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Full Length Research Paper

Estimation of the technical efficiencies of Ethiopian agro-food processors using stochastic frontier approach

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This study was conducted to estimate the level and determinants of technical efficiencies of Ethiopian food processing firms using stochastic frontier approach. Two stages stratified sampling technique was used to draw 90 sample firms during the years (2000 - 2006) from a data collected by Central Statistical Authority of Ethiopia. Cobb-Douglas stochastic frontier production function model in combination with a technical inefficiency effects model were employed to study the level and determinants of technical efficiency of the firms in a simultaneous one step estimation procedure. The software used in this study was Frontier 4.1 written by Tim Coelli (1998). The test result indicated that mean technical efficiency of Ethiopian agro – food processing firms is 0.866 indicating that there is a room to improve production of processed foods by 13.4% given the existing level of inputs, price of inputs and technological level. Among the explanatory variables of the technical inefficiency effects model, incentive, capacity utilization, ownership type and age were found to be positive determinants of technical efficiency. Furthermore, it is investigated that there is a parabolic relation between age and technical efficiency. A decrease in the technical efficiency of food processors through the study period was also observed.

Key words: Food processors, technical efficiency, Cobb – Douglas production function, Ethiopian, stochastic.

INTRODUCTION

Unlike its European counter parts, the modern Agro food processing sector of Ethiopia is not the outcome of its ancient tradition in handicrafts and cottage industries. The sector emerged in the early 20th century through foreign entrepreneurs. During its establishment, all of the food processors of that time were concentrated in urban centers near Addis Ababa, Dire Dawa, and Harar (MEDaC, 2005). After its establishment, the food processing sector in Ethiopia passed through different phase of trade and industrial strategies and policies which highly influenced its entire development. First, the export of primary agricultural products and the import of finished products to and from capitalist countries became the main feature of the trade. This pattern seriously hurt the agro food processing sector. Then, socialism became the dominant ideology of the country and this led nationalization of all agro–food processing firms of the country. Firms were put under the administration of the then ministry of National resource development (MEDaC, 2005). Again, all the inefficiency problems associated to nationalization hurt the development of the sector seriously. Finally, a public enterprise reform programme was undertaken aiming at enhancing efficiency, productivity and competitiveness in public enterprises through the granting of managerial autonomy and responsibility to the firms. Though firms are showing an improvement by this strategy, there are still some major problems faced by Ethiopian food processing firms. Poor

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quality and inadequate supply of essential raw materials, high cost of availing raw materials, under capacity utilization and inappropriate or obsolete processing and ancillary equipments are the major one. Currently, there is an indication of growth opportunity for agro-food processing firms due to an increased demand for processed foods in world market as a result of newly emerged big number of middle class societies in China, India and Russia (IFPRI, 2008). To harvest from this ripe opportunity, it will be essential to improve the productivity of food processing sector through different mechanisms. One of the approaches is through horizontal expansion approach (change in scale) according to which, outputs could be increased through utilization of more inputs. The other approach is the improvement approach (technical efficiency) which argues for the possibility of increasing productivity with a decreased cost of production only by improving efficiencies of producing units. The third approach is a transformation approach (technical change) which focuses on the possibility of increasing the level of production by a shift or an improvement in production technologies such as the use of modern processing and packaging machineries which shifts the production function outward. Though a mix of all the approaches is essential, the improvement approach (improved efficiency) will be the most applicable approach for developing countries where financial deficit is a serious problem to apply the other two.

As far as the analytical models for measuring production or technical efficiency is concerned, they are classified into frontier efficiency models, the ones based on the concept of best practice frontier and non-frontier efficiency models. Under this category are parametric method which is based on econometric estimation of best practice frontier function and the other is non – parametric method which is based on linear programming techniques such as Data Envelopment Analysis (DEA). Farrel (1957) was the first to formulate non – parametric frontier to measure technical efficiency, according to whom, inefficiency could be measured as the observed deviation from a frontier isoquant using linear programming technique. As this approach attributes all the deviation from the frontier to technical inefficiency, it is categorized under deterministic approach. Later, Aigner and Chu (1968) specified another deterministic homogenous Cobb-Douglas production frontier using linear and quadratic programming techniques to express the production behavior of firms in a mathematical form which allowed accommodating non-constant returns to scale. However this method had its own limitations. There is no means of statistical inference about the reliability of the estimates as they are estimated via programming techniques. To include statistical inference about the estimates, Afrait (1972) and later Greene (1980) proposed a deterministic statistical frontier. However, these approaches also face a common problem with the earlier approaches in that they interpret all the deviations from frontier as inefficiency of the firm. To solve the above problem, Meuseen and Van Den Broeck (1977) proposed the stochastic frontier approach for measuring technical efficiency of firms by splitting the random term into two other terms in which one attribute to statistical noise which are out of the control of the producing firm and the other attributes to the technical efficiency of the producing unit, which is under the control of the firm.

