Input and output technical efficiency and total factor productivity of wheat production in Tunisia

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Abstract

This paper investigates farm level technical efficiency of production and its determinants in a sample of 51 cereal producing farms in Tunisia that focus on wheat production. The empirical findings show that the labor input factor has a minimal effect on production. In addition, the technical efficiency of wheat production in the sample varied widely, ranging from 52.63 to 94.62%, with a mean value of 77%. This suggests that, on average, wheat producing farmers could increase their production by as much as 23% through more efficient use of production inputs. The results of Timmer and Kopp indexes of technical inefficiency show that the level of inefficiency was related to farm size: small and large farms were shown to be more technically efficient than medium-sized farms. Alternatively, inputs could be reduced by 17% on average to produce the same quantity of wheat output. These results call for policies aimed at providing training programs and extension services and improving input management by wheat farmers.

Keywords: technical efficiency; Timmer index; Kopp index; TFP (total factor productivity); wheat producing farms; Tunisia

JEL classification: O13; C43; N57

Dans cet article, l'efficacité technique de la production au niveau de l'exploitation et de ses déterminants est étudiée à partir d'un échantillon de 51 exploitations en Tunisie axées sur la

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production de blé. Les résultats empiriques montrent que le facteur de production travail possède un effet minime sur la production. En outre, l'efficacité technique de la production de blé dans l'échantillon a varié considérablement, allant de 52,63 pour cent à 94,62, avec une valeur moyenne de 77 pour cent. Ceci suggère que, en moyenne, les producteurs de blé pourraient augmenter leur production de près de 23 pour cent grâce à l'utilisation plus efficace des facteurs de production. Les résultats des indices de Timmer et Kopp de l'inefficience technique montrent que le niveau d'inefficience est lié à la taille des exploitations : les petites et grandes exploitations sont techniquement plus efficaces que les exploitations de taille moyenne. À défaut, les facteurs de productions pourraient être réduits de 17 pour cent, en moyenne, pour produire la même quantité de production de blé. Ces résultats appellent à des politiques visant à offrir des programmes de formation, des services de vulgarisation ainsi qu'une meilleure gestion des intrants de la part des producteurs de blé.

Mots-clés : *efficacité technique ; indice de Timmer ; indice de Kopp ; PGF (productivité globale des facteurs) ; exploitations de blé ; Tunisie*

Catégories JEL : *O13 ; C43 ; N57*

1. Introduction

The cereal sector in Tunisia plays an important role in agricultural production, employment and the agro-food industry. Cereals are the dominant agricultural commodity in the Tunisian economy and the country's main food staple, providing on average 70% of the calories and 55% of the protein in the average Tunisian diet and accounting for about a third of the average household's total food expenditure (NSI, 2005).

In recent years, about one third of the country's arable land has been devoted to cereal production (1.5 million hectares, and two thirds of farms). In 2009/10, about 60% was in durum wheat, 10% in bread wheat and 30% in barley. In 2009 the sector produced 2.5 million tons – 13% of the total agricultural production. The average annual production of the last 10 years was approximately 1.7 million tons, with a variation of 0.73 million tons. The fluctuation is attributed mainly to climatic conditions, particularly rainfall, and to inadequate management practices at farm level. However, cereal productivity in the country remains very low compared to its potential. The average yield per hectare is below 1.3 tons.

Tunisia was once a net exporter of cereals, particularly of durum wheat. But increased demand caused by rising population and per capita income and stagnating production have turned the country into a net importer of this commodity. At times during the last three decades Tunisia has supplied about half her cereal needs with imports. A continuing rise in demand for cereals for human consumption, coupled with the demands of a developing livestock sector, will maintain pressure on cereal production. Some relief is, however, anticipated with increasing technological progress in cereal production, particularly in bread wheat.

