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ARTICLE

Disaster Induced Agricultural Productivity in Coastal Regions of Bangladesh: A Stochastic Frontier Analysis Approach

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ABSTRACT

The production and technical efficiency of the rice sector in Bangladesh's coastal areas are vulnerable to a wide range of natural disasters and climate change issues. These regions face recurring threats from climatic events such as salinity intrusion, inundation, rising sea levels, and cyclones, which can significantly disrupt agricultural activities. In this paper, we conduct a comparative analysis of the rice producers' technical efficiency based on their exposure to disaster-induced impacts over the past five years. Using the Stochastic Frontier Analysis, we examine factors influencing household-level productive efficiency in three coastal districts—Patuakhali, Cox's Bazar, and Khulna. Our findings reveal that rice-producing households affected by natural disasters between 2014 and 2018 exhibited, on average, an 8.29 percentage point higher productive efficiency compared to unaffected households. When controlling for other confounding variables, such as household characteristics and external conditions, the efficiency gain rises to 19.8%. This suggests that households exposed to adverse climatic events may have adapted their farming practices to become more resilient, thus improving their productive efficiency in the long term. Moreover, our results indicate that a larger household size enhances efficiency by 6.7%. Households where rice farming is the primary occupation also tend to be more efficient, likely because of greater specialization and focus on improving agricultural practices. Finally, the age of the producer is positively associated with efficiency, reflecting the

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ARTICLE INFO
Received: 31 August 2024 | Revised: 19 October 2024 | Accepted: 23 October 2024 | Published Online: 3 December 2024
DOI: https://doi.org/10.36956/rwae.v5i4.1290

CITATION
Ehsan, S.M.A., Jakariya, M., Alam, M.S., et al., 2024. Disaster Induced Agricultural Productivity in Coastal Regions of Bangladesh: A Stochastic Frontier Analysis Approach. Research on World Agricultural Economy. 5(4): 517–532. DOI: https://doi.org/10.36956/rwae.v5i4.1290

accumulation of farming experience and knowledge over time.

Keywords: Technical Efficiency; Stochastic Frontier Analysis; Rice Production; Sustainable Agriculture; Vulnerability

1. Introduction

Bangladesh has experienced significant economic progress in the last decade. Since 2010, the GDP of Bangladesh has grown at an average rate of 6.38 percent per annum, whereas the annual per capita GDP growth rate was 5.13 percent during the same period [1]. Even though the agricultural sector has played a vital role in the tremendous economic growth of Bangladesh and provided food security for the growing population, the contribution of this sector has gradually declined to less than 15 percent since 2015. The agricultural sector's contribution to GDP in 2018 was 14.23 percent, which fell to 13.60 percent in 2019 [2]. However, according to the World Bank [1], a large portion of the population (36.86 percent) is still primarily employed in the agricultural sector. Hence, the agricultural sector plays a crucial role not only in providing food security but also is important for alleviating poverty, especially in the rural areas of Bangladesh. In this backdrop in order to maintain the steady economic progress that Bangladesh has been experiencing in recent years, it is only appropriate to attach due priority to the improvement of efficiency in the agricultural sector of the country.

The dominant food crop in the agricultural sector of Bangladesh is rice, which is also the source of livelihood for 48 percent of the rural population [3]. The rice sector constitutes about 70 percent of the agricultural GDP and about 92 percent of the total food grain in Bangladesh [3]. Over the years, Bangladesh has achieved significant success in terms of adopting modern agricultural technologies in rice production, increasing the yield by more than threefold since the 1970s. However, to meet the demand for food grains for the growing population, Bangladesh needs to substantially improve rice productivity through efficient agricultural practices [4, 5].

While several studies have estimated the degree of efficiency of rice production in Bangladesh, only a few papers have conducted such estimation for the coastal disaster-prone areas. Rahman and Anik [6] investigated the impact of climate change and the socioeconomic characteristics of farmers on the agricultural production efficiency for the coastal regions of Bangladesh, utilizing a rich panel dataset. The estimated efficiency score found in this study was much lower in the low-lying floodplain and coastal regions of Bangladesh compared to the other areas. The level of inefficiencies further deteriorates as the salinization of water and soil becomes severe due to progressive climate change [7]. Another crucial reason for the low level of efficiency in rice production in the coastal areas of Bangladesh is the wide range of natural disasters. Being one of the most vulnerable countries in the world, the climatic events and increased frequencies of natural disasters experienced by Bangladesh have been adversely affecting the lives and livelihoods of the population in the coastal areas and resulting in damages to the agricultural sector.

