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Abstract

This paper investigates farm level technical inefficiency of production and its determinants in a sample of 150 citrus producing farms in Tunisia using a stochastic frontier production function approach applied to cross section data. Results indicate that technical efficiency of production in the sample of citrus producing farms investigated ranges from a minimum of 26.84% to a maximum of 97.98% with an average technical efficiency estimate of 86.23%. This suggests that citrus producers may increase their production by as much as 13.77% through more efficient use of production inputs. Further, the estimated coefficients in the technical inefficiency model indicate the positive effect on technical efficiency of the share of productive trees, the agricultural training, irrigation operations and the experience of farmer.

Keywords: Technical Efficiency, stochastic frontier production function, citrus farms, Tunisia.

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1. Introduction

The crucial role of efficiency gains in increasing agricultural output has been widely recognized in the research and policy arenas. It is not surprising; therefore, that considerable effort has been devoted to the measurement and analysis of productive efficiency, which has been the subject of a myriad of theoretical and empirical studies for several decades since Farrell's (1957) seminal work. Forsund, Lovell and Schmidt (1980) provide in an earlier survey an overview of various approaches to frontier analysis and efficiency measurement. More recent surveys of these techniques include Bauer (1990), Battese (1992) and Greene (1993).

Equally important in the analysis of production efficiency is to go beyond the measurement of performance and examine exogenous influences on efficiency. To this end, exogenous variables characterizing the environment in which production occurs have been incorporated into efficiency measurement models in a variety of ways. Early contributions to the literature on this issue include Pitt and Lee (1981) and Kalirajan (1981). These applications adopted a two-step formulation. More recently, approaches to the incorporation of exogenous influences have been refined and significant improvements in modelling technical inefficiency effects in stochastic frontier models opened new directions for empirical analysis (Kumbhakar and Lovell, 2000).

This paper contributes to the rare literature on firm level efficiency measurement and explanation using a stochastic frontier production model with technical inefficiency effects for cross section. This formulation has the advantages of simultaneously estimating the parameters of the stochastic frontier and the inefficiency models, given appropriate distributional assumptions associated with the error terms.

The stochastic frontier model is applied to a sample of Tunisian citrus producing farms in order to provide empirical evidence on the sources of technical inefficiency in the sector.

Measuring technical efficiency in the citrus sector is important for a number of reasons. First, the citrus sector is an important ingredient in the Tunisian economy in terms of employment and income generation. In the year 2005, this sector produced 0,243 millions tons of citrus, which amounted to 2.5% of the value of agricultural production and contributed to 0.5% in the growth of domestic product.

Furthermore, citrus production, which grew at an annual rate of 2.71% during the 2002-2005 period, is an important source of foreign exchange earnings, accounting for 10% of agricultural exports. Second, Tunisia's implementation of the free trade agreement with the EU (signed in 1995) should, over the next decade, lead to the elimination of tariffs and other trade barriers on a wide range of goods and services traded with the EU. The citrus sector, in particular, is coming under increasing international competition, which calls for a major concern for only efficient farms are likely to stand the competitive pressure in the ever changing world economy. Third, in spite of the importance of this sector in the national economy, an important policy issue in the last two decades has been to make this sector more competitive by furthering production growth and increasing exports. Knowledge of the relative contribution of factors productivity and input use to output growth and improvements in technical efficiency is crucial to provide a comprehensive view of the state of the citrus producing sector in the country and help farm managers and policy makers draw appropriate policy measures.

The objectives of this paper are twofold. First, we measure the technical efficiency of a sample of citrus producing in Tunisia. Second, we analyse the determinants of technical efficiency variation among these farms.

To achieve the mentioned objectives, the remainder of the paper is organized as follows. In section 2, we present the theoretical background of the stochastic frontier model. In section 3, we describe the frontier/inefficiency models assumed for the sample of Tunisian citrus producing farms. Section 4 presents the empirical results and discussions, and section 5 concludes with some remarks on policy implications.