The food balance in Tunisia has been destabilized by the latest increases in world cereal prices. Improving the cereal yield has thus become a must for policymakers who seek to reduce the deficit and the Tunisian government is engaged in an intensive effort to adopt new, high yielding varieties of bread wheat and to improve methods of cultivating wheat. This effort is designed to increase Tunisian cereal yields and reduce the country's dependence on cereal imports. Important policies were implemented in 2008 to encourage cereal producers, using strategies such as expanding the cereal producing areas, introducing new varieties and subsidizing the costs of production and inputs. Research plots have shown a potential exceeding 1.6 kg per m^3 of irrigation water, with an average yield per hectare of 6.4 tons, while in practice the productivity of irrigated cereals does not exceed 0.9 kg per m^3.

Since wheat production has increased in Tunisia, concern for efficiency has become a major topic in research on the economics of production. There are two levels of concern. At the micro-economic level, measuring and analyzing the efficiency of cereal farms is crucial for understanding not only what makes farms productive but also how regulatory market policies affect them. At the macro-economic level, it is important to understand how these individual levels of efficiency determine social and collective efficiency. To achieve efficiency in the agricultural sector as a whole requires reversing the inefficiency of individual farms. It is also necessary to study production technologies to discover what makes them effective or ineffective and suggest ways to improve them by adapting them to the regions and farm types.

In this paper we examine a sample of cereal farms in Tunisia mainly producing wheat. We focus in particular on their technical efficiency. We analyze the determinants of variation in the sampled farms' technical efficiency using a model of simultaneous estimation of the stochastic production and effects of technical inefficiency (Kumbhakar et al., 1991; Reifschneider & Stevenson, 1991; Huang & Liu, 1994). This approach has a major advantage over the approach used by earlier empirical contributions, as explained in Section 2 below. In addition, we develop the relationship between a farm-level output-based technical efficiency measure (the Timmer index) and an input-based measure (the Kopp index) and estimate these technical indexes. Finally, we measure and analyze the determinants of total factor productivity in our sample of farms. This will help to guide policy aimed at improving the income and thus the welfare of cereal farmers, since knowing the main drivers of their total factor productivity will help decision makers to improve farmers' productivity and reduce their costs.

The remainder of the paper is organized as follows. Section 2 presents the theoretical background of the stochastic frontier model, Timmer and Kopp technical efficiency indexes and the concept of total factor productivity (TFP). Section 3 describes the data analysis and the models assumed for our sample of Tunisian cereal producing farms. Section 4 presents and discusses the empirical results, and Section 5 concludes with policy implications.

2. Methodological framework and theoretical background

2.1 Stochastic production frontier estimation

Since the stochastic production frontier model was first, and nearly simultaneously, published by Meeusen and Van den Broeck (1977) and Aigner et al. (1977) there has been considerable research to extend the model and explore exogenous influences on producer performance. Early empirical contributions (Schmidt & Lovell, 1979, 1980) investigating the role of exogenous variables in explaining inefficiency effects adopted a two-stage formulation, which suffered from a serious econometric problem.[1]

[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.

Recently, Kumbhakar et al. (1991), Reifschneider and Stevenson (1991) and Huang and Liu (1994) have 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 use 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 & Coelli (1995) model but specified for a cross-section data context. The model consists of equations (1) and (2). The first specifies the stochastic frontier production function and the second, 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 :

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

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

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

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

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

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

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

where

[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 & Coelli (1993).

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

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

2.2 Technical efficiency: Timmer and Kopp indexes

In the empirical literature, efficiency is defined as producing a maximum amount of output, given a set of inputs, or producing a given level of output using a minimum level of inputs, or a mixture of both. Efficient farms either use less input than others to produce a given quantity of output, or for a given set of inputs they generate a greater output.

One of the most popular approaches to measuring technical efficiency is based on the calculation of the output-based Timmer (1971) and the input-based Kopp (1981) indexes of technical efficiency. The output-based TE_T is simply the ratio of the observed level of output to the potential (frontier) output, given a set of inputs, while the input-based TE_K is the ratio of frontier input (cost) to the observed level of input (cost), given the level of output. According to Llewelyn and Williams (1996), these two indexes are not necessarily the same, because the input efficiency index does not focus on the same aspects of production as the output efficiency index. According to Fare and Lovell (1978), a unique measure of these two indexes cannot be calculated in the case of non-homothetic technology. Homotheticity, for which homogeneity is sufficient but not necessary (Laidler & Estrin, 1989), implies that all the isoquants have the same slope on a ray through the origin in the input space. These relationships are illustrated using the Cobb-Douglas production function shown in equation (1). In the production function in equation (1), the degree of homogeneity is equal to the sum of the β_i coefficients.