METHODOLOGY

The Data

All the information regarding the variables included both in production function and technical inefficiency effects models were obtained from annual census survey of CSA (Central Statistical Authority of Ethiopia) for the time periods 2000 - 2006. The firms which were included in the study are grouped according to International Standards for Industrial classification (ISIC) in which those firms with similar nature of inputs, outputs and technology are grouped together. These groups are meat, fruit and vegetable processors, dairy products processors, flour processors, bakery product processors, sugar and confectionary processors, pasta and macaroni processors and animal feed processors. Two stages random sampling technique was used to select the sample units in this study. In the first stage, stratification was carried out to draw all types of agro food processing firms according to their proportion and in the second stage, stratification was carried out on each type of agro food processing firms to draw the appropriate number of firms in all regions of the country.

Technical Efficiency Measurement

In order to investigate the level and determinants of technical efficiency of Ethiopian Agro – Food processors, the stochastic frontier approach was used. A stochastic frontier production function for panel data as proposed by Battese and Coelli (1995) can be defined as:

$$Y_{it} = f(X_{it}, \beta)e^{\varepsilon\, it} \qquad (1)$$

Where, Y_{it} is output vector for the ith firm at time t. X_{it} are vectors of inputs, β is a vector of parameters and ε_{it} is an error term which is defined as:

$$\varepsilon_{it} = v_{it} - u_{it} \qquad (2)$$

The error term in this model is decomposed into two other terms one of them capture the deviation from the frontier due to technical inefficiency (u_{it}) and the other capture the deviation from the frontier due to random effects which are out of the control of the firm (v_i). The parameters of u and v can be estimated by maximizing the log-likelihood function as:

$\ln(Y \sim \beta, \gamma, \sigma^2) = \frac{N}{2}\left(ln\frac{2}{\pi}\right) - Nln\sigma + \sum_{i=1}^{N} \ln(1 - F(\varepsilon it,\gamma,\sigma-1)) - 12\sigma 2i=1N\varepsilon it2$ (3)

Where:

$\varepsilon_{it} = Y_{it} - f(X_{it};\beta)$

$\sigma^2 = \sigma_u^2 + \sigma_v^2$

$\gamma = \frac{\sigma_u}{\sigma_v}$

$\sigma = \sqrt{\alpha_u^2 + \alpha_v^2}$

F= the standard normal distribution function

N= Number of observations

The conditional mean of u_{it} at a given ε_{it} is equal to:

$E(u_i\varepsilon_i) = \frac{\sigma_u\sigma_v}{\sigma}\left[\frac{f(\varepsilon_i\gamma\alpha)}{1-f(\varepsilon_i\lambda\alpha)} - \frac{\varepsilon_i\gamma}{\sigma}\right]$

Where f and F are the standard normal density and distribution functions evaluated at $\frac{\varepsilon_i\gamma}{\sigma}$. Measures of technical efficiency (TE_{it}) for each term can be calculated as:

$TE_{it} = \exp(-E[u_{it}/\varepsilon_{it}])$ so that $0 \le TE_{it} \le 1$.

The Production function model

Cobb – Douglas functional form was specified to model the production function of Ethiopian Agro – Food processors as:

$$\ln Y_{it} = \beta_o + \beta_1 \ln R_{it} + \beta_2 \ln EN_{it} + \beta_3 \ln L_{it} + \beta_4 \ln C_{it} + v_{it} - u_{it} \quad (4)$$

Where

Y_{it} = is the total quantity of output (food) produced in Birr by firm i at time t.

