Production Risk of Input and Technical Efficiency for Boro-Rice Production in Dumuria Upazila, Khulna: A Stochastic Frontier Modeling Approach

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Abstract: Rice is the foremost food crop in Bangladesh. Like Aman and Aus varieties, Boro rice also grows leaps and bounds in the country. The production of Boro rice during the dry season is welcomed as increasing use of irrigation in the country is expected to raise Boro rice production to achieve food self-sufficiency. This study investigates whether the marginal production risk of inputs is positive or negative and assesses firms' technical efficiency as a function of input levels in Boro rice production in Dumuria Upazila, Khulna, using a stochastic frontier modeling approach. Recognizing the importance of Boro rice in Bangladesh's agricultural sector, the study aims to evaluate how various inputs influence both efficiency and production risk among local farmers. Data was collected from a sample of 120 farmers in Dumuria through a structured questionnaire, capturing input costs such as labor, fertilizer, seeds, and irrigation, along with socio-economic characteristics. The stochastic frontier model, utilizing the Cobb-Douglas production function, was employed to assess technical efficiency scores and to identify significant inputs contributing to production variability. Findings reveal an average technical efficiency score of 0.82, indicating that farmers could potentially increase production by optimizing input use. Seed cost, land size, ploughing cost, and irrigation are highlighted as primary contributors to output variability, suggesting a need for targeted management to minimize risk. The study concludes with recommendations for policy and agricultural extension services to improve input management, particularly for small-scale farmers, to enhance production stability and efficiency in Boro rice cultivation in the Khulna region.

Keywords: *Boro Rice, Stochastic Frontier Approach, Production Function, Technical Efficiency, Bangladesh.*

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I. INTRODUCTION

Rice remains a cornerstone of Bangladesh's agriculture and food security, with the country ranking among the top rice-producing nations worldwide (FAO, 2015). Within the different varieties of rice cultivated, Boro rice is particularly important as it is grown during the dry season using irrigation, accounting for a significant portion of the nation's rice production. Boro rice farming has seen substantial growth in recent decades, supported by government policies aimed at achieving food self-sufficiency. This growth underscores the need for efficient input management, as resource optimization in rice production is essential for meeting both domestic and international food demands (Hossain & Rahman, 2012; Rana & Bapari, 2018).

Dumuria Upazila in Khulna, a coastal region in southwestern Bangladesh, is a prominent area for Boro rice production. However, farmers in this region face unique challenges, including environmental risks such as soil salinity, irregular rainfall, and water scarcity. These environmental issues, combined with rising input costs for labor, seeds,

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fertilizer, and irrigation, create substantial production risks that can impact farm profitability and yield stability (Hasan et al., 2016; Sadika et al., 2012). Production risk, defined as the variability in output due to uncertain input performance and environmental conditions, is a critical factor in the technical efficiency of rice farmers. Managing this risk is essential for enhancing productivity and ensuring food security in areas like Dumuria Upazila.

Technical efficiency is a measure of a farmer's ability to maximize output from a given set of inputs, reflecting the effectiveness of resource use under varying environmental conditions. In resource-constrained settings, high technical efficiency can help mitigate the effects of production risk and increase farmers' resilience against economic and environmental uncertainties (Coelli et al., 2005). Previous studies in Bangladesh have used stochastic frontier analysis (SFA) to assess technical efficiency among rice farmers, identifying key inputs such as labor, fertilizer, and irrigation as major factors influencing efficiency levels (Mitra & Yunus, 2018; Alam et al., 2012). Despite this research, there is limited analysis specific to coastal areas like Dumuria Upazila, where the unique environmental context intensifies production risks.

This study seeks to address this gap by applying a stochastic frontier model with a Cobb-Douglas production function to evaluate the technical efficiency of Boro rice farmers in Dumuria Upazila, Khulna. The model also aims to quantify the production risks associated with key inputs, thereby offering insights into how these factors contribute to yield variability. By analyzing both technical efficiency and production risk, this research provides a holistic view of the challenges faced by rice farmers in this region, offering evidence-based recommendations to optimize resource allocation and enhance productivity.