The Timmer index for an individual farm, calculated as the ratio of observed output Y to frontier output Y_f, , for μ =0, is defined as:

$$TE_T = \frac{Y}{Y_f} = \frac{\left(A\prod_{i=1}^{N} X_i^{\beta I} e^{v+\mu}\right)}{\left(A\prod_{i=1}^{N} X_i^{\beta I} e^{v}\right)} = e^{-\mu}, \tag{7}$$

while the Kopp index can be formulated (for any j) as (Russell & Young, 1983):

$$TE_K = \frac{X_{fj}}{X_j} = \left(e^{-\mu}\right)^{1/\Sigma\beta_i} = \left(TE_T\right)^{1/\Sigma\beta_i} \tag{8}$$

where X_{fj} and X_j are the frontier and the observed levels of the jth input, respectively (for μ=0).

The Timmer and Kopp indexes can be calculated directly. The relationship between the two indexes depends on the returns to scale of the production function (Figure 1). Thus, in the case of constant returns to scale ($\sum \beta_i = 1$), the Kopp index is equal to the Timmer index. However, the Kopp index is greater than the Timmer index if $\sum \beta_i > 1$ (which is the case of increasing to scale). Finally, the Kopp index is less than the Timmer index if the production function is decreasing to scale ($\sum \beta_i < 1$).

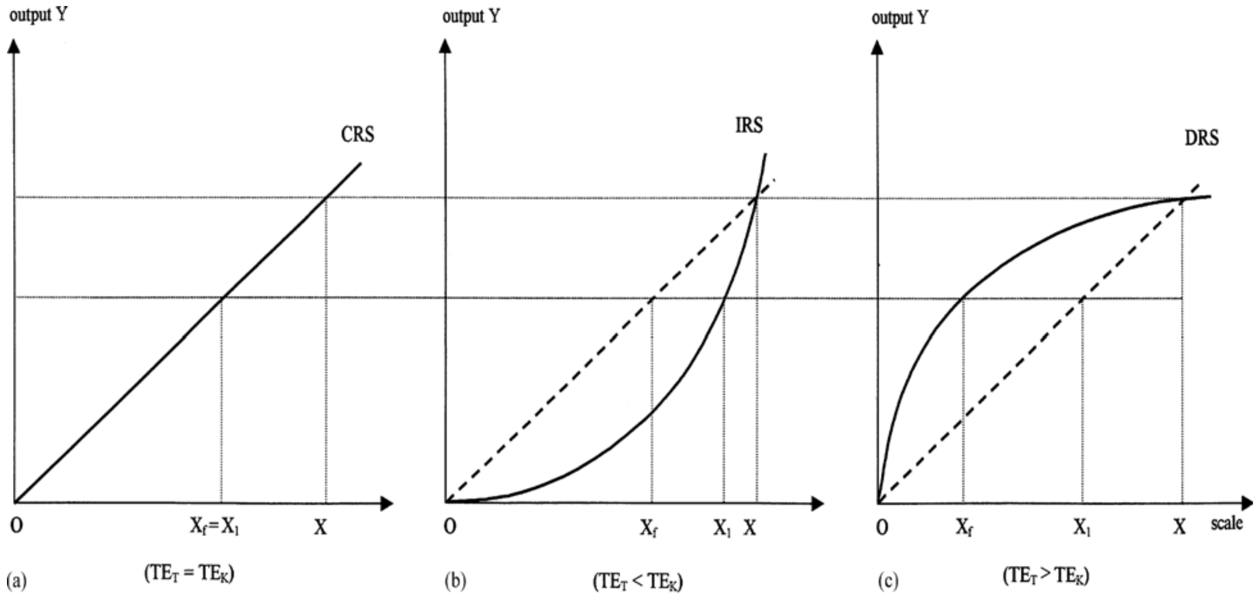

Fig. 1. TE indexes with: (a) constant returns to scale (CRS); (b) increasing returns to scale (IRS) and (c) decreasing returns to scale (DRS).