2. Theoretical Background

Since the stochastic production frontier model was first, and nearly simultaneously, published by Meeusen and van den Broeck (1977) and Aigner, Lovell and Schmidt (1977), there has been considerable research to extend the model and explore exogenous influences on producer performance. 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].

Recently, Kumbhakar, Ghosh and McGuckin (1991), Reifschneider and Stevenson (1991) and Huang and Liu (1994) 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 (1995) formulated a stochastic frontier production model similar to that of Huang and Liu and specified for panel data. In this study, we adopt the Battese and Coelli 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 function. The second equation, which captures the effects of technical inefficiency, has a systematic component $\delta' z_i$ associated with the exogenous variables and a random component ε_i :

$$LnY_i = Lnf(x_i;\beta) + v_i - u_i \quad (1)$$

$$u_i = \delta' z_i + \varepsilon_i \quad (2)$$

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 β is a vector of unknown parameters to be estimated. The non-negativity condition on u_i is modelled as $\varepsilon_i \sim \mathrm{N}\,(0, \sigma_\varepsilon^2)$ with the distribution of ε_i being bounded below by the

[1] In the first stage of this formulation, the stochastic frontier model is estimated and the residuals are decomposed using the Jondrow *et al.* (1982) 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.

truncation point $-\delta' z_i$. Finally, v_i are assumed to be independent and identically distributed N (0, σ_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:

$$TE_i = \exp(-u_i) = \exp(-\delta' z_i - \varepsilon_i) \qquad (3)$$

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

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

Where,

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

$$\sigma_*^2 = \frac{\sigma_v^2\, \sigma_u^2}{\sigma_v^2 + \sigma_u^2} \qquad (6)$$

3. A Frontier/Inefficiency Model for Tunisian Citrus Producing Farms

To implement the above-specified model, mean cross-section data on 150 Tunisian citrus producing farms in the Nabeul region (Tunisia) covering the 2002-2003; 2003-2004 and 2004-2005 periods are used. 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 for 80% for national citrus production and for more than 90% for national citrus exportation.

As we posed at the outset, data on output, production inputs (labour, land, fertilizers, pesticides, water, fuel, etc.) and other explanatory variables such as the share of family labour, the share of citrus productive trees, farmer's age and its square, farmer's education,

[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 (1993).

farmer's training and irrigation were chosen for the representation of the underlying *translog* functional form. The Source of these data is the survey carried out in the *Nabeul* region by the *Department of Agricultural Economics of the National Research Institute of Tunisia (INRA-Tunisia)*. Summary statistics of these variables is given in table 1.

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
A	Land in Ha	2.61	3.04	0.2	18,5
L	Labour in Working Days	428.44	364.93	46.5	2950.0
F	Fertilisation in TD	1937.83	2491.76	0.00	14000.0
OC	Other Costs in TD	1715.29	2349.46	81.66	16714.67

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

Given the above, the stochastic frontier production model to be estimated is defined in equation (7) and the technical inefficiency effects are defined in equation (8) as follows:

$$\begin{aligned} LnY_i &= \beta_0 + \beta_1 LnA_i + \beta_2 LnL_i + \beta_3 LnF_i + \beta_4 LnOC_i \\ &+ 1/2\beta_5 (LnA_i)^2 + 1/2\beta_6 (LnL_i)^2 + 1/2\beta_7 (LnF_i)^2 + 1/2\beta_8 (LnOC_i)^2 + \beta_9 LnA_i LnL_i \\ &+ \beta_{10} LnA_i LnF_i + \beta_{11} LnA_i LnOC_i + \beta_{12} LnL_i LnF_i + \beta_{13} LnL_i LnOC_i + \beta_{14} LnF_i LnOC_i \\ &+ v_i - u_i \end{aligned} \quad (7)$$

$$\begin{aligned} u_i &= \delta_0 + \delta_1 (FL)_i + \delta_2 (PPP)_i + \delta_3 (AGT)_i + \delta_4 (IRI)_i \\ &+ \delta_5 (EDU)_i + +\delta_6 (FA)_i + \delta_7 (FSA)_i \, \varepsilon_i \end{aligned} \quad (8)$$