II. REVIEW OF LITERATURES

The evaluation of technical efficiency and production risk in agricultural sectors, especially rice farming, has been a focal point of research globally. Technical efficiency refers to a farmer's ability to maximize output from a given set of inputs, while production risk includes the variability in outputs due to unpredictable factors such as weather, market prices, and input costs. Numerous studies have employed stochastic frontier analysis (SFA) to assess these factors, particularly in rice-growing regions, underscoring the importance of efficient input management and risk mitigation in agriculture.

In the context of Bangladesh, several studies have examined the technical efficiency of rice production using SFA. Hasan et al. (2016) analyzed Boro rice production in the Jhenaidah District of Bangladesh, identifying irrigation, seed quality, and fertilizer as key inputs that influence technical efficiency. Their findings suggested that inefficiencies in these input areas led to considerable productivity losses, and that optimizing these factors could significantly enhance output. Similar studies by Hossain and Rahman (2012) in Naogaon District used the Cobb-Douglas production function to assess efficiency levels and found that technical inefficiencies could be minimized by better allocation and management of resources.

Ahmed et al. (2017) conducted a comparative study on rice farmers in Nigeria and China, utilizing SFA to understand the determinants of rice yield and efficiency. Their study revealed that production risks associated with labor, water availability, and fertilizer significantly influenced the efficiency of farmers in both countries. This comparative approach highlighted that environmental factors and resource access differences play crucial roles in shaping production efficiency, which is also relevant for the coastal regions of Bangladesh, where soil salinity and water scarcity present unique challenges.

In the South Asian context, Piya et al. (2012) explored technical efficiency among rice farmers in Nepal using SFA, identifying similar issues of input inefficiency and production variability. They found that labor and irrigation were critical inputs affecting productivity, with input costs and availability impacting efficiency levels across diverse farming environments. This study emphasized the role of socio-economic factors in determining efficiency, suggesting that increased training and support services for farmers could help mitigate input-related risks.

Coastal areas like Dumuria Upazila in Khulna face additional environmental challenges, such as soil salinity and erratic weather patterns, which can exacerbate production risks. According to Sadika et al. (2012), socio-economic and environmental factors significantly influence technical efficiency, particularly in vulnerable areas. Their study on shrimp farming in coastal Bangladesh illustrated that environmental stressors, combined with input-related risks, could lead to substantial efficiency losses, pointing to the importance of adaptive farming practices in managing these risks effectively.

Additional research by Rana and Bapari (2018) focused on credit availability and its impact on technical efficiency among rice farmers in Bangladesh’s Pabna District. They observed that access to credit allowed farmers to invest in better inputs, thus improving efficiency levels and reducing production risks associated with poor-quality resources. This study underscored the importance of financial support mechanisms in enhancing productivity and mitigating input-related uncertainties.

Globally, studies such as those by Coelli et al. (2005) have established the stochastic frontier approach as an effective method for assessing technical efficiency in agriculture. This method accounts for both random errors and

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inefficiencies in production, allowing researchers to quantify the extent to which farmers could improve their output by optimizing input use. SFA's application in various agricultural contexts, including rice farming, supports its relevance in examining efficiency and risk factors in Bangladesh's rice sector. In Bangladesh, few studies on the agricultural sector are found to be conducted in searching the required potential (Khan et al., 2010; Kabir et al., 2015; Rana & Bapari, 2018; Mitra & Yunus, 2018; Hossain & Majumder, 2018; Rabbani et al., 2017; Hasan et al., 2016; Hasnain et al., 2015; Sadika et al., 2012; Hossain and Rahman, 2012; Alam et al., 2012; Hasnain N et al., 2015; Ranjan Kumar Kundu et al., 2020; Rahman et al., 2021; Rabbany et al., 2021; Salam, M.A., 2022; Thapa et al., 2024).

In summary, the literature underscores the significance of technical efficiency and production risk in determining the productivity and sustainability of rice farming. Factors such as irrigation, seed quality, fertilizer, and socio-economic conditions consistently emerge as critical to efficiency. However, coastal regions face unique challenges that require localized strategies to mitigate production risks. This study builds on existing research by focusing on Dumuria Upazila, Khulna, to offer insights into the specific production risks and efficiency levels of Boro rice farmers in this coastal region.