Approximately 40 million people, representing 29% of the population, live in the coastal areas of Bangladesh [8]. In this region, the primary livelihood activity of the local community is agriculture, and it plays a crucial role in alleviating poverty [9–12]. The damages induced by the climatic and natural hazards impose varying negative impacts on the agricultural livelihoods of different communities living in the coastal areas of Bangladesh, and the policies are not always a reflection of the poor coastal communities [13–15]. The coastal farmers practice different innovative strategies to mitigate the loss of crops and reduce their vulnerability to the situation. These coping mechanisms include the inundation of seedbeds due to early floods and renting land with higher elevations for agricultural practices. Such practices help to reduce financial loss, securing the production of rice. Existing literature suggests that the agricultural efficiency in Bangladesh, especially in the coastal areas, has significant room for improvement through the reallocation of resources. Due to the heavy reliance on rice production as a livelihood for a large portion of the coastal population, the degree of efficiency in rice production prevailing among different groups of the population in the disaster-prone coastal areas of Bangladesh warrants further research.

A large body of literature has explored how the incidents of climatic events such as drought, storms, increased levels of salinity, and cyclones have induced disaster-resilient practices and coping mechanisms among the farmers living in the coastal areas. These resilience activities are often characterized by the knowledgeability and changes in the behavior of the farmers who experienced these climatic events in adapting and applying appropriate actions [16–18].

While the nature and the type of these practices have been heavily explored in the literature, the effectiveness of such practices in improving agricultural productive efficiency has not been explored quantitatively. This paper fills this gap in the literature by utilizing a primary household survey dataset collected from the coastal areas of Bangladesh. More specifically, this paper answers the following research questions:

(1) What is the in-situ condition of the productive efficiency in the rice sector of the disaster-prone coastal regions of Bangladesh?
(2) How does the productive efficiency in rice production differ between the two groups of households based on their natural disaster exposure during the last five years?
(3) How can several socio-economic factors improve or hinder the household-level productive efficiency in rice production in these low-lying floodplain areas?

Utilizing econometric techniques following a translog specification and applying a stochastic frontier analysis framework, we estimate the rice production function and the productive efficiency for the coastal areas of Bangladesh in this paper. We organized the remainder of the paper as follows. In Section 2, we briefly discuss the existing literature pertinent to the research questions. Following this, in the Section 3, we discuss the methodology of the paper. The description of the survey dataset, the empirical methods, and hypotheses have been discussed in this section. Section 4 presents and discusses the estimation results, and finally the conclusion and the policy recommendations are discussed in Section 5.

2. Literature Review

A number of research papers have evaluated the in-situ extent of inefficiency in the rice sector of Bangladesh by measuring the technical efficiency in this sector. Rahaman et al. [19] found that the overall production efficiency of Boro and Aman rice in the northern regions of Bangladesh was 83.25 percent and 85.15 percent, respectively. Similarly, Hasnain, Hossain and Islam [20] and Hasan, Hossain and Osmani [21] reported that the efficiency of Boro rice production in the Meherpur and Jhenaidah districts ranged from 89.5 percent to 92 percent. Khan, Huda and Alam [22] also assessed the technical efficiency of Boro and Aman rice production in Bangladesh, finding efficiencies of 91 percent and 95 percent, respectively.

The essential preconditions for ensuring efficiency in rice production include the optimal use of inputs and effective management of production practices at both the farm and household levels [15]. Additionally, the education and agricultural experience of farmers were shown to significantly reduce inefficiencies in production. Bala et al. [23] found similar results for both Aman low-yielding varieties (LYV) and high-yielding varieties (HYV), and suggested that factors such as access to microcredit, training, farm size, age, and education have a substantial impact on the technical efficiency of rice production. The decisions of rice-producing households with regard to supplying their own labor or hiring outside labor can also affect the productive efficiency of rice [24].

Rice production in Bangladesh, particularly in the coastal regions, is highly vulnerable to the impacts of climate change. Various studies have highlighted how climatic variability—including increased temperatures, erratic rainfall patterns, salinity intrusion, and rising sea levels—has disrupted rice farming, a critical component of food security for the country [7, 9, 25]. These coastal regions, where rice farming is predominant, have become epicenters for the most severe effects of climate change, threatening the livelihoods of millions of farmers who depend on rice cultivation [10].