R_{it} = is the total quantity of raw materials used for production in Birr by firm i at time t

EN_{it} = is the value of energy used for production in Birr by firm i at time t.

L_{it} = is the value of labor used for production in Birr by firm i at time t. As the wages and salaries of employee could homogenize the labor inputs (as they are good weighting mechanisms for differences in experience, training, motivation and so on), they are used to measure the value of input used in food processing.

C_{it} = is the value of capital inputs such as machineries over the production year by firm i at time t. The value of capital input is calculated following the method of Huang and Bagi (1984) in which capital input is measured by adding all costs related to the usage of capital inputs (machineries, buildings, etc.) such as the annual depreciation of the capital, costs of maintenance and repair, expenditure for rent and interest payment for machineries and buildings for the given production year

v_i= is the disturbance error term independently and identically distributed as N $(0,\sigma v^2)$ intended to capture events beyond the control of firms.

u_{it} = is a non negative random variable, independently an d identically distributed as $N^+(\mu,\sigma\mu^2)$

The Technical Inefficiency effects model

u_{it} in the above frontier production model was assumed to be a non negative random variable and is independently and identically distributed as $N^+(\mu_{ti}, \sigma\mu^2)$. It is intended to capture technical inefficiency effects of food processors measured as the ratio of observed output to maximum feasible output of the i^{th} firm at time t. It is assumed to follow truncated normal distribution with μ_{ti} and σi such that;

$$\mu_{ti} = \delta_o + \delta_1 INC + \delta_2 LRTR + \delta_3 time + \delta_4 Age + \delta_5 Age^2 \\ \delta_6 type + \delta_7 \exp ort + \delta_8 size + \delta_9 size^2 + \delta_{10} CapU \quad (5)$$

Where,

μ_{ti} = The level of technical inefficiency of firm i at time t.

INC = Incentive given to workers in the form of commission, bonuses, professional allowance….

LRTR = is the ratio of local raw material to total raw materials used in production of foods.

Time = is a time variable used to see whether the firms increased their efficiency over time and takes a value of 1 for year 2000, 2 for 2001…… and 7 for 2006

Age = the age of the firm in years used to capture the effect of experience on technical efficiency

Age^2 = the square of the age of the firms in years used to see the parabolic relation b/n TE and age

Size = the size of the firm is proxied by the number of perma nent employees in the reference year.

$Size^2$ = the square of the size of the firms used to see the parabolic relation b/n TE and size.

CapU = extent of capacity utilization which can be captured as a percentage of the existing gross value of production to gross value of production if capacity is utilized fully. Its value range from 0 to 100%. A magnitude of 0 implies the firm did not utilize any of its capacity while a magnitude of 100% means the firm fully utilized its capacity.

type = A dummy variable used to see whether type of ownership of firms have relation with TE. It takes the value 1 if the firm is owned by privates and 0 otherwise.

Export =is a dummy variable, which would take a value of 1 if the firm exports its produce abroad and 0 otherwise and incorporated in the model to see whether there is variation in technical efficiency of exporters and non – exporters.

ECONOMETRIC RESULTS

Parameter estimates of the Frontier Models

As it can be seen from Table 1, the elasticity of raw material

Table 1. Maximum Likelihood estimates of the SPF model.

	Cobb – Douglas SPF	
Variables	**Coefficient**	**t – ratio**
Constant	0.640	7.91*
Raw material	0.621	33.92*
Energy	0.114	6.17*
Capital	0.110	7.50*
Labor	0.181	9.40*
Sigma squared	0.074	7.43*
Gamma	0.640	9.50*
Log – Likelihood function		121.2

* Significant at 1%

is 0.621 which indicate that during production process, the amount of product could be raised by 62.1% as the amount of raw material is raised by 100%. When this value is compared to the elasticity of other variables of the model, it shows that the most important factor for production of processed foods is raw material. The value of gamma calculated is 0.64 and significant at 1% significance level indicating that 64% of the deviation from the frontier is due technical inefficiency and the rest 36% is due to random factors which are out of the control of producing unit.

Testes of Hypotheses on SPF Model

One of the attractive features of using stochastic production frontier in preference to data envelopment analysis for estimation of technical efficiency is its suitability to test different hypotheses.