III. METHODOLOGY

A. Study Area and Data Collection

Khulna district is in 22°49'12" north latitudes and 89°33'0.01" east longitudes. Among the southern region of Bangladesh, Khulna district is predominantly an agricultural area where a lot of rice is grown. The district comprises 9 administrative upazilas: Batiaghata, Dacope, Dighalia, Dumuria, Koyra, Paikgachha, Phultala, Rupsa and Terokhada. In this study, the target area was Dumuria Upazila of Khulna district. A multistage sampling technique was employed to collect the data. Dumuria was selected among the Upazilas of Khulna districts purposively and in the second stage, six villages were randomly selected. In the first stage Dumuria Upazila was chosen based on its potential for rice production and the population is all boro rice farmers in the Upazilas. From Dumuria upazilas six villages were randomly selected from a list of major boro rice-producing villages. Finally, 10% of farmers from each village were taken as respondents using a simple random sampling technique based on the up-to-date list of farmers provided by the respective upazilas agriculture office. The sampled farmers were interviewed personally either at their farms or at residence with the help of a well-structured questionnaire designed for the study from December to June. The demographic, institutional, and socioeconomic variables were included in the questionnaire. The required data are collected from a total of 120 boro rice-producing farmers.

B. Concept of Technical Efficiency

Technical efficiency refers to the ability of a producer to maximize output from a given set of inputs under specific conditions. It measures how well resources, such as labor, land, and capital, are utilized in the production process without considering cost or price factors (Farrell, 1957). In agriculture, particularly in settings where resources are limited, technical efficiency is essential as it enables producers to achieve the highest possible yields with their available resources, contributing directly to productivity and economic viability.

The concept of technical efficiency is grounded in production economics and was formalized by Farrell (1957), who differentiated between technical and allocative efficiency. While allocative efficiency relates to choosing the optimal combination of inputs given their costs, technical efficiency focuses solely on maximizing production with the resources available. This distinction is critical in agricultural contexts where optimizing input use can significantly affect output and profitability, especially in resource-constrained regions (Coelli et al., 2005).

Technical efficiency is often measured using stochastic frontier analysis (SFA), which accounts for random factors beyond the farmer's control, such as weather or market fluctuations, alongside inefficiencies in input use (Kumbhakar & Lovell, 2003). This approach is advantageous because it separates the effects of inefficiency from those of external randomness, offering a clearer picture of how efficiently resources are being used. Studies applying SFA to agriculture have shown that factors such as irrigation, fertilizer, and labor directly influence technical efficiency levels. For example, in rice farming, optimizing input use has been found to substantially increase productivity, particularly when combined with effective risk management strategies (Hasan et al., 2016; Alam et al., 2012).

In the context of Bangladesh, technical efficiency has become a focal point in agricultural studies, as enhancing efficiency in crop production, especially rice, is vital for food security. Research shows that Bangladeshi farmers often operate below their maximum efficiency potential due to constraints like limited access to quality inputs and irrigation infrastructure (Hossain & Rahman, 2012). Improving technical efficiency can help address these limitations by enabling farmers to produce more output with the same resources, thus reducing dependency on additional inputs and mitigating the impacts of production risk (Rana & Bapari, 2018).

In summary, technical efficiency is a critical concept in agricultural productivity, emphasizing the maximization of output from available resources. Understanding and improving technical efficiency can enhance food production, reduce input costs, and increase resilience against external risks, ultimately supporting sustainable agricultural development.

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C. Stochastic Frontier Modeling Approach

The Stochastic Frontier Model (SFM) captures the stochastic part of the data sets making it popular among the practitioners in the econometric area of research. The Stochastic Frontier Analysis (SFA) is a parametric approach that is based on the econometric estimation of a production frontier with one output and multi-inputs. In agricultural studies, the stochastic frontier method is frequently employed to measure technical efficiency, owing to its numerous advantages. This approach to the frontier production function incorporates both random error and an inefficiency component specific to each producer. Building on the foundational work of Debreu (1951), Koopmans (1951), and Farrell (1957) in empirically assessing the efficiency of production units, the general form of the stochastic production frontier can be represented as follows

$$Y_i = f(X_i, \beta)\exp(v_i - u_i), \qquad i = 1, 2, 3, \dots\dots\dots, N \quad \text{…………(i)}$$

