Analysis of Technical Efficiency of Litchi (*Litchi chinensis)* Production in Bangladesh: A Stochastic Frontier Analysis

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Abstract

Agriculture plays a crucial role in Bangladesh's economy by providing employment, alleviating poverty, enhancing food security, and supplying inputs for industrial production. While crops and cereals dominate the agricultural sector, fruits, including litchi, play a significant role in Bangladesh agriculture. However, it is found that litchi growers in Bangladesh are not fully efficient in optimizing their inputs, highlighting the need for interventions and improvements in the sector. Thus, the objective of the present study is to estimate the technical efficiency of litchi production in Bangladesh. Required data are collected from 100 litchi producing farmers of Ishwardi Upazilla selected by using multistage random sampling procedure. In analyzing the data, farm specific technical efficiency scores are estimated using the Cobb- Doughlas Stochastic Frontier Production function approach. The study found that the mean technical efficiency of the litchi producer is about 84.20% that means there have still 15.80% room for increasing technical efficiency of the litchi producer. Again, by using farm specific technical inefficiency as dependent variable multiple regression is performed for understanding the factors' that affect technical inefficiency. According to the result it is found that in case of litchi production training, education and loan has significant impact for enhancing technical efficiency.

Additional keywords: Technical efficiency, Litchi (*Litchi chinensis)* production, Bangladesh, Stochastic Frontier Analysis.

Introduction

Bangladesh relies heavily on agriculture as its primary economic activity, which has a significant impact on creating jobs, reducing poverty, ensuring food security, and developing human resources. The agricultural sector contributes significantly to the GDP, with its share estimated to be around 11.50% in FY 2021-22 (BBS, 2022). According to World Bank data, the total arable land in Bangladesh is approximately 80, 00,000 hectares, which accounts for around 61.5 percent of the country's total land area (World Bank, 2020). This confirms that Bangladesh has a significant proportion of land suitable for cultivation.

While crops and cereals form the primary components of agriculture in Bangladesh, it is worth noting that fruits also significantly contribute to the sector (Khandoker et al., 2017). In recent years, there has been a notable emphasis on fruit production due to the growing popularity of fruits among consumers and the nutritional value of fruits (Khandoker et al., 2017). According to the BBS (2021), 996,000 acres of land were used for fruit production, where 207,000 acres were for temporary fruit production and 789000 acres for permanent fruit production. Though litchi production has been becoming popular in Bangladesh in the recent years it has a long and fascinating history. Its origins can be traced back to ancient China, where it has been cultivated for over 2,000 years (Wu, 2016). The exact date of litchi's domestication is unclear, but it is believed to have been cultivated as early as 2000 BCE in the southern regions of China. The Chinese imperial court prized litchi trees, and the fruit was reserved exclusively for royalty and nobility Mitra et al. (2008). In recent years, litchi production is become popular in Bangladesh due to several reasons such as a high-value export commodity, high yield of litchi, contributing to rural livelihoods and poverty reduction, primary materials for the various products such as juice, jam, jelly, and canned litchi, etc. (Mitra et al., 2008). According to Yang et al. (2015), litchi fruits may have several health benefits, including antioxidant, anti-diabetic, anti-angiogenic (preventing tumors from growing blood vessels), anti-carcinogenic (inhibiting or preventing cancer), anti-inflammatory, and cardio protective effects.

Pabna district is one of the most litchi producing area in Bangladesh. According to information from the local Department of Agricultural Extension (DAE, 2022), litchi cultivation in the Pabna District has witnessed remarkable growth in the recent years. A significant area of 11691 acres has been dedicated to litchi farming, aiming to produce an unprecedented yield of 42,579 tones (DAE, 2022). This production volume sets a new record, surpassing previous litchi cultivation achievements in the country. It has also been found that many farmers are switching to litchi production from other crops and hoping for higher economic return. However, higher economic returns form litchi production depends on how efficiently farmers are utilizing the land and other factors of production. Examining technical efficiency is an important indicator in this regard.

Research carried out by various authors have shown variations in technical efficiency across different agricultural productions (Hasnain et al. 2015), (Rahman et al. 2013), and (Alam et al. 2012). Technical efficiency (TE) is an approach used to assess the effectiveness and productivity of production processes, focusing on how efficiently inputs such as labor, capital, and resources are utilized to achieve a desired output level (Mokhtar et al., 2006). There are several methods for measuring technical efficiency. Stochastic Frontier Analysis (SFA), Data Envelopment Analysis (DEA), and the Two-Stage DEA Model (also known as the Extended DEA) are the most widely used models among them. (Balcombe et al., 2006) used two different frontier techniques- Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA) to estimate the technical efficiency of dairy firm and identify the factors affecting it. In many cases, DEA and SFA are used simultaneously for research. Cullinane et al. (2006) used both DEA and SFA in their research and found that both gives quite similar results.