The first hypothesis testing was conducted to identify the best functional form between Cobb- Douglas and translog functional forms that fits the data set more appropriately. The data was fitted to both types of functional forms and selection was done based on their log likelihood ratio statistics. The test statistics is calculated as:

$$\lambda = LR = -2\{[\ln H_0]/[\ln H_1]\} = -2\{[\ln H_0] - [\ln H_1]\}$$

Where, $\ln H_0$ and $\ln H_1$ are the log likelihood functions under the null hypothesis H_0 and alternative hypothesis H_1 respectively. A null hypothesis was formulated to see whether the extra coefficients in translog functional form (coefficients of the interaction and square terms) over Cobb – Douglas functional form are all together zero ($H_0 = \beta_{11} = \beta_{12} = \ldots = \beta_{44} = 0$). The log likelihood ratio (λ) for the hypothesis under consideration was calculated to be -242.16 (see Table 2) indicating that Cobb – Douglas functional form better fits the production function of food processors. The next hypothesis testing was conducted to see whether technological shift occurred in food processors during the study period. Two estimations on SPF were carried out separately, one with time incorporated as an additional explanatory variable (with a coefficient, β_5) and the other without. The log likelihood ratio (λ) for the hypothesis under consideration was calculated to be -11.4. Thus the null hypothesis which states that the influence of time factor on the SPF is zero ($H_0 = \beta_5 = 0$) was accepted and the alternative hypothesis which states that there is a technological change through the study period was rejected so that comparison of technical efficiency of firms through the time period included in this research is justifiable. The third type of testing was conducted to verify whether the food production is characterized by constant or increasing returns to scale. A log likelihood function was then estimated for the null hypothesis which states that the production process is characterized by constant return to scale ($\Sigma\beta_i = 1.0$) and the alternative hypothesis which states that the production system is characterized by increasing return to scale ($\Sigma\beta_i = 1.04$). The calculated log likelihood ratio test was -1886.4 (Table 2) indicating that, the production process is characterized by constant returns to scale.

Parameter Estimates of the Technical Inefficiency Effects Model

The coefficients of incentive, extent of capacity utilization, and age in the technical inefficiency effects model are all significant and negative hence they are positively related to the level of technical efficiency of agro food processing firms (see Table 3). The level of technical inefficiency of firms will decrease as the level of these variables increase. Age squared was also found to be significant at 5% significance level and appeared with positive sign that there is a parabolic relationship between age and the technical efficiency of food processors. Size, percentage of local raw materials to total raw materials, export and type of ownership are insignificant and consequently are not able to explain the variation in level of technical efficiencies of EAFPs. The coefficient of time in the inefficiency effects model indicated that food processing firms decreased their technical efficiency throughout the study period.

Table 2. Hypothesis testing on SPF Model.

Null Hypothesis	$L(H_0)$	$L(H_1)$	λ, calculated	λ, critical	Decision
$H_0 = \beta_{11} = \beta_{12} = \ldots = \beta_{44} = 0$	121.2	0.119	-242.16	18.3	Accept H_0
$H_0 = \beta_5 = 0$	121.2	115.5	-11.4	3.84	Accept H_0
$\Sigma\beta_i = 1$	1064.4	121.2	-1886.4	3.84	Accept H_0

Table 3. Maximum Likelihood estimates of Technical inefficiency model.

Variables	Technical Inefficiency model	
	Coefficient	t - ratio
Constant	-0.0055	-0.04
INC	-0.00000013	-4.66***
LRTR	0.0014	-1.22
CapU	-0.0060	-5.46***
Age	-0.008	-2.14**
Age^2	0.00015	2.59***
Size	0.00016	0.73
$Size^2$	-0.00000011	-1.76**
type	0.086	1.59
export	-0.105	-1.51
time	0.027	2.25**

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Tests of Hypotheses on Technical Inefficiency Effects model

A null hypothesis (H_0: $\gamma = 0$) was formulated to check whether there exists a technical inefficiency in the firms or not. The null hypothesis states that there is no inefficiency in the production process, as there is no difference between the average response and the frontier functions. Another test was conducted to check whether all explanatory variables of the technical inefficiency effects model were all simultaneously zero (H_0: $U_i = \delta_1 = \delta_2 = \ldots = \delta_{10} = 0$). The calculated values of λ for both cases indicated that the hypotheses should be rejected at ten degrees of freedom. Thus it is assured that there is technical inefficiency in Ethiopian food processors and all the explanatory variables included in the technical inefficiency effects model simultaneously explain the difference in the technical efficiency of the firms. The last test was conducted to select between half normal or truncated normal distributional assumptions of U_i that could better fit the data at hand. Based on their log likelihood function, the null hypothesis (H_0: $\mu = 0$) which states truncated normal distributional assumption of U_i better fits the data was accepted (see Table 4).

