

Stochastic Production Frontiers and Decomposition of Output Growth: The Case of Citrus-Growing Farms in Tunisia

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Abstract: The aim of this paper is to investigate the relative contribution of technical efficiency, technological change and increased input use to the output growth of the Tunisian citrus growing farms using a stochastic frontier production function approach applied to panel data for the period 2003-2005. 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 proposed methodology is based on the use of a flexible *translog* functional form. Results indicate that technical efficiency of production in citrus producing farms investigated ranges from a minimum of 11.19% to a maximum of 96.82% with an average technical efficiency estimate of 49.97%. This suggests that citrus producers may increase their production by as much as 50.03% through more efficient use of production inputs. Furthermore, the production is characterized by increasing returns to scale, which on average was 1.057. Finally, investigation of the sources of production growth reveals that the contribution of total factor productivity is found to be the main source of that growth.

Key words: Citrus sector, Tunisia, productivity, technical change, technical efficiency.

1. Introduction

Tunisian arboriculture occupy an important place in the agricultural sector, contributing with nearly 36% of the added value, where the citrus fruits take part with non negligible value (10%), after olives (33%) and dates (14%). Citrus fruits production remains tradition in Tunisia. It extends on a surface of 18,600 ha distributed between 11,654 farms with more than 4.67 millions plants. It represents 0.7% of Tunisian arboriculture area, and 5% of irrigated surface [1]. This surface does not cease rising recording an increase rate of 12% between 1999 and 2005 with 9% in the area of

Cap Bon, the principal producing area [2].

The citrus sector plays an important role in the socio-economic life, remaining the fact that allows to supply fresh fruit to the interior market for a period going up to six months per year. Moreover, it brings back to the equivalent on average of 15 million dinars in currency. This represents 3% of the food trade exports balance. In terms of employment, the citrus fruits sector employs more than 25,000 occasional workers and approximately 7,000 permanent workers [2]. Moreover, it contributes to the creation of an industrial dynamics for the stations of conditioning to export and a commercial dynamics for the local market.

The citrus sector, in particular, is coming under increasing international competition, which calls for a major concern for only efficient farms, which are

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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.

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 [3] seminal work. Forsund et al. [4] provided an overview of various approaches to frontier analysis and efficiency measurement.

In addition, there are various studies concerning technical efficiency analysis in agriculture, with a given complex input structure ranging from land, water to labor and chemical ingredients. Some recent analyses mainly incorporating stochastic frontier approach, which provides more inferable outcomes of these techniques, include the researches [5-26].

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 the researches [27, 28]. These authors adopted a two-step formulation. More recently, approaches to the incorporation of exogenous influences have refined and significant improvements in modeling technical inefficiency effects in stochastic frontier models opened new directions for empirical analysis [29].

Traditionally, output growth has been attributed to three effects, namely, input growth, technical change and improvements in technical efficiency [30-34]. These applications, however, assumed implicitly that technical

change and improvements in technical efficiency are the only components of total factor productivity (TFP) changes. Nevertheless, returns to scale and allocative efficiency may also be significant sources of TFP growth and consequently, of output expansion.

Indeed, there is empirical evidence that scale economies stimulate output growth even in the absence of technical change and improvements in technical efficiency as long as input use increases. Analogously, diseconomies of scale could slowdown output growth under similar circumstances, which is more likely to be the case for agriculture. On the other hand, output gains may also be obtained by improving allocative efficiency. In a highly protected sector, such as agriculture, allocative inefficiency tends to be an important source of TFP slowdown [35, 36]. Nevertheless, in the presence of price support schemes, the improvement of allocative efficiency provides an additional incentive for output increases.

Taking all the above mentioned factors into account, this paper investigates the relative contribution of technical efficiency, technological change and increased input use to output growth in the Tunisian citrus sector using a stochastic frontier production function approach applied to panel data. A flexible *translog* functional form is used to represent the underlying production technology and maximum likelihood procedure is implemented to estimate a single time trend model.

