A Panel Data Approach to the Measurement of Technical Efficiency and its Determinants: Some Evidence from the Tunisian Agro-Food Industry

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Abstract

This study investigates firm level technical efficiency of production and its determinants in the Tunisian agro-food industry. To this end, a stochastic production frontier model, in which technical efficiency effects are assumed to be a function of firm-specific variables and time, is estimated using panel data on 46 agro-food firms observed over a period of 14 years. Results indicate that technical efficiency in the sample of firms investigated ranges from a minimum of 45% to a maximum of 90% with an average technical efficiency estimate of 67%. Further, investigation of the sources of technical inefficiency in the sample reveals that the age of capital stock and firm size are negatively associated with efficiency, the share of skilled labour is positively associated with efficiency and, on average, technical efficiency tendes to decline during the period of investigation.

Keywords: *Technical efficiency, panel data, stochastic frontier production function, food industry, Tunisia*

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 characterising 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).

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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 panel data. 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 food industry firms in order to provide empirical evidence on the sources of technical inefficiency in the sector. Measuring technical efficiency in the food sector is important for a number of reasons. First, the agro-food industry in Tunisia constitutes the second major industrial activity in terms of its contribution to total manufacturing industry value added. Indeed, with its 4 800 agro-food units, the food industry ranks second to textile in terms of the value of output and employment, accounting for 25 per cent of total industrial output and 16 percent of total manufacturing employment of whom only one fifth is considered as skilled labor (API, 2000). 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 food industry, in particular, is coming under increasing international competition which calls for a major concern for only efficient firms are likely to stand the competitive pressure in the ever changing world economy. Third, a study that addresses the main issues that have bearings on technical efficiency in the food processing industry in Tunisia is important for, to the authors' knowledge, not a single study has investigated these issues.

The remainder of this paper is organised into five sections. First, we present the methodological framework adopted in this study followed by the data and empirical model specification. Results and discussions are presented next. Conclusions and policy implications of the study are presented in the last section.

Methodological framework

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.

In this study, we adopt the Battese and Coelli (1995) stochastic frontier production model for panel data[2]. The model consists of two equations. The first equation specifies the stochastic frontier production function. The second equation, which captures the effects of technical inefficiency, has a systematic component $z_{it}\delta$ associated with the exogenous variables and a random component w_{it}:

$$Ln\, Y_{it} = Ln\, f\,(x_{it}\,; \beta) + v_{it} - u_{it} \qquad (1)$$

$$u_{it} = +z_{it}\delta' + w_{it} \qquad (2)$$

Where Y_{it} denotes the production of the i-th firm at the t-th time period; x_{it} is a vector of input quantities of the i-th firm at the t-th time period and β is a vector of unknown parameters to be estimated. The non-negativity condition on u_{it} is modelled as $w_{it} \sim N\,(0,\ \sigma_w^2)$ with the distribution of w_{it} being bounded below by the truncation point $-z_{it}\delta'$. The authors note that the distributional assumption on w_{it} is consistent with the distributional assumption on u_{it} that $u_{it} \sim N^+(z_{it}\delta'\,; \sigma_u^2)$. Finally, v_{it} are assumed to be independent and identically distributed $N\,(0,\ \sigma_v^2)$ random errors, independent of the u_{it}.

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. After re-parameterisation of the model, the likelihood function is expressed in terms of the variance parameters as follows: $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$, and $\gamma = \sigma_u^2 / \sigma_s^2$ (Battese and Coelli, 1993). The technical efficiency of production for the i-th firm at the t-th period can be defined as follows:

$$TE_{it} = exp(-u_{it}) = exp(-z_{it}\delta' - w_{it}) \qquad (3)$$

A predictor for which is provided by its conditional expectation, given the above model assumptions[3].

Data and empirical model specification

To implement the above-specified model, panel data on 46 Tunisian food manufacturing industry covering the 1983-1996 period are used. In particular data on output, production inputs and other explanatory variables of firm size, share of skilled labour, age of capital stock and time are considered[4]. The output variable, consisting of value-added, is measured in value terms at constant 1990 prices. The capital stock variable comprises all fixed capital equipment and is measured in value terms at constant 1990 prices. The labor variable is measured by the firm's total number of employees. The Source of these data is the national survey report on firms carried out by the National Statistics Institute.