Technical Efficiency Scores

The panel mean technical efficiency of Ethiopian agro food processing firms was calculated to be 86.6% (see Table 5). This indicated that, there is a room to increase the level of output at an average of 13.4%, given the existing level of input, input price and technology only by removing constraints of the firm that hindered them from operating on the frontier.

Apezteguia (1997) found similar results in mean technical efficiency (90%) of Spanish Agro food processing industries. As it can be seen from Table 5, 49% of the firms (46 firms) were 90% (and above) technically efficient where as 47% of them (40 firms) were technically efficient in the range of 80 – 90% for the year 2000. This distribution gradually shifted to a point where only 28% of them (25 firms) were 90% (and above) technically efficient where as 56% of the firms (51 firms) were technically efficient in the range of 80 – 90% for the year 2000.

When firms are grouped into those which scored above and below panel mean technical efficiency, the number of firms which operated above mean value roughly showed a gradual decline from the highest (72% of the firms) for the year 2000 to the lowest (48% of the firms) for the year 2006 (see Table 6). In contrast, the number of firms which operated below the panel mean showed a relative increase through the panel from the lowest (28% of the firms) for the year 2000 to the highest (52% of the firms) for the year 2006.

Determinants of Technical Efficiency of EAFPs

Incentive and Technical Efficiency

The coefficient of incentive in the technical inefficiency effects model indicated that the level of technical efficiency of firms increase with incentive. This could be due to the increased motivation of employees that initiate them to do

Table 4. Hypotheses testing on technical inefficiency effects model.

Null Hypothesis	$L(H_0)$	$L(H_1)$	λ, calculated	λ, critical	Decision
H_0: $\gamma = 0$	69.34	121.2	103.72	19.68	Reject H_0
H_0 : $U_i = \delta_1 = \delta_2 = \ldots = \delta_{10} = 0$	76.1	121.2	90.2	18.3	Reject H_0
H_0 : $\mu = 0$	119.7	121.2	3.0	3.84	Accept H_0

Table 5. Frequency distribution of TE of EAFPs in the panel (2000 – 2006).

	Year						
TE	2000	2001	2002	2003	2004	2005	2006
0.0 – 0.39	–	–	–	–	–	–	–
0.4 – 0.49	–	–	–	3	–	–	1
0.5 – 0.59	–	1	–	2	1	–	–
0.6 – 0.69	1	–	2	3	3	6	2
0.7 – 0.79	3	7	5	13	5	4	11
0.8 – 0.89	40	37	44	28	39	39	51
0.9 – 1.0	46	45	39	41	42	41	25
average	0.890	0.883	0.878	0.847	0.872	0.870	0.850

Table 6. Frequency distribution of firms above and below panel mean technical efficiency.

	Year						
TE	2000	2001	2002	2003	2004	2005	2006
Below(=) average	28	36	37	42	38	39	49
Above average	62	54	53	48	52	51	41
Total	90	90	90	90	90	90	90

more jobs than those which are not provided. This means, the firm can exploit the potential of its labor inputs and produce more outputs, without increasing the number of labor force. This makes the firm more technically efficient. Furthermore, the increased level of motivation of employees could develop belongingness to the firm and encourage employees to use the other inputs of production (raw material, energy and capital) more appropriately there by giving extra dimension for the increment of technical efficiency of the firm by decreasing unnecessary loss. As it can be seen from Table 7, incentive providers exceed non – providers by a technical efficiency level of 3%.

