farms in Tunisia of total cost. For this reason, the estimated mean $ITCE_t$ is much higher than IE^I_i. Results from table 3 showed that the estimated mean irrigation water technical cost efficiency is found to be 70.81% indicating a potential decrease of 29.19% in total cost by adjusting irrigation water to its efficient level. In addition, the vast majority of farms have achieved irrigation water technical cost efficiency greater than 90% (71% of farms).

Thus, even though irrigation water is used least efficiently in technical sense, it offers only few potential cost savings if it is adjusted to its technically efficient level. In order to enrich the analysis, the second step of the analysis addresses the sources of efficiency differentials among farmers. For this reason, the inefficiency effects model (equation 6) and the second stage regression (equation 9) have been estimated. Estimation results from theses models are presented in table 4.

In the first 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 and the variable under consideration, while in the latter a positive sign depicts a positive relationship between irrigation water efficiency and the corresponding variable.

According to the empirical findings, farmer's age squared does not seem to affect either technical or irrigation water efficiency. In contrast the farmer's age affect positively technical and irrigation water efficiency. This finding indicates that young farmer's are becoming relatively more technically efficient over time by improving learning by doing. On the other hand, farm's size, education level, agricultural training, the share of productive trees and the water disposable perception tend to affect positively the degree of both technical and irrigation water efficiency. Finally, it is important to note that the share of family labour affect positively the efficient use of irrigation water, but negatively technical efficiency.

Table 4: Explaining efficiency differentials.

Parameter	TE^O		IE^I	
	Estimate	Std Error	Estimate	Std Error
δ_0	0.911	0.291	1.415	0.5068
δ_{FS}	-0.0079	0.0044	-0.0016	0.0078
δ_{AG}	-0.0073	0.0106	-0.0197	0.0174
δ_{AAGG}	0.000008	0.0000	0.0001	0.00015
δ_{EDC}	-0.0081	0.0334	-0.0177	0.0580
δ_{AT}	-0.012	0.0381	-0.0132	0.0661
δ_{FL}	0.007	0.0422	-0.0184	0.0733
δ_{SPT}	-0.035	0.0673	-0.1351	0.1168
δ_{WDP}	-0.012	0.0295	-0.0154	0.0512
R^2			**0.42**	

Notes: FS: is the farm's size in hectares; AG and AAGG: is the farmer's age and age squared in years; EDC: is the level of schooling (1: illiterate; 2: primary level; 3: secondary level and 4: high school level); AT: 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 % and WDP: is a dummy variable indicating water disposable perception by farmer's.

Concluding Remarks

Our major task is to propose an alternative measure of irrigation water efficiency based on the concept of input- specific technical efficiency. The proposed methodology is applied to a randomly selected sample of 144 citrus growing farms located in Nabeul, Tunisia. A stochastic production frontier approach, based on Battese and Coelli's (1995) inefficiency effect model, is used to obtain farm-specific estimates of technical and irrigation water efficiency. In addition, a second-stage regression approach is used to identify the factors influencing irrigation water efficiency differentials across citrus growing farms.

Empirical results concerning the estimated parameters of the *translog* stochastic production frontier indicate that the technical inefficiency effects are in fact stochastic and a significant part of output variability is explained by the existing differences in the degree of output-oriented technical inefficiency.

According to our findings, the estimated production elasticities of all five inputs are positive. They indicate that in Nabeul region chemical inputs are the foremost important inputs followed by irrigation water, other costs and land, while labour has the lowest point estimate, with an average of 0.117. In economics terms, this latter means that holding all other inputs constant, a 1% reduction in irrigation water requires a sacrifice of 2.98% of marketable output. On the other hand returns to scale were found to be increasing (1.106).