While there is no study found for this particular issue on litchi production in Bangladesh, several studies are available on other crops. For instance, Hasnain et al. (2015) identified that the average technical efficiency in rice cultivation within Meherpur district, Bangladesh was approximately 89.5%. Similarly, in maize production, Rahman et al. (2013) documented an average technical efficiency of around 96.9 percent. Concurrently, in the realm of tilapia fish farming, Alam et al. (2012) found an average technical efficiency of about 78 percent within the context of Bangladesh. Therefore, it is justifiable to emphasize the significance of technical efficiency as an indicator for understanding how efficiently farmers utilize their resources. Again, a study conducted by Mar et al. (2013) assessed the technical efficiency of mango production in central Myanmar. The findings revealed that farmers exhibited a mean technical efficiency of 71%, suggesting potential for enhancement. This study also found that labor and pesticides had positive effects on yield, while the usage of fertilizer and mechanization had a detrimental impact. Similarly a study by Mango et al. (2015) estimate the technical efficiency of maize production within smallholder farming communities in Zimbabwe, findings revealed that the average technical efficiency is about 65 percent.

Numerous factors can influence technical inefficiency, and their impact can vary depending on the product type. Therefore, to better understand the factors that affect technical efficiency, this study examine various studies that focus on the subject of different goods. Research undertaken by Karani et al. (2015) aimed at investigating factors determining the technical inefficiency of passion fruit cultivation in Kenya indicates that the age of the orchard, the amount of credit utilized, non-passion fruit income, and county variables exerted a significant and positive impact on technical efficiency at a 5% significance level. Again a study by Dunchev et al. (2019) shows that in the case of soft fruit production introducing innovations in water and nutrient management can lead to improved efficiency in their use, resulting in higher yields and reduced negative impact on the environment. These innovations can also have a positive impact on human health. Litchi production in Bangladesh has been rapidly increasing and serving both household consumption and commercial purposes. Existing literature suggests an absence of studies that have been undertaken to assess the technical efficiency of litchi farms in Bangladesh. Despite the significant growth of litchi production in the country, there is a noticeable gap in research regarding the assessment of how efficiently farmers utilize their inputs in litchi cultivation. Therefore, it is necessary to address this gap and conduct a study to estimate the technical efficiency of Litchi farms, providing valuable insights for the industry.

Materials and Methods

Concept of Technical Efficiency

Firm efficiency can be divided into two components: technical efficiency (TE) and allocative efficiency (AE), as originally suggested by Farrell in 1957. Subsequently, Farrell and Fieldhouse (1962) introduced a third element, scale efficiency, as an additional factor contributing to potential inefficiency. The concept of technical efficiency for farms was introduced by Farrel (1957), and according to him, technical efficiency is a concept that depends on the specific factors and measurement methods that have been used for producing any goods. Any changes to these will affect the measurement of technical efficiency. The technical efficiency of production refers to the level at which a production unit achieves its highest possible output. In simpler terms, it measures the proximity of the actual output of a production unit to its maximum potential output (Färe et al., 1978).

Farm technical efficiency measures how efficiently the inputs are used for getting the maximum output (Kalirajan et al., 1983). Technical efficiency quantifies how effectively a firm utilizes its resources to generate output, and it is an essential factor in determining its overall productivity and profitability (Bravo-Ureta et al., 2007). Therefore, technical efficiency represents how well we farms used their available resources to get the highest output. Farrell's (1957) analysis of efficiency can be better understood by Figure 3.1, which illustrates the relationship between input- and output-oriented efficiency measures as shown below:

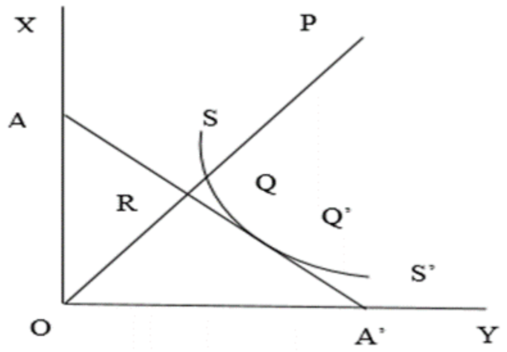

Figure1: Technical and Allocative efficiency

Contemplating a firm employing two inputs to manufacture a single product under the assumption of constant returns to scale, the isoquant SS' signifies the minimal combination of inputs necessary to produce one unit of output. Any point along this isoquant is technically efficient. In this scenario, points Q and Q' are technically efficient, while point P represents inefficiency. The distance QP reflects the input package that could be saved by the firm at point P without reducing output. The ratio QP/OQ signifies the percentage by which inputs must be reduced to attain technical efficiency. Consequently, the technical efficiency (TE) of the producer can be expressed as the ratio TE = OQ/OP