Figure 1: TE indexes with: (a) constant returns to scale (CRS), (b) increasing returns to scale and (c) decreasing returns to scale (DRS)

Given the absence of detailed farm-level data (farmer training programs, extension, etc.)[3] which may represent the sources of inefficiency, we use farm size as a variable determining inefficiency. This variable is examined by means of a simple quadratic function. The potential efficiency gains, i.e. the rise in the level of output that could be gained ($G_T = 1 - TE_T$) or the share of input that could be saved ($G_K = 1 - TE_K$) if the farmer were 100% efficient, may be defined as a function of the input ratios.

[3] In the data from our questionnaire we did not have completed responses from farmers on farmer training and extension programs and the responses that we do have are in dummy variables. We thus use farm size as a determinant of inefficiency since it is a continuous variable. Education level and use of crop rotation are good determinants of efficiency but are also collected as dichotomy variables.

2.3 Total factor productivity

The next step is to estimate the total factor productivity (TFP) and its determinants. TFP as a measure of overall productivity has been gaining recognition and acceptance not only for its theoretical relevance but also for its practicality for researchers and consequently agricultural decision makers.

Here we use the OLS regression method to analyze the effects of various determinants (variables) on the TFP of cereal farms. Following Key & McBride (2003), TFP can be measured as the inverse of the unit variable cost since the TFP is the ratio of the output and the total variable cost (TVC) as shown in this equation:

$$TFP_i = \frac{Y_i}{\sum_{j=1}^{N} P_{ji} X_{ji}} \tag{9}$$

where Y_i is the output (in value or in quantities), TVC_i is the total variable cost of farm i, P_{ji} is the unit price of j^{th} variable input used in farm i, and X_{ji} is the quantity of j^{th} variable input used in farm i.

Since this methodology ignores total fixed cost, total fixed cost does not affect profit maximization and the resource-use efficiency conditions (Bamidele et al., 2008). The TFP for an individual farm can then be derived from cost theory as:

$$AVC_i = \frac{Y_i}{TVC_i} \tag{10}$$

where AVC_i is the average variable cost measured in Tunisian dinars (TND).

Therefore,

$$TFP_i = \frac{Y_i}{TVC_i} = \frac{1}{AVC_i}. \tag{11}$$

Thus, TPF_i is the inverse of the average variable cost (AVC_i) of farm i.

3. Data and empirical model

3.1 Data

A cross-section of data from 51 Tunisian cereal producing farms covering the 2008–2009 period was collected from surveys conducted in five 'delegations' (districts) of the governorate of Beja, Tunisia. Cereal growing farms were selected from a sample used by the

Tunisian Ministry of Agriculture, Water Resources and Fisheries to investigate farm structure in the Beja region. We made this selection in collaboration with the statistical and agricultural development office and the territorial information units of the Agricultural Regional Office of Beja, taking into account the statistical representation and cultivated areas. We chose this region because of its importance in the national wheat production; indeed, according to the Ministry's statistics, this region accounted for more than 20% of the national cereal production.

The selected sample comprises seven farms of less than 2.5 ha (13.7%), 20 farms of between 2.5 and 8 ha (39.3%) and 24 farms larger than 8 ha (47%). For our farmer survey we used a six-section questionnaire to obtain (1) farmers' socio-economic details (age, education level, agricultural training, experience in the cereal sector, etc); (2) the history of the farm; (3) the structure of the land (area, allocation of area, number of farms); (4) production factors, namely labor (permanent, seasonal and family labor and its allocation among farm operations), farming operations (such as rotation of crops, share of area planted to wheat, the presence of livestock), materials (inputs, such as seed and fertilizer), machinery, buildings and irrigation operations; (5) intermediate consumption data; and (6) output, i.e. total production data, production by speculation and fixed costs.