Where:

- Y_i is citrus production of the i-th farmer in Kg;
- A_i is the land of the i-th farmer in Hectares;
- L_i is total hired labour by the i-th farmer (permanent and casual), family and contract labour, measured in working Days;
- F_i is the fertilizers including nitrogenous, phosphate, potash, complex and other, measured in Tunisian Dinars;

- OC_i is the other costs expenses, consisting of pesticides, fuel, mechanization, irrigation taxes and other miscellaneous expenses, measured in Tunisian Dinars;
- FL is the share of family labour;
- PPP is the share of citrus productive trees (10 to 40 years old);
- AGT is agricultural training dummy variable, = 1 if the farmer has gone through agricultural training, 0 otherwise;
- IRI is water disposable perception dummy variable, = 1 if the farmer considered that disposable water is sufficient, 0 otherwise;
- EDU is education dummy variable, = 1 if farmer accumulated at least 6 years of schooling, 0 otherwise;
- FA is the farmer's age, measured in years;
- FSA is the square of farmer's age measured in years; and
- v_i and ε_i are random errors.

4. Empirical Results and Discussions

Maximum likelihood estimates of the parameters of the *translog* stochastic frontier production and the technical inefficiency effects models are obtained using the computer package FRONTIER version 4.1 (Coelli, 1996). Parameters estimates, along with the standard errors and T-ratios of the ML estimators of the Tunisian citrus producing farms inefficiency frontier model are presented in table 2. The signs of the estimated parameters of the *translog* stochastic frontier production model are as expected. Estimated coefficients for land, labour, fertilizers and for other costs are positive and significant, which confirms the expected positive relationship between these production factors and citrus production.

Estimated partial production elasticities with respect to these production factors indicated that land impact factor is greater than labour, fertilizers and other cost factors. The value of these elasticities for land, labour, fertilizers and other costs are 0.46, 0.14, 0.22 and 0.21, respectively. These results reflect the economic reality of citrus producing farms in the region, subject of study. Indeed, citrus production is principally related with land, fertilization and water. The labour factor appears with a minimal effect on the production since the high share of family labour.

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

Parameters	Estimates	t-Student
Stochastic Frontier Model		
Cte	0.24	1.56**
Ln(A)	0.29	3.14*
Ln(L)	0.21	1.88**
Ln(F)	0.23	2.96*
Ln(OC)	0.26	2.94*
$Ln(A)^2$	-0.62	-5.53*
$Ln(L)^2$	0.03	0.24
$Ln(F)^2$	-0.0056	-0.13
$Ln(OC)^2$	-0.41	-2.93*
Ln(A)*Ln(L)	0.98	3.87*
Ln(A)*Ln(F)	-0.38	-2.52*
Ln(A)*Ln(OC)	0.79	3.27*
Ln(L)*Ln(F)	-0.07	-0.43
Ln(L)*Ln(OC)	-0.74	-3.38*
Ln(F)* Ln(OC)	0.44	3.23*
Partial Production Elasticity		
$E_{P/A}$	0.46	-
$E_{P/L}$	0.14	-
$E_{P/F}$	0.22	-
$E_{P/OC}$	0.21	-
Returns to Scale	**1.03**	
Inefficiency Effects Model		
Cte	-1.18	-0.98
FL	0.28	0.93
PPP	-1.15	-4.99*
AGT	-0.44	-1.65**
IRI	-0.21	-1.56**
EDU	-0.29	-1.92**
FA	0.08	1.97*
FSA	-0.0007	-1.89**
Variance Parameter		
σ^2	0.13	2.35*
γ	0.20	5.05*
Log-Likelihood	-54.81	