Research Methodology

This study has used a quantitative research approach for estimating the technical efficiency of litchi farms of Ishwardi Upazila located in the Pabna district of Bangladesh. This particular region is renowned for its significant litchi production for its favorable climatic conditions and fertile soil. This study used a multistage random sampling technique and selected 100 litchi farms from the study area to estimate the technical efficiency of litchi production. To understand how efficiently farmer using their inputs this study used stochastic frontier analysis.

Stochastic Frontier Analysis (SFA)

Stochastic frontier analysis, a method introduced independently by Aigner et al. (1977) for estimating technical efficiency. Moreover, Meeusen et al. (1977) have extended the insight to use the stochastic frontier approach. (SFA) is a statistical modeling technique commonly used to estimate industry production functions using cross-sectional data (Battese et al. 1995). Again Kumbhakar et al. (2003), in their book "Stochastic Frontier Analysis," provide a depth insight into the stochastic frontier production function and its application in empirical analysis. This approach allows for a more accurate assessment of agricultural production efficiency (Bravo-Ureta & Pinheiro, 1993).
The general functional form of this model can be expressed as:

$$Y_i = f(X_i, \alpha) + \varepsilon_i \qquad (1)$$

The equation presented is a basic linear regression model where the output variable (Y_i) is a function of the input variable (X_i) and an unknown parameter (α). Error term ε_i is made up of two separate parts, $V_i and\ U_i$, where V_i is the random (symmetric) error term assumed to be normally distributed with a mean and variance N $(0, \sigma^2)$ and $U_i\ is$ known as a one-sided error term. The parameters of the stochastic frontier model can be accurately estimated through the maximum-likelihood estimation technique. By maximizing the likelihood function, which assesses the probability of observing the sample data given the model parameters, this method is employed to estimate the parameters of the model. Throughout the process of maximum-likelihood estimation, it is possible to derive estimates of the parameter variances within the likelihood function. These estimates provide information about the degree of uncertainty associated with the parameter estimates and can be used for various statistical purposes, such as hypothesis testing and constructing confidence intervals. And variance can be stated as:

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

and $$\gamma = \sigma_u^2 \big/ \sigma_s^2 = \sigma_u^2 \big/ \sigma_v^2 + \sigma_u^2$$

There have been empirical studies that aim to examine both production risk and technical efficiency together using a unified approach. Kumbhakar et al., (1993) devised a methodology to assess production risk and technical efficiency by utilizing a flexible production function that characterizes the production technology. Additionally, the model proposed by (Kumbhakar et al., 1993) accommodates the potential for either negative or positive marginal effects of inputs on production risk, aligning with the framework introduced by (Just and Pope, 1978). After the research conducted by Kumbhakar, (1993) and Battese et al., (1997), the formulation of the error structure in equation (1) will be

$$\varepsilon_i = g(X_i, \beta)[V_i - U_i] \qquad (2)$$

So from (1) and (2) we can write

$$Y_i = f(X_i, \alpha) + g(X_i, \beta)[V_i - U_i] \quad (3)$$

These (3) were first described by Battese et al. (1997) which incorporate versatile risk.
It is possible to estimate the average and variability (risk function) of the output of the i^{th} farmer, taking into account the input values and the effect of technical inefficiency, using the following equation:

$$E(Y_i \backslash X_i, U_i) = f(X_i, \alpha) - g(X_i, \beta)U_i \quad (4)$$

and

$$Var(Y_i \backslash X_i,\ U_i) = g^2(X_i, \beta) \quad (5)$$

Through the application of this risk function, the marginal production risk can be computed by taking the partial derivative of the variance of production concerning inputs, and this value can be either positive or negative. That is

$$\frac{\delta Var Y_i \backslash X_i, U_i}{\delta X_{ij}} > 0, or < 0 \qquad (6)$$