where Yi is the output of Boro rice (kg) of the ith farmer, Xi is a 1×k vector of inputs used by the ith farmer, β is a 1×k vector of unknown parameters to be estimated, $f(X_i, \beta)$is suitable functional form of Cobb-Douglas function. The two-sided systematic error term, $v_i's$ $(-\propto \leq v_i \leq \propto)$ are identically and independently normally distributed random error [v~N (0, $\sigma^2{}_v$)]. The one-sided efficiency component $(u_i \geq 0)$ captures the inefficiency in production relative to the stochastic frontier (Coelli et. al.,2005). Following half-normal distribution of $u_i(u \sim \text{N } [\mu,\ \sigma^2{}_u])$. the technical efficiency of individual farmer, $(TEi\ )$ can be obtained as the ratio of the observed output (Yi) to the corresponding frontier output (Y^*) conditioned on the level of inputs used by the farmer. Mathematically it is expressed as-

$$(TEi\ ) = \frac{Y_i}{Y^*} = \frac{f(X_i,\beta)\exp(v_i - u_i)}{f(X_i,\beta)\exp(v_i)} = \exp(-u_i) \quad \text{………………(ii)}$$

The technical efficiency lies between 0 to 1. The specified empirical model of the Cobb-Douglas production function for Boro rice producers of the study region have been analyzed using this model

$$lny_i = \beta_0 + \sum_{j=1}^{6} \beta_j \ln X_{ij} + v_i - u_i$$

$$lnY_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \beta_7 \ln X_7 + v_i - u_i \quad \text{.... (iii)}$$

Where, β_0 = Intercept; Yi = total production of boro rice (in Mound); X_1= Seed cost (Tk.); X_2= Land size (bigha); X_3= Cutting cost (Tk.); X_4= Fertilizer cost (Tk.); X_5= Irrigation cost (Tk.); X_6= Pesticide cost (Tk.); X_7= Ploughing cost (Tk.).

IV. DISCUSSION OF RESULTS

Socio-demographic characteristics of Boro Rice production are important and it is related to the stochastic frontier analysis also. Thus, the descriptive statistics of the socio-demographic characteristics of the Boro rice production are presented in Table 1. It is seen from Table 1 that 100% of the farmers are male and the remaining 0% are female. A maximum of 88.3% of the farmers are Muslim and the rest 11.7% are from non-Muslim communities. It is found that the occupation of Dumuria Upazila peoples is 46.7% farmers, 23.3% Day-labor, 19.9% Fishermen & prawn culture and 10.8% others.

Table 1: Socio-Demographic Characteristics of Boro Rice Production.

Characteristics		**N (%)**
Gender	Male	120(100%)
	Female	0(0%)
District	Khulna	120(100%)
Main Occupation	Farmer	56(46.7%)
	Day labor	28(23.3%)
	Fisherman & prawn culture	23(19.9%)
	Others	13(10.8%)
Religion	Muslim	106(88.3%)
	Non-Muslim	14(11.7%)

In the present study, data on output and inputs are used to estimate the land-level technical efficiency of rice production. Before estimation, some properties of data such as mean, minimum, and maximum are calculated. From Table 2 it is seen that the mean land size of sample farmers is 8.03 bighas with a minimum of 1.00 bighas and a maximum of 30 bighas in the present study. Again, the fertilizer cost, seed cost, irrigation cost, pesticide cost, ploughing cost, and cutting cost are Tk.3878.17, Tk.547.58, Tk.5293.67, Tk.1348.50, Tk. 1363.58 and Tk.2268.25 respectively, of the sample farmers. Table 2 also exposes that the average production of boro rice per bigha in the present study is 20.13 mounds with a minimum of 15 mounds and a maximum of 28 mounds.

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Table 2: Description of Collected Data of Boro Rice

Variables	Mean (SD)	Minimum	Maximum
Land Size (bigha)	8.03(5.63)	1	30
Fertilizer cost (Tk.)	3878.17(191.662)	3000	4500
Seed cost (Tk.)	547.58(103.78)	300	850
Irrigation cost (Tk.)	5293.67(872.03)	450	6500
Pesticide cost (Tk.)	1348.50(120.21)	1100	2000
Ploughing cost (Tk.)	1363.58(128.49)	1100	2000
Cutting cost (Tk.)	2268.25(200.87)	1800	2800
Per bigha production (mound)	20.13(2.59)	15	28

The FRONTIER 4.3.1 program in R environment has been used to estimate the Maximum Likelihood Estimators of the parameters for Boro rice production of Dumuria Upazila, Khulna, and the results are presented in Table 3.