The findings of the questionnaire were as follows. The respondents' average age was 55, with a range of 27 to 80. The average land holding was 19.55 ha, with a range of 0.5 to 100 ha. As regards education, 55% of the sampled farmers were illiterate, 23% had primary education, and 22% had completed at least six years of schooling. Over 80% of the sample had never followed a training program on cereal farming and improved agronomic techniques. Total labor included a high level of family labor (45%). In terms of machinery, only 73% of the sample had tractors, with the remaining 27% having to resort to hiring.

3.2 Empirical model

To implement the model specified in Section 2 above, we used mean cross-section data on production inputs (land, labor, seed, fertilizer, machinery) and production output. These variables are summarized in Table 1.We used other explanatory variables, such as farmer's level of education, rotation of crops, share of wheat area, share of family labor and presence of livestock to represent the underlying Cobb-Douglas functional form.

Table 1: Summary statistics of the variables used in the frontier model for cereal producing farms in Tunisia

Notation	Variables	Mean	Std dev.	Min	Max
Y	Production (in TND)	25,448.41	40,064.06	287.00	158,000.00
A	Land (in ha)	19.55	23.84	0.50	100.00
L	Labor (in TND)	1,214.41	3,899.60	0.00	26,550.00
S	Seed (in TND)	1,746.02	2,163.94	60.00	8,160.00
F	Fertilizer (in TND)	2,137.10	3,182.83	0.00	12,750.00
M	Mechanization (in TND)	1,384.64	1,278.63	139.04	6,650.50

Notes: Number of observations: 51; 1TND = 0.7 USD (average, 2011)

The stochastic frontier production model to be estimated is defined in equation (12) and the technical inefficiency effects are defined in equation (13) as follows:

$$LnY_i = \beta_0 + \beta_1 LnS_i + \beta_2 LnF_i + \beta_3 LnM_i + \beta_4 LnL + v_i - u_i \qquad (12)$$

$$u_i = \delta_0 + \delta_1 (INL)_i + \delta_2 (ROT)_i + \delta_3 (Liv)_i + \delta_4 (FLAB)_i + \delta_5 (SBLE)_i + \varepsilon_i \qquad (13)$$

where (with all values being in TND):

- Y_i is the value of the i-th farmer's production, i.e. output;
- S_i is the value of seed used by the i-th farmer ;
- F_i is the value of total fertilizer used by the i-th farmer ;
- M_i is the value of machinery used by the i-th farmer ;
- L_i is the value of labor (permanent and occasional) used by the i-th farmer ;
- INL is an education level dummy variable (= 1 if the farmer has accumulated at least six years of schooling, 0 otherwise);
- ROT is a rotation dummy variable (=1 if the farmer has rotated his crops, 0 otherwise);
- Liv is a livestock dummy variable (=1 if the farmer has livestock, 0 otherwise);
- FLAB is the share of family labor with respect to total labor;
- SBLE is the percentage of wheat crops within total cereals; and
- v_i and ε_i are random errors.

4. Results and discussion

4.1 Frontier production function

Maximum likelihood (ML) estimates of the parameters of the Cobb-Douglas stochastic frontier production and the technical inefficiency effects models are obtained using the computer package Frontier Version 4.1 (Coelli, 1996). The estimate for the variance parameter γ being significantly different from zero implies that the inefficiency effects are significant in determining the level and variability of the output of the farms in our sample.

Parameter estimates, along with the standard errors and T-ratios of the ML estimators of the inefficiency frontier model for the farms in our sample are presented in Table 2. The signs of the estimated parameters of the Cobb-Douglas stochastic frontier production model are as expected. All estimated coefficients of inputs are positive and significant, which confirms the expected positive relationship between seed, fertilizer, machinery and labor and cereal production.

Average estimates of production elasticities and returns to scale are also presented in Table 2. Estimated partial production elasticities with respect to these production factors indicate that the seed impact factor is greater than other intermediate input factors such as fertilizer, machinery and labor. The value of these elasticities for seed, fertilizer, machinery and labor are 0.78, 0.07, 0.10 and 0.032, respectively.