Extent of Capacity Utilization and Technical Efficiency

The extent of capacity utilization was positively related to the level of technical efficiency at 1% significance level (see Table 7). Firms tend to be more technically efficient when they utilize their capacity more and more. This could be as a result of the utilization of an otherwise idle capital input of the firm such as machineries, whose cost is already incurred in the form of depreciation even if they are not used. In economic terms, it means that, the firm if utilizes its capacity, could produce more outputs without an introduction of additional capital inputs (increased technical efficiency). In order to compare the difference between two groups of firms which utilized different levels of capacity, the following table was constructed. As it can be seen from Table 8, firms which utilized their capacity above 50% exceeded those firms which utilized below 50% by a technical efficiency level of 7%.

Age and Age Squared

The technical efficiency of food processing unit is found

Table 7. Comparison of panel mean TE of incentive providers and non – providers.

Incentive	N	panel mean TE	SD	t - ratio
Providers	460	0.88	0.161	2.36*
Non – providers	170	0.85	0.075	

*Significant at 5%

Table 8. Comparison of panel mean TE of firms with different capacity utilization.

Capacity utilization	N	panel mean TE	SD	t - ratio
Below (=) 50%	296	0.83	0.085	3.89*
Above 50%	334	0.90	0.165	

* Significant at 1%.

to increase with age. This could be due to an increase in firms' experience through time toward the major activities of the overall food processing system such as managerial ability of resources and employees, better control of quality of raw materials, processed foods, and intermediary products, better control of operating conditions, better adaptation to engineering as well as economic aspects of food production, improvement in marketing strategies, improvement in interaction with other processing firms and institutional units and so on. However, it was again investigated that this positive relationship would not proceed indefinitely. A maximum point will be attained beyond which technical efficiency start to decline with age. The existence of parabolic relationship between age and technical efficiency was captured by age squared. The sign of age squared was opposite to that of age in the technical inefficiency effects model. This could be due to the prevalence of loss associated to wear and tear of machineries as they get too old, more than the gain in technical efficiency of firms associated to improvement in experience. This implies that middle age firms are more technically efficient than new and old firms. Comparison was made on the mean technical efficiency of firms with different age groups. Three category of ages, where in one group firms which served for less or equal to 5 years (average age minus standard deviation), in the other group firms which served for greater than 45 years (average age plus standard deviation) and the third, between the two groups (6 – 45) were constructed. As it can be seen from Table 9, middle age firms are more technically efficient than newer firms by 5.6 and older firms by 1.4%.

Time and Technical Efficiency

It was found that firms decreased their technical efficiency through time in the study period. This may be due to the increased number of firms passing the middle age category and joining the old age category through time. The other explanation could also be due to the increased level of shortage of raw materials through time during the study period, and that forced firms to use only a portion of their capacity and there by decrease the their technical efficiency. As it can be seen from Table 10, firms decreased their mean technical efficiency with time in the study period.

CONCLUSIONS

Cobb-Douglas stochastic frontier production function was applied in the analysis of panel data collected on Ethiopian Food Processors by central Statistical Authority of Ethiopia with a view to estimating the levels and determinants of their technical efficiency. The empirical result revealed that inefficiency exists in food processing system. There was no technical change (transformation in technology) during the study period. Food processing firms are strongly advised to erect their firms based on prior capacity estimation from market analysis and utilize their capacity fully and provide incentives to their employees during operation. Furthermore, newer firms are advised to share the experiences of middle age firms and older firms are advised to inspect their plant frequently for replacement of older spares before they lead to a failure during operation. In order to promote efficient utilization of resources, the authors recommend for smooth flow of spare parts.

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Table 9. Comparison of panel mean TE of firms with different Age groups.

Age	N	panel mean TE	SD	t - ratio
≤ 5	116	0.856	0.075	2.67*
6 – 45	420	0.880	0.165	
>45	94	0.866	0.097	

* Significant at 1%.

Table 10. Comparison of panel mean TE of EAFPs through the study period (2002 – 2006).

	Year						
TE	2000	2001	2002	2003	2004	2005	2006
N	90	90	90	90	90	90	90
Mean TE	0.890	0.883	0.878	0.847	0.872	0.870	0.850
SD	0.058	0.006	0.005	0.118	0.077	0.076	0.078
t – ratio	1.240	1.096	2.970*	-2.4958*	0.523	2.099*	

Source: Own computation.

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ABBREVIATIONS:

TE: Technical Efficiency
CSA: Central statistical Authority
SPF: Stochastic Production Function
EAFPs: Ethiopian Agro–Food processors