Table 3: Maximum Likelihood Estimators of SFP Function for Boro Rice Production.

Variables	Parameter	Coefficients	Standard Errors	Z-value	P value
Stochastic frontier					
Constant	β_0	3.91	1.91	2.05	0.04
Seed cost (X_1)	β_1	0.19	0.06	3.34	0.00
Land size (X_2)	β_2	0.04	0.01	2.83	0.00
Cutting cost (X_3)	β_3	0.20	0.13	1.48	0.13
Fertilizer cost (X_4)	β_4	-0.58	0.25	-2.29	0.02
Irrigation cost (X_5)	β_5	-0.10	0.05	-2.08	0.03
Pesticide cost (X_6)	β_6	0.02	0.14	0.13	0.89
Ploughing cost (X_7)	β_7	0.28	0.13	2.14	0.03
Diagnostic Statistics					
Sigma square (σ^2)		0.04	0.01	4.37	0.00
Gamma (γ)		0.95	0.05	16.48	0.00
Log likelihood function = 91.33					

From Table 3, including the constant term five of the classical inputs are found to be significant. The positive values of the estimated coefficient of seed cost and land size are significant at a 1% level of error and are found to be 0.19 and 0.04. This implies that increasing of 5% in the seed cost and land size causes an increase of the output by about 0.19 units and 0.04 units if the other factors are constant. The estimated coefficient of cutting cost (0.20) is also positive but statistically insignificant implying that the output of Boro rice may increase with an increase of cutting cost considering other factors as constant. The coefficient of fertilizer cost and irrigation cost under Boro rice production has surprisingly negative signs with an elasticity of -0.58 and -0.10 are statistically significant. This implies that increasing in the study area under Boro rice production would significantly increases Boro rice output for keeping other variables constant. Similarly, the estimated coefficient of pesticide cost (0.02) is positive but statistically insignificant implying that the output of Boro rice may increase with an increase in pesticide cost considering other factors as constant. The ploughing cost is important to the Boro production and has been found as significant at a 5% level of error with its estimate, 0.28 indicating that one unit increase of such cost caused an incursion of the Boro production by 0.28 units.

Further, the variance parameters sigma squared (σ^2) of the stochastic frontier production function is significant and noted as 0.04 which indicates a good fit and correctness of the specified distributional assumption of the composite error term. Furthermore, the variance ratio denoted by gamma (γ) is a measure of the level of the inefficiency (if any) in the variance parameter has been found as 0.95. Thus, at a 1% significance level, approximately 95% of the variation in total Boro rice output can be attributed to differences in technical efficiency, indicating that the observed output variation is not solely a result of random effects.