Given the above, the stochastic frontier production model to be estimated is defined in equation (4) and the technical inefficiency effects are defined in equation (5) as follows:

$$LnY_{it} = \beta_0 + \beta_1 LnK_{it} + \beta_2 LnL_{it} + \frac{1}{2}\beta_3 (LnK_{it})^2 + \frac{1}{2}\beta_4 (LnL_{it})^2 + \beta_5 LnK_{it} LnL_{it} + v_{it} - u_{it} \quad (4)$$

$$u_{it} = \delta_0 + \delta_1 (MED)_{it} + \delta_2 (LRG)_{it} + \delta_3 (BIG)_{it} + \delta_4 Ln(Kage)_{it} + \delta_5 (Slab)_{it} + \delta_6 Time + w_{it} \quad (5)$$

Where,

Y_{it} is the value-added of the i-th firm at the t-th time period;
K_{it} is the stock capital of the i-th firm at the t-th time period;
L_{it} is the total number of employees of the i-th firm at the t-th time period;
SML is firm size dummy variable =1 if firm has less than 20 employees, 0 otherwise (reference variable).
MED is firm size dummy variable = 1 if firm has between 21-49 employees, 0 otherwise;
LRG is firm size dummy variable = 1 if firm has between 50-199 employees, 0 otherwise;
Big is firm size dummy variable = 1 if firm has more than 200 employees, 0 otherwise;
Kage refers to the age of capital stock measured in years;
Slab is the share of skilled labour;
Time is a time trend to account for the change of the inefficiency effects over time; and v_{it} , w_{it} are as defined in the previous section.

The firm size variable is an attempt to provide empirical evidence on the relationship between technical efficiency and firm size[5]. Firms with higher shares of skilled labor are hypothesized to be technically more efficient. Similarly, technical efficiency is hypothesized to be higher for firms who own relatively newer capital stock assets. Finally, the time variable is introduced in our model to have an idea on how technical efficiency in the Tunisian agro-food industry has evolved over time.

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 program FRONTIER version 4.1 (Coelli, 1996). Parameters estimates, along with the standard errors and T-ratios of the ML estimators of the Tunisian food industry inefficiency frontier model are presented in table 1. The signs of the estimated parameters of the translog stochastic frontier production model are as expected. Estimated coefficients for both *capital stock* and *labor* are positive and significant, which confirms the expected positive relationship between capital stock and labor and the value added of production.

The estimated coefficients in the technical inefficiency model are also as expected, with the exception of the positive sign of the time trend variable, which indicates that overall technical inefficiency of production in the food industry in Tunisia tended to increase throughout the period of investigation 1983-1996. The estimated coefficient of the age of capital stock variable is positive and statistically significant, which indicates that the more depreciated capital stock is the less efficient firms are. With respect to firm size effect, the positive estimate for the medium size firm (between 20 and 49 employees) is not significant. However, the positive coefficients for the *large* (between 50 and 199 employees) and *big* (more than 200 employees) variables are statistically significant at the 5% level with respect to the reference variable *small* (less than 20 employees). This indicates that, on average, larger firms make less efficient use of their resources compared to smaller ones.

The estimated coefficient of the share of skilled labor variable is of particular interest to policy maker. The negative and statistically significant at the 5% level coefficient suggests that an increase in the share of skilled labor contributes to higher technical efficiency levels of production in the Tunisian agro-food industry.

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 firms value added. Further, a number of statistical tests of hypotheses for the parameters of the stochastic frontier inefficiency model for Tunisia food industry are carried out and results are presented in table 2[6]. 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 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

Table 1. Parameters estimates and t-values of the inefficiency frontier model for a sample of Tunisian agro-food firms

Variables	Estimates	t-values
Stochastic frontier model		
Intercept	-6.090*	-5.060
Ln(K)	0.446*	2.548
Ln(L)	1.539*	6.900
$(Ln\mathrm{K})^2$	0.137*	6.200
$(Ln\mathrm{L})^2$	0.148*	10.411
Ln(K)**Ln*(L)	-0.176*	-10.290
Inefficiency effects model		
Intercept	-2.685*	-7.905
MED	0.116	1.606
LRG	0.208*	2.026
BIG	0.311*	2.114
Ln(Kage)	1.695*	10.184
Slab	-0.538*	-4.658
Time	0.039*	7.512
Variance parameters		
σ^2	0.142	15.516
γ	0.161	4.367
Log-likelihood	-270.623	

* indicates significance at the 5% level.

Table 2. Tests of hypotheses for the parameters of the stochastic frontier inefficiency model of a sample of Tunisian agro-food firms.

Null Hypothesis	Log-likelihood under H_0	Test statistic	Critical value at 5%	Decision
Cobb-Douglass $\beta_3=\beta_4=\beta_5=0$	-342.032	142.818	7.815	Reject H_0
No inefficiency effects $\gamma=\delta_o=\delta_1=\delta_2=\delta_3=\delta_4=\delta_5=\delta_6=0$	-388.162	235.078	15.507	Reject H_0
No firm specific effects $\delta_1=\delta_2=\delta_3=\delta_4=\delta_5=\delta_6=0$	-388.266	235.286	12.592	Reject H_0
Time invariant inefficiency $\delta_6=0$	-284.037	26.828	3.841	Reject H_0

The value of log-likelihood function under the specification of alternative hypothesis (i.e. unrestricted model) is –270.623.

to the explanation of the inefficiency effects and the fourth null hypothesis, which specifies that there is time invariant inefficiency are rejected.