Therefore, the main purposes of this study are: (i) to analyze the technical efficiency and (ii) to decompose productivity growth into its different components for a sample of Tunisian citrus farms from 2003 to 2005.

2. Analytical Tools

2.1 Frontier Production Function

To investigate the decomposition of output growth in Tunisian citrus-growing farms, the production frontier function is used. The function is approximated by the quasi-*translog* functional form, proposed by

Fan [30] and Karagiannis and Tzouvelekas [37].

When panel data are available, the function takes the following form:

$$y_{it} = \beta_0 e^{\beta_T t + 0.5 \beta_{TT} t^2} \prod_{j=1}^K x_{jit}^{(\beta_j + \beta_{jT} t)} e^{v_{it} - u_{it}}$$

or

$$\ln y_{it} = \ln \beta_0 + \beta_T t + 0.5 \beta_{TT} t^2 +$$

$$\sum_{j=1}^K \beta_j \ln x_{jit} + \sum_{j=1}^K \beta_{jT} \ln x_{jit} t + v_{it} - u_{it} \quad (1)$$

where $i = 1, \dots, N$ denotes farms in the sample, $t = 1, \dots, T$ represents time periods, $j = 1, \dots, K$ is the conventional inputs used in the production process, β is the parameter to be estimated, $v_{it} \sim N(0, \sigma_v^2)$

is a symmetric and normally distributed error term (i.e., statistical noise) which represents those factors that cannot be controlled by farmers and left-out explanatory variables; and $u_{it} \sim N_+(\mu, \sigma_u^2)$ is an independently and identically distributed one-sided random error term representing the stochastic shortfall of the i th farm output from its production frontier due to the existence of technical inefficiency (i.e., farm-specific output-oriented technical inefficiency). It is further assumed that the two error terms are independently distributed from each other.

The temporal pattern of u_{it} is the changes in technical efficiency over time rather than the degree of technical efficiency *per se*. For this purpose Battese and Coelli [38] adopted this specification to model the temporal pattern of technical inefficiency, i.e.,

$$u_{it} = \{ \exp[-\xi(t - T)] \} u_i$$

where ξ captures the temporal variation of individual output-oriented technical efficiency ratings, and $t \in [1, 2, \dots, T]$. If the parameter ξ is positive (negative), technical efficiency tends to improve (deteriorate) over time. If $\xi = 0$, output-oriented technical efficiency is time-invariant. The above production frontier function can be estimated by

single-equation methods under the assumption of expected profit maximization.

2.2 Decomposition of Total Production Growth: Theoretical Framework

The input-oriented measure of productive efficiency may be defined as:

$$E(y, w, x; t) = C(y, w; t) / C$$

where $0 < E(y, w, x; t) \leq 1$, $C(y, w; t)$ is a well-defined cost frontier function, C is the observed total cost, y is a vector of output quantities, w is a vector of input prices, and t is a time index that serves as a proxy for technical change.

Using Farrell's decomposition of efficiency,

$$E(y, w, x; t) = T(y, x; t) \cdot A(y, w, x; t)$$

where $T(y, x; t)$ and $A(y, w, x; t)$ are respectively the input-oriented measures of technical and allocative efficiency. By definition, both $T(y, x; t)$ and $A(y, w, x; t)$ lie within the (0, 1) interval, and are independent of factor prices scaling and have an analogous cost interpretation.

Taking the logarithm of each side of $E(y, w, x; t) = C(y, w; t) / C$ and totally differentiating it with respect to t yields the following equation:

$$\dot{E}(y, w, x; t) = \varepsilon^{Cy}(y, w; t) \dot{y} + \sum_{j=1}^m s_j(y, w; t) \dot{w}_j + C^t(y, w; t) - \dot{C} \quad (2)$$

where a dot over a variable or function indicates its time rate of change, $\varepsilon^{Cy}(y, w; t) = \partial \ln C(y, w; t) / \partial \ln y$, $s_j(y, w; t) = \partial \ln C(y, w; t) / \partial \ln w_j$, and $-C^t(y, w; t) = \partial \ln C(y, w; t) / \partial t$ is the rate of cost diminution.