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

The estimated coefficients in the technical inefficiency model are also as expected. The estimated coefficient of the share of productive trees (PPP) is negative and statistically significant at 5% level, which indicates their positive effect on technical efficiency. With respect to the farmer training (AGT), variable of particular interest to policy maker, is negative and significant. Consequently, the negative and statistically significant at the 10%

level coefficient suggests that an increase in the training programs related to the citrus contributes to higher technical efficiency levels of citrus production on these farms. Education (EDU) also has a positive impact on technical efficiency. Schooling helps farmers to use information efficiently since a better educated farmer acquires more information and is able to produce from a given input vector. In addition, the estimated coefficients of water disposable perception (IRI) in the technical inefficiency model are negative and significant at 10%. This implies their positive effect on technical efficiency. Finally, the coefficient measured the square age of the farmer, is also negative and statistically significant at 10% level. This result supports the notion of increasing returns to experience.

However, family labour (FL) and farmer age (FA) variable, used as a proxy of experience and learning by doing, have a positive relationship with technical inefficiency. The value and positive sign of FL and FA, suggest that technical efficiency declines with the share of the family labour and with the farmer age.

Finally, and according to the results reported in table 2, the production is characterised by increasing returns to scale, which on average was 1.03 during the period of study (2003-2005). This implies that the contribution of the scale effect to output growth would be positive as far as output increases.

The estimate for the variance parameter γ significantly different from zero implies that the inefficiency effects are significant in determining the level and the variability of the citrus producing farms. Further, a number of statistical tests of hypotheses for the parameters of the stochastic frontier inefficiency model are carried out and results are presented in table 3[3]. The validity of the *translog* specification over the Cobb-Douglass one, the first null hypothesis $\beta_{ij} = 0$ for all i, j, is strongly rejected.

Thus the *translog* specification is found to be a better representation of the technology than the Cobb-Douglass specification. The second null hypothesis of no inefficiency effects in the

[3] All tests of hypotheses are obtained using a Generalised likelihood-ratio statistic. This statistic has a chi-square distribution and is defined by $\lambda = -2(\ln L(H_0) - \ln L(H_1))$, where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the specification of the null hypothesis, H_0, and the alternative hypothesis, H_1.

model is also rejected at the 5% level of significance. The third null hypothesis, which specifies that no firm specific factor makes a significant contribution to the explanation of the inefficiency effects, is rejected.

Table 3: Tests of hypotheses for the parameters of the stochastic frontier inefficiency model of a sample of Tunisian citrus producing farms.

Null Hypotheses	Log-likelihood ratio	d.f	Critical value at 5%	Decision
Cobb-Douglass $\beta_5=\beta_6=\beta_7=\beta_8=\beta_9=\beta_{10}=\beta_{11}=\beta_{12}=\beta_{13}=\beta_{14}=0$	45.40	10	18.3	Reject de H_0
No inefficiency effects $\gamma=\delta_o=\delta_1=\delta_2=\delta_3=\delta_4=\delta_5=\delta_6=\delta_7=0$	31.67	9	16.9	Reject de H_0
No firm specific effects $\delta_1=\delta_2=\delta_3=\delta_4=\delta_5=\delta_6=\delta_7=0$	29.06	7	14.1	Reject de H_0

Notes: The value of the log-likelihood function under the specification of alternative hypothesis (i.e. unrestricted model) is -70.65.

Frequency distribution results of technical efficiency are presented in table 4. Estimated efficiency measures reveal the existence of substantial technical inefficiencies of production in the sample of citrus producing farms at hand. The computed average technical efficiency is 86.23% ranging from a minimum of 26.84% to a maximum of 97.98%. Given the present state of technology and input levels, this suggests that firms in the sample are producing on average at 86% of their potential.

In addition, during the consideration period of analysis (2003-2005), most farms in the sample (98%) have consistently achieved efficiency scores greater than 50%. This result implies that improvement of technical efficiency should be the first logical step for considerably increasing citrus production in the study region. Further, considering that international competition is increasing and environment regulations are being tightened, the potential for increasing production by using more traditional inputs is limited.