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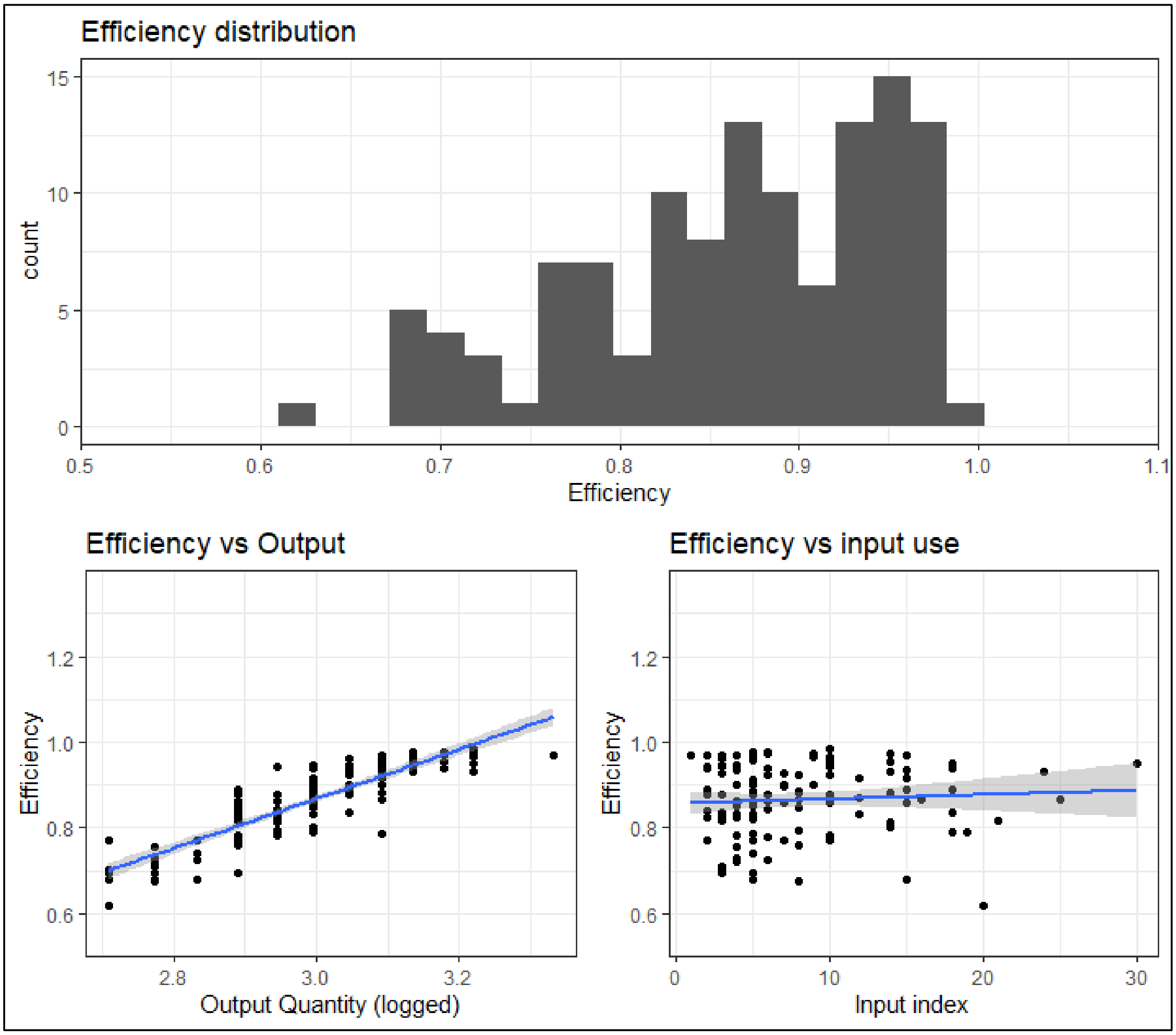

Fig-1: Technical efficiency of Boro- Rice production

The figure clearly shows that the efficiency estimates seem slightly elevated, with firms producing between 70% and 99% of their maximum possible output. Since efficiency directly influences output, it's not surprising that these estimates are closely tied to output levels, as evidenced by the narrow confidence interval around the linear trend. In contrast, the relationship between efficiency and firm size is weak, as indicated by the flat slope and wider confidence interval. Nevertheless, the largest firms generally exhibit above-average efficiency estimates, while only a few of the smallest firms do so.

V. CONCLUSION

The study on the production risk of inputs and technical efficiency in Boro rice production in Dumuria Upazila, Khulna, utilizing a stochastic frontier modeling approach, provides critical insights into the agricultural dynamics of this region. The findings reveal that while Boro rice is a staple crop with significant potential for food security and economic growth, various production risks adversely affect the efficiency of farmers. The parameter γ denotes the proportion of total output variation from the frontier attributable to technical inefficiency, with values ranging from zero to one. In this study, the estimated γ is 0.95 which is close to one indicating that technical inefficiency may occur within the data set. Further, the variance parameter sigma squared (σ^2) of the stochastic frontier production function is significant and noted as 0.04 indicating the correctness of the specified distributional assumption of the composite error term.

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Therefore, together with the other influencing factors, the concerned authority should take care of seed cost, land size, and ploughing cost as well as their management systems to improve and develop the production policy under the existing situation. In conclusion, addressing both the production risks and the technical inefficiencies identified in this study is vital for boosting Boro rice production in Dumuria Upazila, ultimately contributing to the broader goals of agricultural sustainability and food security in Bangladesh.

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