Alternatively, by taking the logarithm of $C = w'x$, and totally differentiating it with respect to t , yields:

$$\dot{C} = \sum_{j=1}^m s_j \dot{x}_j + \sum_{j=1}^m s_j \dot{w}_j \quad (3)$$

Substituting Eq. (3) into Eq. (2) results in:

$$\dot{E}(y, w, x; t) = \varepsilon^{Cy}(y, w; t) \dot{y} + \sum_{j=1}^m s_j(y, w; t) \dot{w}_j + C^t(y, w; t) - \sum_{j=1}^m s_j \dot{x}_j - \sum_{j=1}^m s_j \dot{w}_j \quad (4)$$

Then, the use of conventional Divisia index measure of TFP changes the equation as follows:

$$TFP = \dot{y} - \sum_{j=1}^k s_j \dot{x}_j = \dot{y} - \sum_{j=1}^k s_j \dot{x}_j,$$

The time rate of change of $E(y, w, x; t) = T(y, x; t) \cdot A(y, w, x; t)$, i.e.,

$$\dot{E}(y, w, x; t) = \dot{T}(y, x; t) + \dot{A}(y, w, x; t)$$

Eq. (4) may be rewritten as:

$$\dot{y} = \sum_{j=1}^m s_j \dot{x}_j + [1 - \varepsilon^{Cy}(y, w; t)] \dot{y} - C^t(y, w; t) + \dot{T}(y, x; t) + \dot{A}(y, w, x; t) + \sum_{j=1}^m [s_j - s_j(y, w; t)] \dot{w}_j \quad (5)$$

The first term in Eq. (5) captures the contribution of aggregate input growth on output changes over time (size effect). The more essential an input is in the production process, the higher is its contribution to the size effect. The second term measures the relative contribution of scale economies to output growth (scale effect). This term vanishes under constant returns to scale as $\varepsilon^{Cy}(y, w; t) = 1$, while it is positive (negative) under increasing (decreasing) returns to scale, as long as aggregate output increases, and *vice versa*. The third term refers to the dual rate of technical change (cost diminution), which is positive (negative) under progressive (regressive) technical change.

The fourth and the fifth terms in Eq. (5) are positive (negative) as technical and allocative efficiency increases (decreases) over time. The last term in Eq. (5) is the price adjustment effect. The existence of this term indicates that the aggregate measure of inputs is biased in the presence of allocative inefficiency. Under allocative efficiency, the price adjustment effect is equal to zero. Otherwise, its magnitude is inversely related to the degree of allocative inefficiency. The price adjustment effect is also equal to zero when input prices change at the same rate.

2.2.1 Specific Framework: The Tunisian Citrus-Growing Farms Production Growth

From an empirical point of view, the estimation of the different components in expression Eq. (5) is feasible when reliable panel data set and inputs prices (costs), among others are available. In our case, data on input prices are not available and under these conditions allocative efficiency, cost efficiency and price adjustment effects cannot be estimated.

However, the Tunisian citrus-growing farm's output production growth can be decomposed into aggregate input growth, technical change and changes in technical efficiency using Farrell's [3] and Lachaal [39] decomposition of productive efficiency. The decomposition of a general form of Eq. (1) makes it possible to understand the importance of each one of these components in total production growth:

$$Y = F(X, t) \quad (6)$$

where: Y is the output production, X is a vector of k inputs used in the production process (k=1...K), and t represents neutral technical change.

