

Technical and Economic Efficiency of Rice Production on the Irrigated Plain of Bagre (Burkina Faso): A Stochastic Frontier Approach

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Abstract:
This paper examines the level of technical efficiency, allocative efficiency and economic efficiency of rice farmers on the irrigated plain of Bagré to assess the potential for increasing rice production.
The computer program Frontier version 4.1 was used to estimate a stochastic frontier production function and his dual (cost frontier function) from which we derived the efficiency levels of farmers. Determinant efficiencies were estimated simultaneously with the frontier functions. The data used for analysis were obtained from 170 rice producers selected randomly from the irrigated area of Bagré. The results indicate that technical, allocative and economic efficiency of producers are respectively 80%, 93% and 74% on average. Moreover, it is clear that economic efficiency could be improved if the mineral fertilizer, improved seed and capital are properly used by rice farmers.
Keywords: technical efficiency, allocative efficiency, economic efficiency, production frontier, cost frontier function, Burkina Faso

1. Introduction

In Burkina Faso, rice is ranked number 4 in terms of production and consumption. It has firmly turned into standard food for Burkina populations due to factors such as the rapid urbanisation and the cereal shortage in the country over the last three decades. That situation subsequently led to important food product imports in order to ensure steady food supply for the populations.

The national rice production estimated at 249,000 tons in 2010 (DGPER 2011) barely covers 38% of the current consumption needs. The country has resorted to imports for about 200,000 tons per year over the last seven years to meet local demand. Expressed in values, this represents more than CFA F 27 billion. These imports might reach 300,000 tons per year (for about 70 billion CFA francs) in case a rapid national production growth does not follow.

The global 2008 food crisis, the increase in agricultural product costs, and the shortages seen in the global market have compelled developing countries to place greater store on national production to guarantee food and nutrition security and reduce the vulnerability of their economies to exogenous shocks.

As a Sahelian country, challenged with climate hazards, there are three possible alternatives for Burkina Faso to increase agricultural production as a whole, and rice production in particular; (i) increasing the existing production infrastructures through efficient allocation of productive resources; (ii) developing new irrigated lands with total or partial water control to achieve production security; (iii) a combination of the above.

In the short term, the first alternative is the least costly to be considered for Burkina Faso, firstly because of the high cost of the developed lands (more than 10 million CFA F per hectare), secondly, and most importantly, the country's budgetary constraints.

The main purpose of this paper is to present an analysis of the efficiency level of producers across the combination of production factors and to identify the determinants of efficiency that need to be boosted. The stochastic frontier function was chosen for this purpose. The advantage of this approach is first its ability to allow the estimation of technical efficiency from a Cobb-Douglass production function and then to deduce economic efficiency from dual cost function.

The methodology and the conceptual framework are explored in greater details throughout the first and second parts of this study; then, a subsequent conclusion is drawn from the finding presented in the third part.

2. Methodology

This study was conducted on the irrigated land of Bagre, downstream Nakambe river in the Centre-East inside of the province of Boulgou. The area is 250 km away from Ouagadougou, along the Ouagadougou –Tenkodogo – Bittou road and 30 to 50 km away from Ghana and Togo borders. The region's climate is North Sudanese's type with an annual rainfall ranging from 711 to 1145 mm.

The choice is justified by the fact that this area is known to be representative of larger areas in Burkina Faso. In fact, in term of surface area, it is the second largest irrigated rice production area. An optimal use of productive resources will increase rice production in this respect.

The data collected are based on the 2009 raining season. The sample was randomly selected out of list of producers provided by the directorate of the project management. These lists represent a fair balance, taking into account both the location of the producer (right bank and left bank) and the producers group they belong to. This sample therefore encompasses producers groups from both the left bank (7 in total) and the right bank (10 in total). The survey was based on 10 producers per group who when put together make up 170 producers spread across the area. The data were collected from a questionnaire targeting the quantity of production, factors of production and the cost attached to the factors of production.

3. Theoretical Framework

The conventional estimation of the production function was carried out by means of a production frontier (maximum output possibility) achieved from a given quantity of input. Given the impossibility for producers to achieve a maximum of production beyond their actual potentials, this led researchers to develop the concept of efficiency. As a matter of fact the measure of efficiency originated with the work of Koopmans (1951) and Debreu (1951).

3.1 Efficiency Concept

In his definition of efficiency, Farrell (1957) separates technical factors from inappropriate choice related to the combination of inputs (products) as compared to their price. According to him, technical efficiency (TE) is used to measure the decision making about the quantity of inputs used in the production process, given the factor proportions used. For the same level of production, the most technically efficient producer is the one that uses less input.