Rising temperature and erratic precipitation brought on by climate change have had a major impact on rice production in Bangladesh's coastal regions.

Sarker [26] found that while minimum temperature and rainfall reduced Aus rice yield variability, raising the maximum temperature increased the variability, indicating the need for temperature-tolerant rice varieties. Real [9] observed that rising temperatures (0.4 to 0.5 °C per decade) boosted Aus rice production in Bagerhat District, but decreasing humidity negatively impacted both Aus and Aman rice, with Boro rice suffering from increased temperatures and erratic rainfall. Additionally, Alam [27] confirmed that maximum temperature and rainfall variability reduced yields for Aus and Aman rice, highlighting the necessity of adaptive agricultural practices to address climate-induced challenges.

Natural disasters, particularly in coastal Bangladesh, further exacerbate these difficulties, endangering rice production and driving farming communities toward poverty. Cyclones, tidal surges, and riverbank erosion are instances of disasters that cause significant financial losses for farmers in addition to damaging crops and disrupting the entire agricultural system [28, 29]. Islam [10] reported that in Barguna and Patuakhali Districts, the majority of farmers cited floods (93%) as the primary risk to rice production, followed by cyclones and storm surges (74%) and salinity intrusion (71%). According to Schneider and Asch [30], flooding and salinity intrusion have hindered rice production in deltaic areas like Bangladesh. 53% of the coastal area is affected by salinity, endangering 3.4 million tons of rice production, or 7% of the country's total rice yield.

Moreover, Emran [11] found that in Barishal, Patuakhali, and Barguna Districts, cyclone severity and salinity intrusion have continued to influence farm productivity, especially for households outside of polders, which are areas protected by embankments. These households in polders saw higher yields as a result of improved market accessibility and infrastructure. Additionally, Uddin [29] noted that Cyclone Sidr caused significant agricultural crop losses, affecting up to 94% of farmers in parts of Patuakhali District.

While much of the literature primarily examines the immediate impacts of climate change and meteorological hazards on rice production, there is a lack of studies that quantitatively assess the long-term effects of coping mechanisms adopted by rice producers in coastal regions. A variety of adaptation strategies have been used by farmers in coastal Bangladesh in response to these challenges. Islam [10] observed that in order to increase rice yields and guarantee food security, farmers used supplemental irrigation and weather forecasts. Education, household income, farm size, and access to extension services were all important factors in making these adaptation decisions. The on-farm adaptations, such as adjusting planting dates and adopting salinity-reducing technologies, were found to be prevalent in the literature, while non-farm strategies included wage employment, female participation in income-generating activities, and migration [25, 31].

Particular tactics tailored to their local difficulties were used by farmers in the Satkhira and Patuakhali Districts. Khan [28] observed that farmers in Patuakhali concentrated on maximizing fertilizer use and planting high-value cash crops, while in Satkhira they practiced crop rotation and rice-fish farming. Abir [32] emphasized that while proper training and limited access to health facilities remained issues, social support, infrastructure development, and disaster preparedness training all contributed to community resilience. Mamun [33] underscored the value of rainwater harvesting systems, organic fertilizers, and drought-resistant crops in addressing climate change. However, obstacles like restricted resource availability and gendered vulnerabilities, especially for female-headed households, continue to hinder adaptation efforts [34].

Using 38 years of data from 13 districts in Bangladesh that were divided into seven climate zones, Sarker [26] discovered that the effects of climate change vary by zone, resulting in different effects on rice yield in different places. Nonetheless, the vast majority of recent studies on climate change and natural disasters in Bangladesh's coastal areas have tended to focus on specific districts, including Khulna, Satkhira, Patuakhali, and Noakhali. Despite these areas being especially vulnerable, the findings' applicability to other coastal regions is limited by their narrow geographic scope. The ability to draw conclusions applicable to the entire coastal zone is further restricted by the small sample sizes in many studies [10, 25, 28, 29, 32, 34]. Given the variation in climate impacts across different regions, more comprehensive research is needed that covers a wider range of coastal areas and incorporates larger, more diverse sample sizes [26].