Results for estimates of technical efficiency (TE^0_i) indicate that the estimated mean output-oriented technical efficiency ranges from a minimum of 12.9% to a maximum of 90.7% with an average estimate of 67.7%. This result means that a 32.3% 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 will result into significant increases in farmers' profits. On the other hand, mean irrigation water efficiency (IE^I_i) is found to be 53%, which is much lower than technical efficiency and also exhibits greater variability ranging from 1.6% to 98.87%. The 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 47.0% less of irrigation water. This means that farmer's can achieve significant savings in water use by improving the utilisation of irrigation system and by utilizing more advanced irrigation techniques. Moreover, 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. For this reason, the estimated mean $ITCE_t$ is much higher than IE^I_i. Results showed that the estimated mean irrigation water technical cost efficiency is 70.81%, indicating a potential decrease of 29.19% in total cost by adjusting irrigation water to its efficient level. In addition, the vast majority of farms have achieved irrigation water technical cost efficiency greater than 90% (71% of farms). Thus, even though irrigation water is used least efficiently in technical sense, it offers only few potential cost savings if it is adjusted to its technically efficient level.

Finally, the analysis of the sources of efficiency differentials among farmers showed that farmer's age affect positively technical and irrigation water efficiency. This finding indicates that young farmer's are becoming relatively more technically efficient over time by improving their techniques. On the other hand, farm's size, education level, agricultural training, the share of productive trees and the perception of water availability tend to affect positively the degree of both technical and irrigation water efficiency. This highlights the need for government policies, through extension activities, not only to set up training programs on conducting citrus and improving pruning and irrigation techniques but also to encouraging the setting up and implementation of a rejuvenating pruning program for old citrus plantations.

References

Aigner, D. J. Lovell, C. A. K. and P. Schmidt. 1977. "Formulation and estimation of stochastic frontier production function model's". Journal of Econometrics 6: 21-37.

Akridge, J. T. 1989. "Measuring productive efficiency in multiple product agribusiness firms: A dual approach". American Journal of Agricultural Economics 71: 116-125.

Atkinson, S. E. and C. Cornwell. 1994. "Estimation of output and input technical efficiency using a flexible functional form and panel data". International Economic Review 35: 245-255.

Bachata, M.S. and G. Ghersi. 2004. Agriculture et alimentation en méditerranée : Les défis de la mondialisation. KAHRTALA

Battese, G. E. and T.J. Coelli. 1995. "A model for technical inefficiency effects in a stochastic frontier production function for panel data". Empirical Economics 20: 325–332.

Coelli, T. J. 1992. "A computer program for frontier production function estimation: Frontier version 2.0". Economics Letters 39: 29-32.

Fare, R. and C.A.K. Lovell. 1978. "Measuring the technical efficiency of production". Journal of Economic Theory 19: 150-162.

Karagiannis, G. Tzouvelekas, V. and A. Xepapadeas. 2003. "Measuring irrigation water efficiency with a stochastic production frontier: An application to Greek out-of-season vegetable cultivation". Environmental and Resource Economics 26: 57–72.

Kopp, R. J. 1981. "The measurement of productive efficiency: A reconsideration". Quarterly Journal of Economics 96: 477-503.

Kumbhakar, S. C. and C.A.K. Lovell. 2000. Stochastic Frontier Analysis. New York: Cambridge University Press.

Kumbhakar, S. C. Ghosh, S. and J.T. McGuckin. 1991. "A generalised production frontier approach for estimating determinants of inefficiency in U.S. Dairy farms". Journal of Business and Economic statistics 9: 279-286.

Reifschneider, D. and R. Stevenson. 1991. „Systematic departures from the frontier: A framework for the analysis of firm inefficiency". International Economic review 32: 715-723.

Reinhard, S. Lovell, C. A. K. and G.J. Thijssen. 1999. "Econometric estimation of technical and environmental efficiency: An application to Dutch dairy farms". American Journal of Agricultural Economics 81: 44-60.

Stevenson, R. E. 1980. "Likelihood functions for generalised stochastic frontier estimation". Journal of Econometrics 13: 58-66.