Frequency distribution results of technical efficiency are presented in table 3. Estimated efficiency measures reveal the existence of substantial technical inefficiencies of production in the sample of agro-food firms at hand. The computed average technical efficiency is 67% ranging from a minimum of 45% to a maximum of 90%. Given the present state of technology and input levels, this suggests that firms in the sample are producing on average at 67% of their potential. Within this framework, 17 firms are relatively more efficient than the sample average efficiency level, with an efficiency score greater than 70%, 19 firms with mean efficiency between 60 and 70% and 10 firms show value of mean efficiency less than 60%.

Further, results indicate that there is a steady decline in technical efficiency by approximately 30% from the period 1983-1986 to 1993-1996. The comparison of mean efficiency between agro-food firms over time indicates that average technical efficiency

Table 3. Frequency distribution of technical efficiency of production estimates for a sample of Tunisian agro-food firms.

T. Efficiency (%)	1983 -1986	1987 -1989	1990 -1992	1993 -1996	1983 -1996
≤ 60%	3	11	27	33	10
	(6.5%)	(23.9%)	(58.6%)	(71.7%)	(21.7%)
> 60 ≤ 70%	5	14	6	19	19
	(10.6%)	(30.4%)	(13.0%)	(15.2%)	(41.3%)
> 70 ≤ 80%	5	9	6	10	10
	(10.7%)	(19.5%)	(13.0%)	(8.7%)	(21.7%)
> 80 %	33	12	7	2	7
	(71.7%)	(20.0%)	(15.2%)	(4.3%)	(15.2%)
Mean efficiency	83 %	70 %	62 %	53 %	67 %

Numbers in parenthesis represent the percentage of firms in each class of technical efficiency of production.

scores are higher in the 1983-1986 period (71.7% of firms have technical efficiency scores greater than 80%), whereas, in the 1993-96 period only 4.3% of firms have technical efficiency scores more than 80%.

Conclusions and policy implications

This paper investigates firm level technical efficiency of production and its determinants in the Tunisian agro-food industry. To this end, a stochastic production frontier model, in which technical efficiency effects are assumed to be a function of firm-specific variables and time, is estimated. The single-stage estimation procedure is carried out using a panel of 46 agro-food firms, observed over a period of 14 years.

Results show that significant inefficiencies exist in the sample of firms under investigation. Specifically, 39 out of the 46 firms (84%), on average, produce below 80% of their potential output due to technical inefficiency. Indeed, average technical efficiency measure suggests that agro-food firms in Tunisia could increase their production by about 33% through more efficient use of inputs.

Empirical results of the investigation of the sources of technical inefficiency based on Tunisian agro-food firms in the sample show that firm size is a determining factor of technical inefficiency. Large firms operating inefficiently are not able to achieve some economies of size and are doing so more often because of the high managerial skills required at managing large size firms with a high number of employees. Further, the positive relationship between the share of skilled labor and technical efficiency of production has important implications to both managers and policy makers. Indeed, this result justifies the professional training and conversion programs implemented lately by the government and targeted to employees with limited skills. These programs are elective; however, firms are encouraged to participate on payment of a subsidy in the form of a tax break.

Empirical evidence also suggests that the age of capital stock owned by the firm is an important determinant of the firm's efficiency. Indeed, the efficiency of capital stock assets declines over time and losses in productive capacity would occur. This stresses the need for managers to replace their capital stock assets before the point where the cost of repairs exceeds the value of the increased service flows derived from the repairs is reached.

Finally, the positive coefficient for the *time* variable indicates that, on average, technical efficiency of production in the Tunisian agro-food industry tends to decline during the period of investigation. This finding could be the result of the sustained government price support programs and input subsidization schemes to the food industry. These programs have been used, during the period of investigation, as an income enhancing tool and may have contributed to reducing managerial motivation and effort and led through time to lower levels of technical efficiency. This result corroborates the advanced hypothesis in the economics literature related to the negative effects of government intervention on technical efficiency of production (Lachaal, 1994). It further stresses the need for policy makers to move away from subsidy programs that have a potential to cause heavy distortions in input utilization.

Notes

1. In the first stage of the 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.
2. From an econometric point of view, the use of panel data has some advantages over cross section data in the estimation of stochastic frontier models. Panel data either make it possible to relax the strong distributional assumptions made with cross-sectional data or result in estimates of technical efficiency with more desirable statistical properties (Kumbhakar and Lovell, 2000).
3. 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).
4. Incorporation of exogenous variables will help come up with recommendations on how government policy formulation could be used to influence these variables so as to enhance the technical efficiency of production in the agro-food industry.
5. While the "small and inefficient" hypothesis has been advanced in the agricultural economics literature as one possible explanation for the gradual disappearance of small and medium sized farms, empirical evidence, however, has been rather mixed at best (Kalaitzandonakes *et al.*, 1992).
6. 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.

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