According to Farrell (1957), technical efficiency (TE) is defined as:

$$TE = \frac{Y}{F(X, t)} \quad (7)$$

where $0 < TE \leq 1$

Taking the logarithm time derivate of both sides of Eq. (7) yields:

$$\dot{TE} = \dot{Y} - \sum_{i=1}^k \frac{\partial \ln F(X, t)}{\partial X_i} \frac{dX_i}{dt} - \frac{\partial \ln F(X, t)}{\partial t} \quad (8)$$

Taking into account that the rate of technical change (\dot{TC}) is defined as:

$$\dot{TC} = \frac{\partial \ln F(X, t)}{\partial t} \quad (9)$$

Eq. (8) can be reformulated in the following way:

$$\dot{Y} = \dot{TE} + \dot{TC} + \sum_{i=1}^k \frac{\partial F(X, t)}{\partial X_i} \frac{X_i}{F(X, t)} \dot{X}_i \quad (10)$$

Where, the first term on the right hand side captures the effect of changes in technical efficiency

on production growth. The second term represents the technological change effect. The last term indicates the effect of input change on production growth, approximated by the sum of input growth rates weighted by the relevant production elasticities.

3. Sources and Data Analysis

A panel data of 150 Tunisian citrus producing farms covering the 2002-2003; 2003-2004 and 2004-2005 periods are collected from surveys conducted in two delegations of the governorate of *Nabeul*, region-Tunisia (Table 1). 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 export.

The selected sample comprises 34 farms of size lower than 1 ha (which represent 22.66%), 61 of size ranging between 1 and 2 ha (40.66%) and 55 of size higher than 2 ha (36.66%). It represents a total agricultural surface of about 392.22 ha. Results from the questionnaire indicate also that the average age of respondents is 55.8 years, ranging from 29 to 80. The average land holding is 2.61 ha, ranging from 0.2 to 18.5. Thirty five point three percent (35.33%) of the sample farmers are illiterate, 30.66% are with primary level, whereas 34.00% accumulated at least six years of schooling. In terms of structure of land, it appears that 81.33% of sample farmers are successors of farms, the other 18.66% are purchasers. Over 86.00% of farmers never followed a training program on

conducting citrus plantation and improving conduct techniques. Only 71% of farmers are agreeing with the disposable of water especially in summer period. About 90.6% of farmers make resort for fertilization operations. There is high level of family labor with respect to total labor (68.65%), especially for citrus speculation (82.38%). In terms of machinery, only 28.00% of sampled farmers have tractors, the other 72.00% resort to hiring.

4. Results and Discussion

4.1 Descriptive Statistics Analysis

As we posed at the outset, the outputs that include in the *translog* production function in Eq. (1) are the total annual production of citrus in metric tones. The inputs considered in the model are: (1) land measured in hectares; (2) total labor measured in working days; (3) fertilizers measured in Tunisian Dinars, and (4) other costs, comprising the rest of inputs used in producing citrus (chemical inputs, water, mechanization, etc.) measured in Tunisian Dinars.

Summary statistics of these variables is given in Table 2. From this table, it appears that fertilizer is considered the principal input for the citrus production followed by other costs, etc.

4.2 Production Frontier Estimates

Maximum likelihood estimates of the parameters of the *translog* frontier production model are obtained using the computer package FRONTIER version 4.1 [40]. Parameter estimates, along with the standard errors of the ML estimators of the Tunisian citrus-growing farms frontier model are presented in Table 3.

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

Delegations	Private farms			Total
	< 1 ha	1 - 2 ha	> 2 ha	
Beni Khalled	21	32	18	71
Menzel Bouzelfa	13	29	37	79
Total <i>Nabeul</i> Region	34	61	55	150

Source: Own elaboration from citrus producing farms in Nabeul Region (Tunisia).

Table 2 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	47,814.27	54,577.96	2,096.76	415,129.1
A	Land in ha	2.61	3.04	0.2	18.5
L	Labor in working days	428.44	364.93	46.5	2,950.0
F	Fertilization in TD	1,937.83	2,491.76	0.00	14,000.0
OC	Other costs in TD	1,715.29	2,349.46	81.66	16,714.67

1 TD = 0.704 \$US (Average 2011).

Source: Own elaboration from citrus producing farms in Nabeul Region (Tunisia).

Table 3 Maximum likelihood estimates of the *Translog* production frontier function for citrus producing farms in Tunisia.