While considerable research has been done on how climate change and natural disasters affect rice production in coastal Bangladesh, most of it has focused on short-term adaptation strategies like switching to new crop varieties or rearranging planting schedules. Examples of these studies include the work done by Kabir [25], Khan [28], Schneider and Asch [30], Abir [32], and Ahmed and Kiester [34]. However, these studies frequently overlook how sustainable these methods will be in the long run, especially as climate variability increases and extreme weather events become more frequent. There is also limited exploration of integrating modern technologies, such as precision agriculture or climate-prediction models, into traditional farming practices to enhance long-term resilience.

Furthermore, quite a few studies, such as those by Khan [28], Ahmed & Kiester [34], and Alam [27], primarily depend on self-reported data, which may introduce recall bias and compromise the validity of the results. More robust research methodologies, such as longitudinal studies that track adaptation effectiveness over time, are needed to provide a clearer understanding of how farming communities are coping with the evolving impacts of climate change.

The absence of comprehensive research evaluating the effects of climate change on every type of rice production throughout the entire coastal region, specifically in relation to climate change impacts and the adaptation strategies adopted in response to natural disasters represents a major gap in the literature. Most research focuses on specific rice varieties or localized regions, without evaluating the broader effects on Aus, Aman, and Boro rice collectively. Furthermore, although some studies draw attention to socioeconomic differences, specifically in the availability of adaptation resources between households headed by men and women, more inclusive, gender-sensitive policies are desperately needed to guarantee fair resource distribution and assistance for all impacted communities [34].

3. Methodology

3.1. Sampling Design and Survey Dataset

In this study we focus on the analysis of rice production and its technical efficiency in the coastal regions of Bangladesh. Additionally, we examine how the experience of disaster affects the productive efficiency of coastal regions' rice-producing farmers. In conducting the primary household survey, we have considered the production of Aman rice, taking into account the fact that most rice producers in the survey areas produce this type of rice. Four upazilas from three coastal districts, Patuakhali, Cox's Bazar, and Khulna, were selected for the questionnaire survey of this study, as highlighted in **Figure 1**.

These three districts represent the varied coastline of the country. The four upazilas, namely Kalapara upazila (in Patuakhali district), Kutubdia Upazila (in Cox's Bazar district), and Dacope and Koyra Upazilas (in Khulna district), were selected for a primary household questionnaire survey due to their climate change vulnerability and consequential agricultural sustainability. These coastal upazilas are affected by sea-level rise, tidal fluctuations, and increased frequency of cyclones leading to an increase in saltwater intrusion and waterlogging, which directly hamper agricultural production.

According to the Population and Housing Census [35] of Bangladesh, the number of households in the four target upazilas, Kalapara, Kutubdia, Dacope, and Koyra are 70,474, 28,364, 42,186, and 55,518, respectively. With a population of 196,542 households, a confidence level of 90 percent, and a margin of error of 5 percent, the required sample size for the primary household survey is 272. Assuming 11% nonresponse and spurious or incomplete survey information, we have conducted the survey on 303 households.

A disproportionate multistage stratified random sampling was used in obtaining the distribution of the 303 households. The distribution of surveyed households by districts, upazilas, and villages is presented in **Table 1**.

Considering that rice production is seasonal, our study period covered the whole production duration of the crop. In the Aman season, rice is transplanted in October–November and harvested in January.