These results reflect the economic reality of cereal producing farms in the region. Indeed, cereal production principally depends on machinery and seed. The labor input factor has a minimal effect on production since all the operations in cereal producing farms are mechanized. In economics terms this means that, holding all other inputs constant, a 1% reduction in labor requires a sacrifice of 0.032% 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 decreasing (0.983).

The estimated coefficients in the technical inefficiency model are also as expected. The estimated coefficient of the farmer's level of education (NIN) is negative and statistically significant at the 5% level, which indicates its positive effect on technical efficiency. The coefficient of the variable ROT is negative and statistically significant. This means that ROT has a positive impact on efficiency, and that crop rotation could help to increase the technical efficiency level and consequently the level of production. Consequently, the negative and statistical significance at the 5% level coefficient suggests that an increase in the area of wheat contributes to higher technical efficiency levels of cereal production on these farms. Finally, the estimated coefficient of the share of family labor (FLAB) and the presence of livestock (ELE) in the technical inefficiency model are positive and statistically insignificant at 10%. This implies that they have a neutral effect on technical efficiency.

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

Variables	Maximum likelihood	t-values
	Stochastic frontier model	
Intercept	0.157	2.320*
Ln (Seed)	0.780	2.773*
Ln (Fertilizer)	0.069	2.544*
Ln (Machinery)	0.102	11.39*
Ln (Labor)	0.032	1.526**
	Partial production elasticity	
$E_{Y/S}$	0.780	-
$E_{Y/F}$	0.069	-
$E_{Y/M}$	0.102	-
$E_{Y/LA}$	0.032	-
Returns to scale	0.983	

Inefficiency effects model		
Intercept	0.272	2.411*
NIN	-0.147	-2.968*
ROT	-0.184	-1.723**
ELE	0.055	0.954
FLAB	0.073	1.00
SBLE	-0.215	-1.898**
Variance parameters		
σ^2	0.030	3.393*
γ	0.89	5.862*
Log-likelihood	29.790	

Note: ** significant at the 10% level, * significant at the 5% level.

The results for the frequency distribution of technical efficiency are presented in Table 3. Estimated efficiency measures reveal the existence of substantial technical inefficiencies of production in our sample of farms. The computed average technical efficiency is 76.93%, ranging from a minimum of 52.63% to a maximum of 94.62%. Given the present state of technology and input levels, this suggests that farms in the sample are producing on average at only 77% of their potential. Within this framework, 20 farms are above the average efficiency level of the sample, with an efficiency score greater than 80%, and 31 farms are below the average. These results prompt questions about heterogeneity and the possibility that these farms could increase their production by 13%, given the current state of technology and the current input level.

Table 3: Efficiency ratings and frequency distribution of Tunisian cereal-producing farms

Technical efficiency (%)	Number of farms	% of farms
TE ≤ 60	4	7.8
60 < TE ≤ 70	11	21.6
70 < TE ≤ 80	16	31.4
TE > 80	20	39.2
Mean efficiency	76.93	
Min.	52.63	
Max.	94.62	

4.2 Timmer and Kopp technical efficiency indexes

Using the values of μ_j, equation (7) is estimated for individual farms as a basis for the TE_T and TE_K inefficiency indexes, whose frequency distributions are shown in Table 4.

The mean value of TE_T is estimated to be 0.80, with a range from 0.54 to 0.98, while the average TE_K is found to be 0.83, with a range from 0.58 to 0.97. The mean values indicate that either the output can be increased on average by 20% using the same amount of input as before, or the current level of output can be maintained using 17% less input than farmers currently use. About 22 of the farms observed were under 80% efficient for the TE_T and under 90% efficient for the TE_K. At least one of these farmers could gain over 20% by input reallocation or over 10% by output maximization.

The frequency distribution of the Timmer and Kopp indexes among the farms indicates that 12 farms (23.5%) had an output-based efficiency level of 0.90 or above and 17 farms (33.5%) an input-based efficiency in that range. About 2% of the farms were in an input-based inefficiency range below 0.5% and 4% of the farms were in an output-based inefficiency range that was also below 0.5%. In summary, most of the farms were found to be more than 80% efficient on both measures, but over 27% of the farms were found to be inefficient on both measures.