Parameters	Estimates	Standard error
β_0	0.677	(0.102)**
β_A	0.782	(0.077)**
β_L	0.02	(0.076)
β_F	-0.03	(0.033)
β_{OC}	0.12	(0.067)**
β_{AT}	-0.017	(0.049)
β_{LT}	0.078	(0.071)
β_{FT}	-0.12	(0.050)**
β_{OCT}	0.053	(0.056)
β_T	0.02	(0.049)
β_{TT}	0.051	(0.077)
$\sigma^2 \cong \sigma_v^2 + \sigma_u^2$	0.408	(0.129)**
$\gamma = \sigma_u^2 / \sigma^2$	0.911	(0.026)**
ξ	0.033	(0.024)**
μ	0.581	(0.269)**
Log-likelihood	-112.77	

A refers to land, L to labor, F to fertilizer and OC to other costs.

* Significant at 1% level of significance. ** Significant at 5% level of significance.

The signs of the estimated parameters of the *translog* frontier production model are as expected. Estimated coefficients for all inputs such as land, labor and other costs inputs are positive and significant, which confirms the expected positive relationship between land, labor and mechanization, chemical inputs and water, and citrus production. These results indicate that land had contributed the most to citrus production followed by labor, other capital inputs and fertilizers

In addition, the ratio of farm specific variability to total variability γ is positive and significant at 5% level, implying that farm specific technical efficiency is important in explaining the total variability of citrus output produced. This affirmation confirms that stochastic production function is justified from empirical point of view. Some recent analyses mainly

incorporating stochastic frontier approach confirmed this justification such as Tzouvelekas et al. [41].

Further, a number of statistical tests of hypotheses for the parameters of the production frontier model are carried out and results are presented in Table 4. The statistical significance of modeling farm effects is examined using likelihood ratio tests.

Firstly, the validity of the *translog* specification over conventional average production is strongly rejected. Thus, this conventional average production does not represent adequately the structure of citrus-growing farms in Tunisia and the traditional average response model in which farms are assumed to be fully technically efficient is rejected. The null hypothesis that $\gamma = \mu = \xi = 0$ is rejected at the 5% level of significance.

Table 4 Tests of hypotheses for the parameters of the production frontier function for citrus producing farms in Tunisia.

Hypothesis	LR test-statistic	Critical Value ($\alpha = 0.05$)
Average production function, i.e., $\gamma = \mu = \zeta = 0$	97.93	$\chi^2_3 = 7.81$
Aigner et al. [42] SPF model with time-invariant output-oriented technical efficiency, i.e., $\mu = \xi = 0$	36.64	$\chi^2_2 = 5.99$
Aigner et al. [42] SPF model with time-varying output-oriented technical efficiency, i.e., $\mu = 0$	95.79	$\chi^2_1 = 3.84$
Time-invariant output-oriented technical efficiency, i.e., $\zeta = 0$	52.04	$\chi^2_1 = 3.84$
Constant returns-to-scale, i.e., $\sum_j \beta_j = 1$ and $\sum_j \beta_{jt} = 0$	57.34	$\chi^2_4 = 9.49$
Hicks-neutral technical change, i.e., $\beta_{jt} = 0 \forall j$	99.28	$\chi^2_3 = 7.28$
Zero-technical change, i.e., $\beta_{jt} = \beta_{jt-1} = \beta_{jt-2} = 0 \forall j$	103.48	$\chi^2_5 = 11.1$

Source: Own elaboration from citrus producing farms in Nabeul Region (Tunisia).

The second null hypothesis of stochastic production frontier (SPF) model with time invariant output oriented technical efficiency (i.e., $H_0: \mu = \xi = 0$) is also rejected at the 5% level of significance. Moreover, testing the null hypothesis, which specifies that stochastic production frontier model with time varying output oriented technical efficiency (i.e., $H_0: \mu = 0$) is also possible. Result is shown in Table 5 that this hypothesis is rejected at the 5% level.

The hypotheses that efficiency is invariant over time (i.e., $H_0: \zeta = 0$) can also be tested. The null hypothesis is strongly rejected at the 5% level of significance. Thus, output oriented technical efficiency is time variant. The estimated parameter ζ is positive and technical efficiency tends to improve over time.