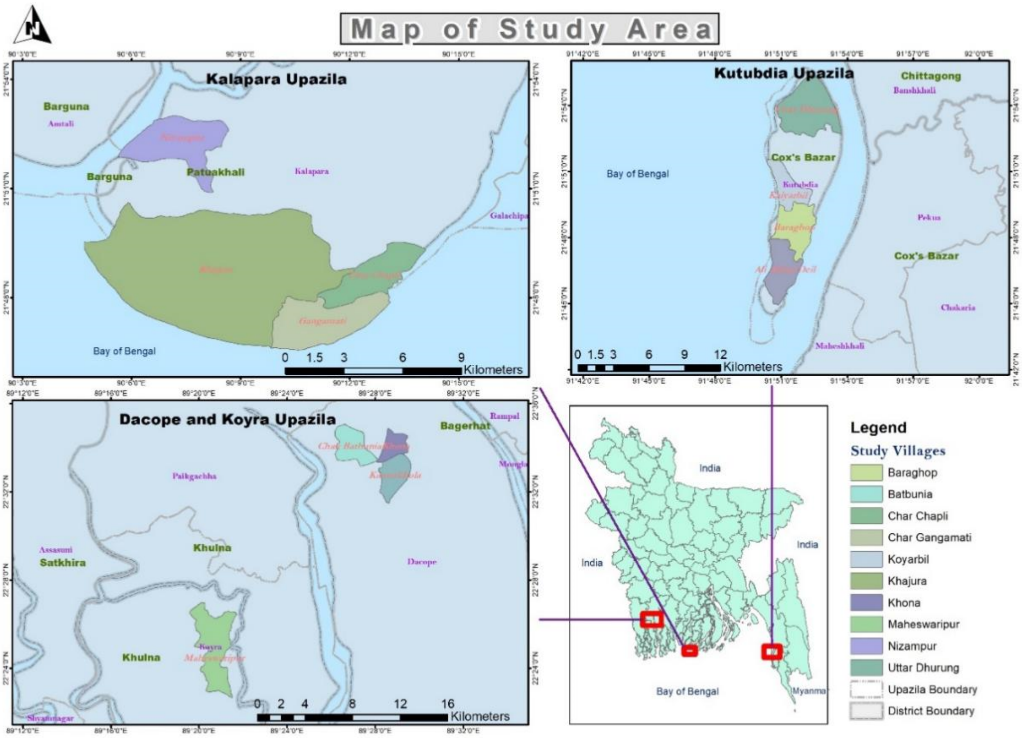

Figure 1. Map of the study area.

Table 1. Distribution of surveyed households.

District	Upazila	Village	Total Surveyed
Cox's Bazar	Kutubdia	Boroghpor	4
		Koyarbil	1
Khulna	Dacope	Botbunia	83
		Jaliakhali	13
		Khona	21
	Koyra	Moheswaripur	9
Patuakhali	Kalapara	Char Chapli	40
		Char Gangamati	34
		Khjura	72
		Nizampur	26
		Grand Total	**303**

3.2. Empirical Methods

For the empirical analysis in the paper, first, we estimate the current scenario of the productive efficiencies in the rice sector of the coastal areas of Bangladesh. Following this part, we investigate if these productive efficiencies differ between the farmers who are adversely affected by natural disasters during the previous years and the farmers who did not experience such disaster-induced adverse effects. Using the primary survey dataset collected for this study, we have utilized a widely used statistical method of efficiency analysis Stochastic Frontier Analysis (SFA) approach. Following the existing literature, a Trans-log production function has been assumed as the underlying rice production function for the SFA method carried out in this paper [36, 37]. For the Trans-log production function, we introduce several interaction terms of the inputs of production.

3.2.1. Specification of the Rice Production Function

The Trans-log production function in our analysis considers five factors of production, namely land, seeds, fertilizers such as Urea, Triple Super Phosphate (TSP), Muriate of Potash (MP); pesticides, and irrigation. In order to obtain unbiased impacts of inputs on the output, important individual and household-level control factors that might affect the rice production have been incorporated in the estimation of the Trans-log production function. These control factors included seven regressors, namely 'primary occupation of household is farming', 'land-ownership', 'household's sole dependence on agriculture', 'average age of non-dependent household members', 'household size', 'disaster exposure of household' and 'number of disaster-exposure of household'.

The following specification has been considered in the estimation of the rice production function.

$$lnY_i = \alpha_0+\sum_{j=1}^{m}\alpha_j lnX_{ji}+\frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{m}\alpha_{jk}lnX_{ji}lnX_{ki}+\sum_{l=1}^{q}\beta_l W_{li}+v_i \quad (1)$$

In the above Equation (1), in addition to the production inputs, other exogenous factors mentioned before have been included to estimate the unbiased input-elasticities of rice production. Here, the coefficients of inputs of production are elasticities, because all the output and inputs in three specifications are expressed in logarithmic forms. Y_i, X_{ji}, and W_{li} are respectively the production or yield of rice, the amount of j-th input used by the i-th farm, and a vector of variables representing the exposure-to-disaster variable, the socio-economic components, household-specific characteristics, and other factors that can affect the production of rice. The ordinary Least Squares (OLS) estimation technique was used to estimate the parameters (α_0, α_j, α_{jk}, and β_l) of the production function model. v_i in Equation (1) indicates the random effects of unobserved factors on rice production that are independent of regressors and are assumed to be identically and independently distributed as $\left\{N\left(0,\sigma_\nu^2\right)\right\}$ two-sided random errors.