The price efficiency or allocative efficiency (AE) is used to measure the producer's decision about the proportions of inputs as compared to the admittedly competitive market price. In theory, a production process is considered to be allocatively efficient if the marginal rate of substitution between each pair input is equal to the proportional price of each. Economic efficiency (EE) is the product of both technical efficiency and price efficiency.

Efficiency is measured based on parametric and non-parametric approaches.

The first one is mathematical programming related. It carries no restriction on the functional form of production function. The production frontier is estimated from a convex polyhedron enveloping the set of observations, with the most efficient ones on the frontier. The non-parametric approach has been criticised for not allowing to compare the theoretical minimum achieved output on one hand, and not making possible the relative efficiency of the factor of production utilisation, on the other hand. Furthermore, measurement errors and random effects that the farmer can meet are not taken into account (plant diseases, rainfall, etc).

The second one is econometric modelling related. Unlike the non-parametric approach, the parametric method requires a functional form to the production function, whereas the estimation of the coefficients of the parameters is carried out either by mathematical programming or by the ordinary least squares method or maximum likelihood.

With regard to the specific characteristics of Burkina Faso agriculture, which is subject to the weather vagaries, price fluctuation of agricultural products and high illiteracy rate, the choice of the stochastic parametric method for the analysis of technical and economical efficiency of rice production is quite relevant.

3.2 The stochastic frontier production function :

Farrell (1957), who extended the formal definition provided by Koopmans (1951) and the measure of technical efficiency by Debreu (1951), made a major step into frontier econometrics.

Farrell's method has been quite successful due to new inputs resulting in some noticeable improvements. Among those major changes, the stochastic model was developed, allowing to measure for the first time the technical, allocative and economic efficiency, using the maximum likelihood method. Aigner et al (1977), Meeusen and Van den Broeck (1977) have been at the forefront of developing the stochastic frontier production function. The former applied this method to the US agricultural analysis and the latter to the analysis of ten manufacturing industries in France. Battese and Corra (1977) also applied this method to the analysis of a pastoral zone in East Australia, while some empirical analyses have been conducted recently by Battese et al (1993) in Pakistan, Belloume (1999) in Burkina Faso, and Ojo (2004) in Nigéria.

The stochastic frontier production functions are characterised by the insertion of a stochastic component into the frontier that includes the cumulative effects of all variables excluded from previous methods.

$$Y_i = f(X_i, \beta)\exp(V_i - U_i) \quad i = 1,2,\ldots,n \qquad (1)$$

Yi is the output;

X_i the vector of input used;

β the vector of parameters to be estimate;

V_i = the random error term. It is assumed independent and normally distributed as $N(0,\delta^2)$.

U_i represents technical inefficiency effects. It is assumed independent and a truncated normal distribution at zero, with a mean μ_i and variance δ_u^2, $(N(u_i,\delta_u^2))$

At the individual farmer level, the technical efficiency index can be calculated as follows:

$$ET_i = \frac{y_i}{y_i^*} = \frac{f(X_i,\beta)\exp(V_i - U_i)}{f(X_i,\beta)\exp V_i} = \exp(-U_i) \qquad 0 \le ET \le 1 \qquad \textbf{\textit{(2)}}$$

Where y_i is the level of output observed, and y_i^* the stochastic production frontier;

3.3 The stochastic frontier cost function :

$$C_i = g(y_i, p_i, \alpha)\exp(V_i + U_i) \qquad \text{i = 1,2,…,n} \qquad (3)$$

C_i is the total production cost observed;

Y_i is the output quantity (rice produced) ;

P_i the price vector of inputs used;

α vector of parameters to be estimate;

V_i and U_i are defined as mentioned earlier.

The allocative efficiency (AE) index is defined as:

$$AE_i = \frac{C_i^*}{C_i} = \exp(U_i) \qquad o \le AE \le 1 \qquad \textbf{\textit{(4)}}$$

Where C_i = the total production cost incurred and C_i^* = the stochastic cost frontier.