Since the hypothesis of constant returns to scale is rejected at the 5% level of significance, the scale effect should be contributed to total factor productivity changes and output growth. In this case, the scale effect is positive as the farms in the sample exhibited increasing returns to scale and the aggregate output index increased over time and *vice versa*.

Moreover, the hypothesis of Hicks neutral technical change is rejected at the 5% level of significance. This means that no neutral component dominated the neutral one. This is true; no neutral component is an average 0.0081%, whereas the neutral component is an average only 0.0008%.

On the other hand, the hypothesis of zero technical change is rejected at the 5% level of significance (i.e., $H_0: \beta_{jt} = \beta_{jt-1} = \beta_{jt-2} = 0 \forall j$). Thus, the technical change should be contributed to total factor productivity changes. The neutral component of technical change is found to be progressive at a constant rate as the estimates for the parameters α_T and α_{TT} are both positive.

The next step after the hypothesis testing consists of estimating the different partial production elasticities with respect to production factors. Estimation results are depicted in Table 5.

Marginal products indicated that all elasticities are positive and decreasing for the land and fertilizer over time. Moreover, empirical results showed that, an average, the land impact factor is greater than the labor, other cost and fertilizer inputs factors. The values of these elasticities for land, labor, fertilizer and other costs are 0.78, 0.166, 0.003 and 0.106, respectively. These results indicated that land has contributed the most to citrus production followed by labor and other cost (chemical inputs, water costs, mechanization, etc.).

The contribution of fertilizer is insignificant in the citrus production. It appears also that production elasticities of land and fertilizer are decreasing: land by 5.8% and fertilizer by 41%. In the case of land, we expect a decrease on the use of this input according to the parceling problem due to the heritage tradition. On

Table 5 Production elasticities of land, labour, fertilisers and other costs used in citrus producing farms in Tunisia.

Years	Land	Labor	Fertilizers	Other costs	RTS
2003	0.828	0.140	0.004	0.076	1.048
2004	0.772	0.171	0.003	0.111	1.057
2005	0.740	0.188	0.002	0.132	1.062
Mean	0.780	0.166	0.003	0.106	1.055

Source: Own elaboration from citrus producing farms in Nabeul Region (Tunisia).

the other hand, the decrease of fertilizer input over time can be justified by environment and consumers reasons such as citrus production from this region is oriented to European markets (France, in particular).

The annual rate of increase for labor and other costs are 14% and 24%, respectively. These results reflect the economic reality of citrus producing farms in the region, subject of study. Indeed, citrus production is principally related with labor and with water, and mechanization.

Average estimates over farms of the returns to scale (RTS) for each year of observation is presented also in Table 3. Empirical coefficients show that returns to scale are growing over time with an increasing trend. In 2003, the RTS estimate was 1.048, while in 2005 it increased to 1.062. For the whole period, on average, the RTS coefficient is 1.055. This implies that the contribution of the scale effect to output growth would be positive as far as output increases. In this case, scale economies can stimulate output growth with increase in input use. Moreover, these inputs seem to be fundamental on the production process of citrus in Tunisia. Thus, the introduction of technological innovations seem to be a fundamental tracks to improve efficiency in the use of the available inputs and, consequently to increase citrus production.

4.3 Technical Efficiency Scores

The estimated farm-specific technical efficiency measures for each year of observation are presented in Table 6 in the form of frequency distribution. Empirical results showed that mean technical efficiency was found to be increasing slowly from 48.96% in 2003 to 50.99% in 2005. A possible

explanation of this slowly increasing almost stability over time in citrus farms technical efficiency variation might lie with short period and the stability of almost fixed, variables inputs and weather conditions.

Further, the comparison among farms shows that during the period of analysis under consideration (2003-2005), about the half farms in the sample (47%) have consistently achieved efficiency scores greater than 50%. The computed average technical efficiency was 49.97% during the period 2003-2005, ranging from a minimum of 11.19% to a maximum of 96.82%.