3.2.2. Technical Efficiency Analysis

The term technical efficiency is defined as the ratio of the observed to maximum feasible output with respect to a given level of production technology and the observed input use. Someone who is "efficient" is assumed to be producing at their maximum capacity. For estimating the extent of efficiency in rice production, we utilized widely used methods of efficiency analysis, namely Corrected OLS (COLS) and Stochastic Frontier Analysis (SFA) approach [6, 38]. Analysis of technical efficiency will portray the degree of inefficiency existing in rice production, implying how far the current production is from the maximum possible given the amount of inputs utilized. Utilizing the approach of Aigner [39] to estimate the technical efficiency, we also use the SFA method developed by Jondrow [40] to estimate the impacts of disaster exposure on the efficiency of household-level agricultural production. To obtain robust results as well as to allow flexibility in the specification, following the literature [41–44], we used the Trans-log production function in our efficiency estimation. The rice production function for the *i*-th farmer (here, farmer and households are treated synonymously) in the SFA specification can be written as,

$$lnY_i = \alpha_0 + \sum_{j=1}^{m}\alpha_j lnX_{ji} + \frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{m}\alpha_{jk}lnX_{ji}lnX_{ki} + e_i \quad (2)$$

$$e_i = v_i - u_i \;\; and \;\; u_i = \delta_0 + \sum_{d=1}^{p}\delta_d Z_{id} + \zeta_i \quad (3)$$

$$TE_i = E\left[exp\left(-u_i\right)|e_i\right] = E\left[exp\left(-\delta_0 - \textstyle\sum_{d=1}^{p}\delta_d Z_{id} - \zeta_i|e_i\right)\right] \\ where\; e_i = v_i - u_i \quad (4)$$

In Equation (2), Y_i and X_{ji} are respectively the production of rice and the amount of j-th input used by the i-th farm, whereas the error term e_i is composed of two components, v_i and u_i. v_i in Equation (3) indicates the random effects of unobserved factors on the rice production that are independent of u_i and are assumed to be identically and independently distributed $\left\{N\left(0,\sigma_\nu^2\right)\right\}$ two-sided random errors. u_is depict the inefficiencies in production, which are nonnegative random variables that are truncated at 0 of a normal distribution with mean $u_i = \delta_0 + \sum_{d=1}^{p}\delta_d Z_{id}$ and variance $\sigma_u^2\left(\left|N\left(\mu_i,\sigma_u^2\right)\right|\right)$.

The technical efficiency term *TE*$_i$ of farm *i* is expressed in Equation (4), where E is the expectation operator. The is obtained using a conditional expectation of u_i after observing the value of TE_i. A maximum likelihood estimation (MLE) technique is utilized to estimate the unknown parameters. The likelihood function in the MLE is expressed in terms of variance parameters $\sigma^2 = \sigma_\nu^2 + \sigma_u^2$ and σ_u^2/σ^2 [45]. Equation (3) also shows a vector of covariates Z_i, that affects the inefficiencies of farm *i*, which includes several socio-economic control factors (namely, 'primary occupation of household is farming', 'land-ownership', 'household's sole dependence on agriculture', 'average age of non-dependent household members', 'household size', 'disaster exposure of household' and 'number of disaster-exposure of household') affecting the household-level production efficiency of rice, in addition to the interest variable 'disaster exposure of household'. Factors included in Z_i are assumed to be uncorrelated with the random inefficiency component ζ_i.

3.2.3. Hypotheses

Hypothesis 1. *The productive efficiency in the rice sector of our study areas—low-lying, disaster-prone coastal regions of Bangladesh—is lower than that reported in the existing literature for other regions of the country.*

This hypothesis stems from previous research indicating that coastal areas, where rice farming is predominant, have become focal points for the most severe impacts of climate change. These include erratic rainfall patterns, salinity intrusion, flooding, and rising sea levels [7, 9, 10, 25]. Such climate-related challenges are expected to negatively affect rice production efficiency in coastal areas compared to other parts of the country.