3.4 The stochastic frontier production function specification

The technical and allocative efficiency estimation model used for Bagre rice producers is based on the model proposed by Battese and Coelli (1995) and Battese et *al* (1996), where the stochastic frontier incorporates inefficiency effects. This is written as follows:

$$\ln Y_i = \beta_0 + \beta_1 \ln eng + \beta_2 \ln SA + \beta_3 \ln SL + \beta_4 \ln Cap + \beta_5 \ln W + v_i - u_i \qquad \textbf{\textit{(5)}}$$

Y_i : Quantity of rice produced in kg ;
Feng: the amount in kg of mineral fertilizer;
SA: the quantity in kg of improved seeds;
SL: the quantity in kg of local seeds;
Cap: the capital in CFAF which includes equipment values, pesticides, water rate and farm operating costs;
W: family labour in man-day (MD)
β_i = the coefficients to be estimate; they represent the elasticities when the production function is based on Cobb-Douglas's type.

3.5 The stochastic frontier cost function estimation

Cobb-Douglas type frontier cost function is specified as follows:

$$\ln C_i = \alpha_0 + \alpha_1 \ln Y_i + \alpha_2 \ln P_{eng} + \alpha_3 \ln P_{SA} + \alpha_4 \ln P_{SL} + \alpha_5 \ln P_{cap} + \alpha_6 \ln P_{mof} + v_i + u_i \qquad \textbf{\textit{(6)}}$$

C_i : The operating cost in CFAF ;
Y_i : is the quantity of rice produced by the farmer in kg;
P_{eng} : mineral fertilizer average price in CFAF per kg ;
P_{SA} : improved seeds average price in CFAF per kg ;
P_{SL} : local seeds average price in CFAF per kg ;
P_{cap} : the average cost of capital employed measured measured in terms of opportunity cost. In fact, the capital

is considered borrowed, with 10% interest rate ;
P_{mof} : the average cost of family labour
α_i = the coefficients to be estimate; they represent the elasticities when the production function is based on Cobb-Douglas's type.

3.6 The technical and allocative inefficiency effects specification

$$U_i = \sigma_1 z_1 + \sigma_2 z_2 + \sigma_3 z_3 + \sigma_4 z_4 + \sigma_5 z_5 + \sigma_6 z_6 + \omega$$

z_1[2] represents the age of the operator ; z_2 the size of the household ; z_3 the level of literacy (binary variable) ; z_4 the investment in other activities (binary variable) ; z_5 access to credit (binary variable) and z_6 the use of organic fertilizer (binary variable).

The maximum likelihood method is used to estimate the frontier functions (output and cost). In this study, FRONTIER version 4.1 programme is used.

However, this programme estimates the cost efficiency (CE), which, conversely, corresponds to the allocative efficiency index ($CE = \dfrac{C}{C^*}$).

The AE index of the individual farmer is shown in the following relationship: $AE = {}^{1}\!/_{CE}$

4. Results and discussions

This part deals with the statistics of the parameters used to compute the models and draw results using Frontier 4.1 software.

4.1 Statistical analysis :

Table 1 summarises the statistics of the parameters used to analyse stochastic production and cost functions. The estimated average output per farmer is 3.9 tons/ha. On average, the mineral fertiliser use is 386 kg/ha, 64 kg/ha for improved seeds, and 77.5 kg/ha for local seeds. While farmers pay attention to recommended dosage for mineral fertilisers, they tend to use 80kg/ha for improved seeds, which is rather below the standards. The average working time for family labour is 141 MD/ha. Here is a proof that family farming is at the heart of rice production.

The average investment in rice production per farmer is 439,777 CFAF / ha. 38% of this cost is related to the capital employed in the farming operations, depreciation of the equipment and the purchase of pesticide. Family labour and mineral fertilisers account respectively for 32% and 24%.

Table 1 : Statistics summary of production costs (CFAF)

variables	mean	min	max	Standard deviation
fertilizer (kg/ha)	386	200	800	97.20
improved seeds (kg/ha)	64	10	140	23.25
local seeds (kg/ha)	77.5	5	175	32.41
capital (CFAF/ha)	167,158	58,775	383,700	61,062
family labour (MD/ha)	141	376	27	57.88
output (kg/ha)	3,893.5	1,785	10,560	1272
age	44	20	70	11.24
size of household (number of people)	12	1	40	5.99
mineral fertilizer cost (CFAF/ha)	107,508	52,000	256,000	29,209
Local seeds cost/ha	11,631	750	26,250	4,862
improved seeds cost (CFAF)	35,104	5,000	120,000	19,464
cost labour/ha	140,821	27,000	376,000	57,885
cost of capital (CFAF/ha)	16,716	5877.5	38,370	61,061.93
Total output cost (CFAF/ha)	439,777	194,850	903,700	97,923.69

Source: survey data

4.2 Estimation of stochastic frontier production function :

The estimated results of the production function parameters are displayed in table 2: The maximum likelihood (ML) ratio test of the model is used to test its overall fit. When the empirical value of ratio (LR) is greater than the theoretical value of the chi-square at 5%, then considered adjustment is significant on a global scale. Herein, the calculated value is 16.66, while the theoretical one is 11.1. Because the calculated value is greater than the theoretical, the model is adequate.