The contribution of land is expected to decrease in the future for the parcelling of land due to the heritage tradition. In this aspect, the decisions makers need to set up land programs in order to ovoid this parcelling and to tray together the smallest farmers in a cooperative system.

Further, the quantity increase of labour will have only limited effect on citrus production. Thus, the improvement of labour quality is the unique feather for considerable citrus production growth. In practice skilled labour and agricultural training particularly used for pruning are associated with higher levels of technical efficiency. This highlights the need for government policies, through extension activities, to set up training programs on conducting citrus plantation, in general, and improving pruning techniques, in particular.

The increase of modern inputs (fertilizers, pesticides, chemical products, etc..) is dissuade today for environment and consumers reasons. Another component of intermediate consumption is machinery and his increase will have a considerable effect on technical efficiency, especially for the machinery of irrigation use. This highlights the need for government policies to encouraging inversion in this type of machinery by facility credit access at lowest interest rates Moreover, irrigation operations should be encouraged whenever water is available.

Table 4: Frequency distribution of technical efficiency of production estimates for a sample of Tunisian citrus producing farms.

Technical Efficiency (%)	Citrus producing farms	Percentage
ET ≤ 20	0	0.00
20 < ET ≤ 30	1	0.06
30 < ET ≤ 40	0	0.00
40 < ET ≤ 50	2	1.33
50 < ET ≤ 60	5	3.33
60 < ET ≤ 70	8	5.33
70< ET ≤ 80	17	11.33
80< ET ≤ 90	37	24.66
ET > 90	80	53.33
Mean Efficiency	86.23	
Min. Efficiency	26.84	
Max. Efficiency	97.98	

Source: Own elaboration from citrus producing farms in Tunisia.

5. Conclusions and Policy Implications

In this paper, farm level technical efficiency of production and its determinants are investigated in a sample of 150 citrus producing farms located in the main citrus production region in Tunisia using a stochastic frontier production model. The data used in this study were gathered through a survey carried out by the *Department of Agricultural Economics of the National Research Institute of Tunisia (INRA-Tunisia)* during the periods 2002-2003, 2003-2004 and 2004-2005.

Selection results among different functional forms demonstrate that *translog* specification is found to be the better representation of technology. The estimated coefficients of land, labour, fertilizers and other cost factors are positive and significant at 10% significance level. To asses the impacts of these factors, partial production elasticities have been calculated. Empirical findings shown that land and fertilizers factors are the greeters among these inputs factors

Estimation results from the technical inefficiency effects model suggest that the share of productive trees (PPP), the agricultural training (AGT), the water disposable perception (IRI), the education level (EDU) of the farmer and the square age of the farmer (FSA) variables have a significant and positive relationship with technical efficiency. On the other hand, a negative relationship between technical efficiency and the share of family labour (FL) and the age of the farmer (FA) variables is found.

Empirical findings show that estimated technical efficiency of citrus production in the sample varied widely, ranging from 26.84% to 97.98, with a mean value of 86%. This suggests that, on average, citrus producing farmers could increase their production by as much as 14% through more efficient use of production inputs. This result implies that improvement of technical efficiency should be the first logical step for considerably increasing citrus production in the study region. Further, considering that international competition is increasing and environment regulations are being tightened, the potential for increasing production by using more traditional inputs is limited.

Indeed, technical efficiency increases when the share of productive citrus trees (PPP), aged between 10 and 40 years old, is high. This highlights the need for government policies to encouraging the setting up and implementation of a rejuvenating pruning program for old citrus plantations.

Further, education level (EDU) and agricultural training (AGT) particularly used for pruning are associated with higher levels of technical efficiency. This highlights the need for government policies, through extension activities, to set up training programs on conducting citrus plantation, in general, and improving pruning techniques, in particular.

Finally, technical efficiency decreases when the percentage of family labour within citrus trees is high. However, technical efficiency can be improved by the resort to skilled labour.

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