Hypothesis 2. *Rice producers who experienced adverse shocks in the past five years exhibit higher productive efficiency compared to those who did not face such shocks.*

This hypothesis is grounded in the fact that farmers in coastal areas, affected by climatic changes and disaster shocks, frequently adopt on-farm adaptations. These include adjusting planting schedules, using salinity-reducing technologies, adopting high-yield seed varieties, and employing other coping strategies, as noted in the literature [25, 28, 33]. While the immediate impact of the climatic shocks may be detrimental, it is hypothesized that farmers exposed to such conditions in the past have developed resilience strategies that enhance their productive efficiency.

4. Analysis of the Survey Dataset

4.1. Descriptive Analysis

A number of descriptive statistics from the dataset, presented in **Table 2**, have helped us to come up with important findings regarding the productivity and efficiency of rice production in the coastal areas of Bangladesh. These descriptive statistics have been calculated utilizing the dataset and information obtained from the primary household survey in the study areas. This part of the paper provides an overall picture of the characteristics of households and agricultural practices in the survey areas of Patuakhali, Cox's Bazar, and Khulna. The household-level factors and agricultural practices are explored for two groups of respondents; one group experienced at least one natural disaster that adversely affected the household, while the other group has not experienced any such disaster during the past five years (during the period 2014–2018).

From **Table 2**, we can see that out of the total 303 surveyed households, 41.25 percent were not exposed to any type of natural calamity, and 58.75 percent experienced at least one natural hazard. 38.76 percent of the 178 households that experienced a disaster faced it more than two times during the past five years (**Table 3**), whereas the percentage of one-time, three-times, and more than three-times exposure are respectively, 21.34 percent, 20.22 percent, and 19.67 percent.

Table 2 also shows that the average size of the agricultural land of the non-disaster-exposed group of households is 140.72 decimals, which is smaller than that of the disaster-exposed group (155.35 decimals). The disaster-exposed households also produced less rice. If we consider the inputs of rice production, households experiencing natural disasters during the 2014–2018 years used more fertilizer and spent more money on irrigation compared to the other group of households, whereas the amount of seeds and pesticides used was smaller for the disaster-exposed group.

In addition to the output and input usage, **Table 2** also presents some important characteristics of the surveyed households in our sample. Even though both groups had similar percentages of households with agricultural land ownership and members with primary occupation as farming, significantly more households in the not-experiencing adverse shock group relied solely on agriculture for their livelihood (43.2 percent against 33.1 percent). A possible reason behind this finding could be the eventual shift of the livelihood reliance from agriculture to other occupations induced by the vulnerability of exposed-to-disaster households that experienced adverse effects due to the disasters. The average age of the working members and the household size of both groups of households are almost the same, around 40 years and eight members, respectively.

Table 2. Descriptive statistics of the households experiencing and not experiencing disasters.

Factor		Did Not Experience Adverse Effects	Experienced Adverse Disaster-Induced Effects	P-Value
Number of households		125	178	
Amount of agricultural land (in decimals)		155.35	140.72	0.52
Values of rice production (in Taka)		2199.20	2020.70	0.4
Total amount of seeds (in KG)		1649.62	916.90	0.016
Total amount of fertilizer (in KG)		367.60	477.96	0.59
Total amount of pesticides (in KG)		24.80	18.55	0.69
Total cost for irrigation (in Taka)		246.40	479.97	0.11
Has member with farming as primary occupation (in percentage)	No	40.8%	38.8%	0.72
	Yes	59.2%	61.2%	
Agricultural land is owned (in percentage)	No	25.6%	25.8%	0.96
	Yes	74.4%	74.2%	
Agri-based livelihood (in percentage)	No	56.8%	66.9%	0.075
	Yes	43.2%	33.1%	
Average age of working-age members (in years)		40.64	39.45	0.19
Household size		8	8	0.67

Source: Authors' calculation using the collected dataset.

Table 3. Number of exposures to natural disasters during the last five years.

	Exposed to Disaster	Not Exposed to Disaster
Number of households	178	125
In percent	58.75%	41.25%
1-time exposure (number of households)	38	
2-times exposure(number of households)	69	
3-times exposure(number of households)	36	
More than 3-times exposure (number of households)	35	

Source: Authors' calculation using the collected dataset.

4.2. Results from the Econometric Analysis

Results from the econometric analyses in this paper have been produced using the statistical software STATA (Version 14) and are discussed in the following section. **Table 4** presents the results from the estimation of the technical efficiency and **Table 5** shows the findings from the investigation of how the variable 'disaster exposure of household' affects productive inefficiency, controlling for several socio-economic and household-specific factors. In both tables, a Trans-log production function for the rice sector is assumed.