[2] In the absence from the database of the variable number of years operating in the area, the variable farmer's age was preferred with the hypothesis that the ones with more experience are the oldest

The estimated gamma (γ) value (0.59) is significant at 5% level. This means that the gap between the actual output and the maximum output is approximately due at 59% by the farmers' technical inefficiency.

The estimation of the stochastic production function parameters reveals that the coefficients of the variables mineral fertilizer, local seeds and capital are significant at 5 % level. The coefficients of the variables mineral fertilizer and capital are positive while this is negative for local seeds. The positif sign for the variables mineral fertilizer and capital shows that the output volume varies proportionally to the quantity of mineral fertilizer used and capital employed. Whereas the negative sign of the variable local seeds shows that the volume of rice output varies inversely to the quantities of the local seeds used. This is a reason why local seeds should be abandoned and farmers should adopt improved seeds.

The elasticity analysis shows that mineral fertilizer has the highest elasticity (0.64). This indicates the importance of that variable in the rice production on the irrigated plain.

The second variable with high elasticity is the capital (0.24). In fact, its mainly represents investments made in farming operations and equipment which allow farmers to respect the crop calendar and ensure a better development of rice plants. A capital increase of 10% leads to 2.4% increase of output.

The socio-economic determinants analysis indicates that age has a positive impact on the technical efficiency of rice farmers. With the same quantity of input, older farmers produce more output compared to younger farmers. One reason comes from older farmers experience in agriculture in general and especially irrigation. Furthermore, older farmers are more diligent in attending training sessions than young farmers.

Table 2: Results of the estimation of the production function

variables	coefficient	Student's t-test
Production modelling		
constant	1.6	2.29**
ln (Eng)	0.64	6.48***
ln(SA)	-0.0056	-1.5
ln (LS)	-0.0078	-1.75*
ln(W)	0.023	0.55
ln(Cap)	0.24	3,8***
Technical inefficiency model		
z_1 (age)	0.0069	3,38***
z_2 (size of household: number of people)	-0.0062	-88
z_3 (level of literacy)	-0.0145	-0.198
z_4 (other crops activities)	-0.1	-1.4
z_5 (credit)	0.049	0.82
z_6 (organic fertilizer)	-0.123	-1.2
δ^2	0.057	3,9***
Γ	0.59	2.24**
LR	16.66	

*** significant at 1% ; ** significant at 5% ; * significant at 10

Table 3 below presents resources productivity. The output scale parameter (0,89) is calculated by summing up the coefficient of input estimates (elasticities). It indicates that rice production in the area is at stage II of the production curve. Stage II represents decreasing output scale where resources and output are at peak level of efficiency.

Table 3 : production resources productivity

Variables	elasticities
Mineral fertilizer	0.64
Improved seeds	- 0.0056
Locale seeds	- 0.0078
Family labour	0.023
Capital	0.24
Return to scale	0.89

4.3 Estimation of stochastic frontier cost function :

The computed results from Frontier 4.1 software of the stochastic frontier cost function are displayed in table 2. The value of LR (373) is above the theoretical chi square at 5 degree of freedom (11.1). This means that the model is properly specified.

Gamma value (γ) estimated (0.91) is significant at 5%, showing that 91% of the variation of the total cost of rice production results from the existence of allocative inefficiency.

The estimated parameter of cost function reveals that the coefficients of production quantity (output), improved seed price and the cost of capital are positive and significant at 5%. Indeed, the output (quantity of rice produced) and the costs of fertilizer, improved seeds as well as the capital have a positive influence on the total production cost. A 10% raise of the quantity of rice produced bring about a 2% increase of total the production cost while a 10% increase of mineral fertilizer price factors, capital and improved seeds leads to some 3.4%, 2.6% and 0.06% increase respectively.

Unlike technical efficiency, the socio-economic determinants analysis indicates that age has a negative impact on the allocative efficiency of farmers. The implication is that older farmers tend to attach little importance to minimising production costs when compared with younger farmers. In other words, younger farmers use the cheapest input combinations throughout the production process.