Given the present state of technology and input levels, this suggests that farms in the sample are producing on average at 49.97% of their potential. This suggests that citrus producers may increase their production by as much as 50.03% through more efficient use of production inputs. Between years that variation remained constant though quite considerable. This could imply differences among production units with regard to non-conventional inputs (socio-economic and demographic characteristics of the farmers), which are directly related to producers' managerial capacity.

4.4 Technological Change and Output Growth

The last step of the analysis explains the decomposition of total production growth. The objective of this section is to determinate the contribution of each considered factor (input growth, technical change and technical efficiency) in the total production growth. The decomposition analysis results for Tunisian citrus-growing farms output growth during the period 2003-2005 are given in Table 7.

Table 6 Measures of technical efficiency (TE) for citrus producing farms in Tunisia.

TE (range %)	2003	2004	2005
<20	9	9	7
20-30	20	16	15
30-40	27	26	23
40-50	24	23	29
50-60	28	31	29
60-70	17	19	18
70-80	15	14	17
80-90	6	7	7
90>	4	5	5
<i>N</i>	150	150	150
Mean	48.96	49.98	50.99
Min	10.38	11.18	12.01
Max	96.68	96.97	97.07

Source: Own elaboration from citrus producing farms in Nabeul Region (Tunisia).

Table 7 Decomposition of output growth for Tunisian citrus producing farms (average values for the 2003-2005 period).

	Average annual rate of change	(%)
Output growth	0.173	100
Aggregate input growth	0.065	37.37
Land	0.00	0.00
Labor	-4.6E-06	-2.6E-05
Fertilizer	0.036	20.70
Other costs	0.029	16.67
Total factor productivity growth	0.1089	62.62
Technical change effect	0.0089	5.11
Neutral	0.0008	0.46
Biased	0.0081	4.65
Change in technical efficiency	0.10	57.5

Source: Own elaboration from citrus producing farms in Nabeul Region (Tunisia).

An average annual rate of 0.173% was observed for output growth. Our empirical findings suggest that this growth stems mainly from the corresponding increase in aggregate input (37.37%), which increase with an average rate of 0.065%. However, 62.63% is attributed to productivity growth that grew with an average annual rate of 0.11%.

From these results, it appears that the input changes effects are not highly significant on total production growth (37.37%) if they are compared with respect to total factor productivity growth effects (62.62%). The land is constant into the period of study, so its contribution is neutral. The increases in fertilization use explain 3.6% of total production growth. It contributed, on average, with the highest amount to

the total input growth (55.38%). The increase in other intermediate consumption inputs (2.9%) such as mechanization, chemical inputs, water, etc., has a relative considerable effect of total production growth. Whereas, the effect of labor is negative but is negligible. These findings are considered consistently with the reality taking into account the short period of the panel (only three years).

Among all inputs, increased fertilizer use was the most important source of production growth. Increased intermediate consumption input ranked second in importance. Total input growth explained 37.37% of total production growth. These findings indicated that citrus farmers have chosen an expensive way to increase their production so an increase in

input use. These affirmations can have an excellent importance from policy implications. First, the unique and best feather to increase output is to improve total factor productivity. Secondly, we have clearly identified the sources of productivity growth.

Results also suggested that total factor productivity increased at an average annual rate of 0.09% between 2003 and 2005. About 8.2% of the total change is attributed to technological progress and 91.8% is attributed to change in technical efficiency. The average annual rate of technical change is found to be 0.0089%. This portion was caused by the biased technical change (0.0081%) and by the autonomous technical change (0.0008%).

Regarding its contribution, technological change accounts for 5.11% of total citrus production growth from which 4.65% is biased. Compared to other determinant such as TFP growth, this proportion is not important. These findings are different to those reported by Dhehibi et al. [22] for the olive oil growing sector in Tunisia. These authors noted that the contribution of technological change in the total olive oil production growth was around the value of 27.15%. In contrast, TFP contribute for about 48.47% in the total olive oil growth. A possible explanation of this variation might lie with the high technology used in the olive oil production process with respect to citrus production.