Table 4: Frequency distribution of Timmer and Kopp technical efficiency indexes

Efficiency index		Frequency		Percentage		Cumulative frequency		Cumulative percentage	
TE_T	TE_K	TE_T	TE_K	TE_T	TE_K	TE_T	TE_K	TE_T	TE_K
[0.5	0.6)	2	1	3.92	1.96	2	1	3.92	1.96
(0.6	0.7)	9	5	17.65	9.80	11	6	21.57	11.76
(0.7	0.8)	11	11	21.57	21.57	22	17	43.14	33.33
(0.8	0.9)	17	17	33.33	33.33	39	34	76.47	66.67
(0.9	1]	12	17	23.53	33.33	51	51	100.00	100.00

Summary statistics of Timmer and Kopp indexes

	TE_T	TE_K	G_T	G_K
Mean	0.80	0.83	0.192	0.162
Std dev.	0.11	0.10	0.11	0.10
Minimum	0.54	0.58	0.018	0.023
Maximum	0.98	0.97	0.45	0.42

4.3 Causes of inefficiency

No studies have measured the efficiency of Tunisian cereal farms and determined the main drivers of this indicator, i.e. their efficiency scores, so official quantitative farm-level data on the sources of inefficiency are not available, although it may be conjectured that these sources include the difficulty of acquiring inputs such as chemical and organic fertilizer. In the absence of such evidence, farm size and input ratios, which differ from large to small farms, are considered as determinants of the potential efficiency gains G_T and G_K (Bakhshoodeh & Thomson, 2001). The relation between both TE indexes and farm size (as measured by land area, L_1) was examined using an estimated quadratic equation (standard errors of coefficients in parentheses):

$$G_T = 0.202\,(0.022) - 0.0000016\,(0.002) * L_1 - 0.000001\,(0.00005) * L_1^2 \qquad (14)$$

$$G_k = 0.165\,(0.022) + 0.000492\,(0.0019) * L_1 - 0.0000013\,(0.0000238) * L_1^2 \qquad (15)$$

The signs of the estimated coefficients suggest that the potential efficiency gains G_T and G_K increase up to a certain point (around 8 ha) and decrease again with larger farm sizes. Therefore, in terms of the general objective of attaining self-sufficiency in agricultural products and raising the level of cereal production, policies for improving efficiency should be directed towards medium-sized farms. The average yield of cereal crops in these farms (20.61 Qx/ha) is higher than that of large and small farms (15.47 Qx/ha) and their lower level of efficiency implies a higher potential output. A comparison of mean efficiency gains between farms of different sizes shows that the efficiency gain for the medium-sized farms (2.5 to 8 ha) is significantly higher than that for very small farms. Such differences could be due to the technologies being applied at different sizes and to the economies of scale related to the degree of on-farm diversification.

Table 5: Mean efficiency gains G_T and G_K by farm size

Farms	Size (ha)	No. of farms	G_T	G_K
Large	> 8	24	0.184 (0.116)	0.160 (0.108)
Medium	5 – 8	6	0.203 (0.109)	0.169 (0.107)
Small	2.5 – 5	14	0.203 (0.111)	0.166 (0.108)
Very small	< 2.5	7	0.184 (0.184)	0.153 (0.153)

Note: Standard errors are in parentheses.

4.4 Total factor productivity and its determinants

In this section we analyze the economic determinants of the total factor productivity (TFP) for the farms in our sample. The results of this analysis are presented in Table 6. The coefficients for age, education level and the share of wheat in the total cropped area were positive and highly significant at the 5% level. This implies that a 1% increase in age, education level and share of wheat area will increase the TFP by 0.29, 1.28 and 0.063%, respectively. In addition, crop rotation was found to be positive and significant, though only at the 1% level. This is expected and implies the importance of this variable for improving the TFP of cereal farms. The adjustment coefficient (R^2) value is around 55%, which implies that 55% of the variation in the TFP of cereal farms in Tunisia was explained by the included variables. The F-ratio was significant at 1%, which implies that the data attest to the overall significance of the regression equation.