Table 4 : Results of the cost function estimation

variables	coefficient	t-ratio
Allocative efficiency		
constant	4.9	4.96***
lny	0.22	4.4***
$\ln P_{eng.}$	0.34	2.59**
LnP_{SA}	0.0058	2,67***
P_{SL}	0.0031	1.17
P_{Cap}	0.26	5.9***
P_{mof}	0.26	1.39
Allocative inefficiency		
z_1 (age)	-0.049	-3.6***
z_2 (size of household: number of people)	0.025	0.59
z_3 (level of literacy)	-0.12	-0.149
z_4 (other crops activities)	-0.34	-0.43
z_5 (credit)	-0.24	-0.34
z_6 (organic fertilizer)	0.46	0.78
Sigma squared	0.18	5.29***
gamma	0.91	38.62***
LR	373	

*** significant at 1% ; ** significant at 5% ; * significant at 10%

4.4 Estimation of efficiency index scores

Efficiency index scores are displayed in table 5

Table 5 : Frequency distribution of rice farmers efficiency level

Efficiency level	Technical efficiency		Allocative efficiency		Economic efficiency	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
<=0.49	-	-	-	-	1	0.62
0.5-0.59	4	3	-	-	9	5.55
0.6-0.69	18	11	1	0.62	32	19.75
0.7-0.79	60	37	3	1.85	71	43.84
0.8-0.89	59	36	24	14.82	48	29.62
0.9-1	21	13	134	82.71	1	0.62
Total	162	100	162	100	162	100
Mean	0.8		0.93		0.74	
Standard deviation	0.088		0.04		0.088	
Minimum	0.52		0.66		0.49	
Maximum	0.94		0.97		0.9	

4.4.1 Technical efficiency :

Farmers' technical efficiency indices vary between 52% and 94%, with a mean of 80%. It was found that a large number of farms (73%) have a TE index ranging between 0.70 and 0.90; whereas 13% of farms have a TE index between 0.90 and 1.

The 80% average index shows that the production level can be increased by 20% on average keeping the same input quantity. These results are consistent with those obtained by Bellomé (1999) in the South-West of Burkina Faso (84%) and Kaboré (2007) in the Kou Valley (76%). In india, Battese and Coelli (1992) obtained indices of 94%.

The 80% mean index suggests that the changes of technology (more productive improved varieties of seeds and better farming practices) could be the best option to substantially increase rice production at Bagre.

4.4.2 Allocative efficiency:

Rice farmers' allocative efficiency scores vary between 66% and 97%, with a mean of 93%. (table 5). This implies therefore that there is a possibility for rice farmers to reduce production costs by 7% on average if they allocate available resources efficiently. 82,71% of producers display an allocative index between 0.90 and 1 and less than 3% have AE inferior to 80%. This shows that farmers display a good level of allocative efficiency.

4.4.3 Economic efficiency:

Economic efficiency is the product of both technical efficiency and allocative efficiency. In other words, it pertains to the combined effects of both. The average level of economic efficiency is 74%, with a minimum of 49% and a maximum of 90% (table 5). Only 30% of farmers show an EE above 0.80.

5 Conclusion

The objective of this study is to assess the technical, allocative and economic efficiencies of bagré plain rice producers, in order to measure the quality of productive resources allocation and to examine the possibilities of increasing rice production. For that, we used a stochastic frontier function

The result of the estimated stochastic frontier production function shows that mineral fertilizer, capital and farmer’s age are all variables that positively participate to rice production increase. The use of local seeds on the contrary causes output decrease.

The result of the estimated stochastic frontier cost function indicates that the variables quantity of rice produced, average price of the kg of mineral fertilizer, average price of local seeds, average cost of capital employed have a positive influence on production costs. As to age variable, it has a negative impact on farmers' allocative efficiency, subsequently showing that younger producers tend to minimise production costs as compared with older farmers.

Another interest from this study is that the producers of the Bagre plain display a high level of efficiency. As a matter of fact, technical, allocative and economic efficiency levels are 80%, 93% and 74% respectively.

These findings suggest that increase in rice production could result only from improving technical efficiency. In that sense, with 80% of technical efficiency, it is possible to increase rice production by only 20% if farmers had better training. The gap between the actual output and the potential output is due at 59% by the technical inefficiency of producers. Efforts still need to be made toward the improvement and mastering of production techniques through providing greater support to producers. Nevertheless, the need to increase rice production at the irrigated plain of Bagre exceeds the expected 20%. Therefore, the necessity arises to explore new varieties that are more productive in comparison with what producers are using currently.

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