Given this, an increase in investment by citrus growing farms, especially in research and development, is needed to stimulate technological change and therefore increase total factor productivity which attribute to output growth. But, the introduction of technological innovations must not only accompanied by a continuous assistance for farmers by government and private operators but also must taking into account the real condition of farmers.

Finally, the contribution of change in technical efficiency in output growth is still important (57.5%, on average). Moreover, it contributes by about 91.8% in total factor productivity growth, which grew with

an average annual rate of 0.1%. However, this efficiency can be improved not only through the efficient use of inputs but also by the conception of practical and feasible strategies including all involucrate partners in the national citrus system (farmers, decisions makers, private sector, exporters, etc.).

5. Conclusions and Policy Implications

In this paper, we investigate farm level technical efficiency of production and the relative contribution of technical efficiency, technological change and increased input use to output growth in the Tunisian citrus growing sector using a stochastic frontier production function approach applied to panel data for the period 2003-2005. The proposed methodology is based on the use of a flexible *translog* functional form. The data used were gathered with a survey carried out by the Department of Agricultural Economics at the National Research Agronomic Institute of Tunisia during the periods 2002-2003, 2003-2004 and 2004-2005.

Estimation of the results among the different functional forms revealed that the *translog* specification is the best representation of technology in the citrus-growing sector in Tunisia. The estimated coefficients for all inputs such as land, labor and other costs inputs are positive and significant, which confirms the expected positive relationship between land, labor and mechanization, chemical inputs and water, and citrus production.

To assess the impacts of these factors, partial production elasticities were calculated. Empirical findings indicated that land has contributed the most to citrus production followed by labor and other costs. These results reflect the economic reality of citrus producing farms in the region, subject of study. Indeed, citrus production is principally related with labor and with chemical inputs, water, and mechanization. The fertilizers input appear with a minimal effect on production given the high use of

fertilizers in citrus production.

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

Further, the quantity increase of labor will have only limited effect on citrus production. Thus, the improvement of labor quality is the unique feather for considerable citrus production growth. Practice skilled labor 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.

Empirical findings show that estimated technical efficiency of citrus production in the sample varied widely, ranging from a minimum of 11.19% to a maximum of 96.82%, with a mean value of 49.97%. This suggests that, on average, citrus producing farmers could increase their production by as much as 50.03% through more efficient use of production inputs.

However, the increase of modern inputs (fertilizers, pesticides, chemical products, etc.) is dissuaded today for environment and consumers reasons. Another component of intermediate consumption is machinery and its increase will have a considerable effect on technical efficiency. This is true for the machinery of irrigation use, but from descriptive analysis it appears that 70.66% of farmers dispose water for irrigation operation. Two reasons are related to this fact; the expensive cost of irrigation machinery and the limitation of water resources. 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.

A significant share of total production growth is attributed to increases in traditional inputs. Total input

growth explained 37.37% of total production growth. These findings indicate that farmers chose a cheaper way to increase their production. These affirmations can have a significant importance on policy implications. First, the unique and best way to increase output is to improve total factor productivity (62.62%). Secondly, we have clearly identified the sources of productivity growth. On the other hand, technological change accounted only for 5.11% of total production growth. Compared to other determinants, this proportion is still important. Thus, an increase in investment in the citrus-growing farms, especially in research and development, is needed to stimulate technological change and therefore increase total factor productivity. However, the introduction of technological innovations must not be accompanied only by a continuous assistance for farmers by the government and private operators but must also take into account the real condition of citrus growing farmers.

Finally, the contribution of technical efficiency in output growth stood at 57.5% and grew at an average annual rate of 0.10%. However, this contribution towards efficiency can be improved not only through the efficient use of inputs but also by the conception of practical and feasible strategies including all involved partners in the citrus sector (farmers, decisions makers, private sector, exporters, etc.).

Notes

All tests of hypotheses are obtained using a maximum 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 .

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**Stochastic Production Frontiers and Decomposition of Output Growth:
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