Table 6: Cobb-Douglas estimates of OLS regression of determinants of total factor productivity (TFP) among cereal farmers in Tunisia

Variables	Estimated coefficients	Std error	t-student
	Dependent variable: TFP		
Intercept	0.714	*0.082*	8.64
Age	0.298	0.134	2.21
Age^2	-0.0024	0.0012	-2.01
Education level	1.28	0.52	2.45
Rotation	0.074	0.473	1.56
% cropped wheat area	0.063	0.013	2.79
N		51	
R^2		0.54	
F- statistics		2.93	

5. Concluding remarks and policy implications

In this study, farm level technical efficiency of production and its determinants were investigated in a sample of 51 cereal producing farms located in the main cereal production region in Tunisia, using a stochastic frontier production model. The data used in this study were gathered through a survey carried out during the period 2008–2009.

The empirical findings show that the labor input factor had a minimal effect on production. In economics terms, this means that, holding all other inputs constant, a 1% reduction in labor requires a sacrifice of 0.032% of marketable output. On the other hand, the hypothesis of constant returns to scale was rejected at the 5% level of significance, and returns to scale were found to be decreasing (0.983). The estimated coefficients in the technical inefficiency model were also as expected. The estimated coefficient of the farmer's level of education was negative and statistically significant at the 5% level, which indicates a positive effect on technical efficiency. With respect to crop rotation, this technical variable of particular interest to farmers was negative and significant. This highlights the need for government policies, through extension activities, to set up training programs for cultivating cereals, in general, and improving rotation techniques, in particular.

The negative and statistical significance of the farm area variable at the 5% level coefficient suggests that an increase in the area planted to wheat contributed to higher technical efficiency levels of cereal production on these farms. Farmers can improve their level of efficiency either by applying a different combination of inputs or by adopting a new technology. They will probably adopt the former option more readily than the latter, because a change in the inputs could reduce the total cost of production and thus increase their profit per hectare. So a policy of encouraging more efficient input techniques is likely to have fairly speedy effects, increasing the profitability of wheat production and releasing surplus inputs to be used to produce either more wheat or other products (essentially barley and legumes).

The empirical findings show that the estimated technical efficiency of cereal production in the sample varied widely, ranging from 52.63 to 94.62%, with a mean value of 77%. This suggests that, on average, cereal producing farmers could increase their production by as much as 23% through more efficient use of inputs. This implies that improving technical efficiency should be the first logical step for considerably increasing cereal production in the study region.

Timmer and Kopp indexes of technical inefficiency were estimated for the same farms using a Cobb-Douglas frontier production function with a composite error term, and a developed relationship between these two indexes. The mean values of the Timmer and Kopp TE indexes were over 0.80, but half the farms were below 0.80 for the Timmer index and below 0.83 for the Kopp index. The level of inefficiency was found to be related to farm size: small and large farms were shown to be more technically efficient than medium-sized farms. With the given inputs, the production of cereals could be increased by 20% on average by making all farms 100% efficient. Alternatively, inputs could be reduced by 17% on average to produce the same amount of cereal output.

The lower level of efficiency but higher yield and total factor productivity (TFP) in the medium-sized farms means that these farms have the potential to increase their cereal production. Significant factors that were found to be related to TFP were age, farmer's education level and the share of wheat in the total cropped area. These findings call for policies aimed at providing training programs and extension services. In addition, experienced farmers, especially wheat farmers, should be encouraged to improve input management on their farms and adopt appropriate new technologies. Our study shows that the cereal production sector's problems are not caused just by shortages of inputs; rather, inefficient use and improper combining of these inputs are most fundamentally responsible. Our findings lead us to conclude that optimum use of existing inputs and improved combination of them should be emphasized rather than increasing the amount of inputs.

Finally, we recommend further research into the sources of inefficiency, such as diversification versus specialization, the availability and suitability of new technologies, and the level of other indexes of inefficiency such as profit efficiency, in order to develop more productive and profitable techniques of cereal production in Tunisia.

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