The technical efficiency of each farmer (TE_i) can be determined by comparing the average production achieved by the i^{th} farmer, by taking consideration of inputs (X_i), and technical inefficiency (U_i), to get maximum potential products that could be achieved without any technical inefficiencies. This can be expressed as the ratio between the mean production of the i^{th} farmers and the maximum possible production, representing the efficiency level in utilizing available resources. It can be shown like this:

$$TE_i = \frac{E(Y_i \backslash X_i, U_i)}{E(Y_i \backslash X_i, U_i = 0)} = 1 - TI_i \quad (7)$$

Where TI_i represents the technical inefficiency of the i^{th} observation, which can be defined as the potential loss of output compared to the maximum attainable output given the available inputs and the stochastic frontier production function and we can write this like below:

$$TE_i = \frac{U_i.g(X_i, \beta)}{E(Y_i \backslash X_i, U_i = 0)} = \frac{U_i g(X_i, \beta)}{f(X_i, \alpha)} \quad (8)$$

According to Jondrow et al. (1982) if we know the parameters, then the term (U_i) would be a conditional expectation of technical efficiency (TE_i)). This predictor is determined based on the realized value of the random variable representing the composite error term $U_i = (V_i - U_i)$. By further analysis and mathematical derivation, it can be demonstrated that $U_i \backslash (V_i - U_i)$ distributed as N(μ_i^*, σ_*^2), where μ_i^* and σ_*^2 are defined by the following:

$$\mu_i^* = -\frac{(V_i - U_i)\sigma_u^2}{(1 + \sigma_u^2)} \quad (9)$$

$$\sigma_*^2 = \frac{\sigma_u^2}{(1 + \sigma_u^2)} \quad (10)$$

Again we can write E$[U_i/(V_i - U_i)]$, denoted by $\widehat{U}_i$ like below

$$\widehat{U}_i = \mu_i^* + \sigma_* \left[\frac{\varphi\left(\mu_i^*/\sigma_*\right)}{\phi\left(\mu_i^*/\sigma_*\right)} \right] \quad (11)$$

Where ϕ (.) and Φ (.) show the standard normal random variable's density function and distribution function. The associated predictors for the random variable, E_i, can be used to estimate Equation (11).

$$\widehat{E}_i = \frac{Y_i f(X_i, \widehat{\alpha})}{g(X_i, \widehat{\beta})} \quad (12)$$

Now after estimating equation (11), we can also estimate equation (8) like this

$$TI_i = \frac{\widehat{U}_i.g(X_i, \widehat{\beta})}{f(X_i, \widehat{\alpha})} \quad (13)$$

Now the predicted technical efficiency of $the\ i^{th}$ farm will be T$\widehat{E}_i = 1 - T\widehat{I}_i$. We can also calculate the technical efficiency of the i^{th} farmer by $TE_i = exp(U_i) * 100$ (We can write technical efficiency in percentage form by multiplying this equation by 100).

Cobb-Douglas Production Function

In this study, the Cobb-Douglas Stochastic Production Frontier Model is used to empirically estimate the level of technical efficiency among litchi-producing farms. The functional form of this model is given below:

$$LnY_i = \beta_0 + \beta_1 lnX_{1i} + \beta_2 lnX_{2i} + \beta_3 lnX_{3i} + \beta_4 lnX_{4i} + \beta_5 lnX_{5i} + \beta_6 lnX_6 + v_i - u_i \quad (1)$$

Where, $\beta_1 \ldots \beta_6$ = Coefficient, Y_i= Output (Pcs of Litchi), $\beta_0 =$ Intercept term, X_1= Farm size (Bigha), $X_2 =$ Use of Labor (person), $X_3 =$ Use of capital (Tk.), $X_4 =$ Use of fertilizer (Kg), $X_5 =$ Use of pesticides (Tk.), $X_6 =$ Safety and security (Tk.), $(v_i - u_i) = U_i =$ Inefficiency.

For exploring factors that affect technical inefficiency this study use a multiple regression analysis and the model is as follows:

$$U_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + W_i \quad (2)$$

Here, $\delta_0 =$ intercept term, $Z_1 =$ Education (Years of schooling), $Z_2 =$ Experience (Years) Z_i =Training, $Z_i =$ Loan $\delta_1 \ldots \ldots \delta_4 =$ Coefficient, $W_i =$ error term

Results

Maximum likelihood estimation is a method that has been used to estimate the parameters of a statistical model by estimating the values that maximize the likelihood function, which measures the probability of observing the data under the assumed model (Meeusen et al., 1977). The results for estimating the maximum likelihood of litchi production for both the Technical efficiency and inefficiency model is depicted in Table 1 and 2 below:

Table 1. MLE of the Efficiency Model

Variables name	Parameters	Coefficient	Standard-error	t-ratio
Constant	β_0	9.32*	0.615	15.16
Size of the land (Bigha)	β_1	0.777*	0.102	7.556
Labor (Person)	β_2	0.040	0.090	0.450
Capital (Tk.)	β_3	0.052	0.037	1.368
Fertilizer (Kg)	β_4	0.070	0.068	1.024
Pesticides (Tk.)	β_5	0.073	0.042	1.739
Safety and Security	β_6	0.019	0.037	0.526
Sigma squared	σ^2	0.051*	0.009	5.553
Gamma	γ	0.973*	0.025	38.69
LR test		12.17		
Log-likelihood estimates		64.01		

Source: Field Survey, 2023, Note: (*, **, shows the significance at 1% and 5% level of significance)

In Table 1 above, the regression coefficient size of the land for litchi production in our study area is positive and at a 1 percent level of significance, it is significant. So it can be said that if farmers increase 1 percent of the land in our study area, the output will increase by 0.77 percent. The variables labor, capital, fertilizer, pesticides, and safety security did not have any significant impact at the 95% confidence level. Descriptive Statistics of Technical Efficiency are most important for getting information about the mean, maximum, minimum, and standard deviation of technical efficiency of litchi production. These will be shown in the table 2 below:

Table 2. Descriptive Statistics of Technical Efficiency.

Mean	Maximum	Minimum	Standard Deviation
84.20%	98.11%	53.66%	10.11%

Source: Field Survey, 2023

According to Table 2, the farmers are not using their input 100% efficiently and still, there is a 15.80% scope of improvement for using their input. This table indicated that the mean technical efficiency is about 84.20 percent and ranging from 53.66 percent to 98.11 percent. Now, the frequency distribution of the technical efficiency of litchi production is shown in the below table 3:

Table 3. Frequency distribution of Technical Efficiency

Class interval (percent)	Frequency (Farms)	Percentage	Cumulative %
51-60	1	1.0	1.0
61-70	11	11.0	12.0
71-80	19	19.0	31.0
81-90	33	33.0	64.0
91-100	36	36.0	100.0

Source: Field Survey, 2023

Based on the information provided in the above table, it is evident that the majority of litchi farms in the study area fall into the category of 91-100 percent technical efficiency, with a frequency of 36. This indicates that approximately 36 percent of the farms are considered highly efficient, operating at a technical efficiency level of 90-100 percent. It is also noteworthy that none of the farms have a technical efficiency level below 50 percent. As efficiency is not 100 percent in this study area for litchi production, it can be said that there is some sort of inefficiency. An insight into factors that affect technical inefficiency can be found in the regression result of the inefficiency model.

Table 4. Regression Result of Inefficiency Model

Variables	Parameters	Coefficient	Standard-	t-ratio	R and R^2
Constant	δ_0	0.144*	0.042	3.41	
Education	δ_1	-0.051**	0.022	-2.37	R=0.321
Experience	δ_2	0.000	0.002	0.21	R^2=0.297
Training	δ_3	-0.054**	0.022	-2.40	
Loan	δ_4	0.000	0.001	0.15	

Source: Field Survey, 2023

Table 4 indicates that for every 1 percent increase in education, Training inefficiency decreases by 0.051% and 0.054%. This relationship is statistically significant at the 5% level of significance, suggesting that education and training play a crucial role in reducing inefficiency in litchi production.

Conclusion

Fruits play a vital role in the development of Bangladesh's agricultural sector, contributing significantly to the economy, food security, and nutritional well-being of the population. Among the various fruits cultivated in the country, litchi holds great importance. This study has estimated technical efficiency which will give insight about how effectively and productively they utilize their resources, such as land, labor, capital, and technology, which can provide valuable information for enhancing productivity and optimizing resource allocation. The study aimed to assess the technical efficiency of litchi production in the designated area, employing stochastic frontier analysis with the Cobb-Douglas production function. The findings revealed an average technical efficiency of around 84.20 percent in the specified region. This means that there is still room for improvement, with a 15.80 percent potential increase in efficiency. The analysis also revealed that the minimum technical efficiency observed was approximately 53.66 percent, while the maximum was around 98.11 percent. The present study looks consistent as Bagchi et al. (2016) got a mean technical efficiency of litchi production in China about 80% which is close to this research. Overall, the findings suggest that there is still a 15.80 percent inefficiency present in litchi production, which could be reduced through the provision of proper training and increasing education. So, policy maker and government should focus on increasing training facilities and education facilities to improve productivity of the farmer engaged in litchi production.

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