4.2.1. Results from In-Situ Technical Efficiency Analysis

For the analysis of technical efficiency, we checked the existence of inefficiency in rice production using two techniques a Skewness test proposed by Schmidt and Lin [46] and a Likelihood-ratio test introduced by Kodde and Palm [47]. Both test results strongly indicated the presence of inefficiency in rice production practices among the surveyed households. Following these tests, we estimated the magnitude of efficiencies presented in **Table 4** using different SFA specifications and explored how the inefficiencies varied depending on households' disaster exposure. Results on the level of efficiencies using different econometric methods are presented in **Table 4**.

We have applied three methods of efficiency analysis to find out how efficiently the group of households exposed to adverse shocks from natural disasters performed in rice production, compared to the overall sample and households that were not affected by such shocks. From **Table 4**, we can see that the average level of efficiency using COLS is 29.79 percent, whereas this number is slightly higher (30.89 percent) for the households experiencing adverse shocks from a natural disas-

Table 4. Productive efficiencies by disaster effect exposure (with different econometric methods).

	Using COLS	Using SFA (Controlling for Effects of Disaster)	Using SFA (Controlling for Disaster Exposure and Other Factors)
Average efficiency of sample (in percentage)	29.79	67.61	73.25
Average efficiency of households with adverse effect exposure (in percentage)	30.89	71.40	77.18
Average efficiency of households with no adverse effect exposure (in percentage)	28.58	63.42	68.89

Source: Authors' estimation using the collected dataset.

ter and lower (28.58 percent) for the households who did not experience such shocks from hazards. However, considering that the COLS estimation technique provides inefficiency values that are overestimated, we used the SFA method in the other two setups. In the first setup of SFA, we only included the household's experience of negative impacts from disaster as a regressor. In contrast, in the second setup of SFA, we introduced many other factors in addition to disaster-induced negative effect exposure. According to **Table 4**, the overall efficiency of our sample is 73.25 percent, which implies that, on average, the rice-producing households in our study are operating at 73.25 percent of their maximum productive efficiency. The level of efficiency is much higher for the negative shock-experiencing households at 77.18 percent, compared to the group that did not face any disaster-induced adverse impact (68.89 percent) during the last five years. In other words, we can say that households exposed to detrimental impacts due to natural calamities during the 2014–2018 period are 8.29 percentage points more efficient in producing rice. **Figure 2** also shows that a significantly larger portion of the households experiencing adverse effects of disasters in previous years belongs to the higher rice-production efficiency level compared to the group of households who did not experience any such effects during previous years.

- Results' discussion:

The estimated productive efficiency results obtained in this section support our hypothesis-1 and align with the findings of existing literature. Several studies found that the level of technical efficiency in the non-coastal regions of Bangladesh ranged from 80 percent to 90 percent [19–23]. In comparison, the rice production efficiency was much lower in the low-lying floodplain and coastal regions at around 70 percent [6, 48]. The findings generally suggest that producers in floodplain and coastal regions are less efficient. However, it is important to note that productivity levels vary across regions, making direct comparisons challenging.

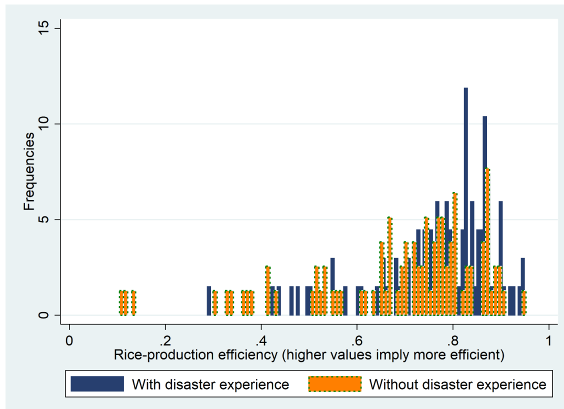

Figure 2. Production efficiency with disaster-experience.

Source: Authors' calculation using the collected dataset.

An important finding of this study is that households adversely affected by natural disasters in the past five years exhibit higher productive efficiency compared to those that were not affected. One possible explanation for this result is that households exposed to natural hazards adopted more resilient production techniques and utilized their productive capacities more effectively, given the likelihood of future exposure to disasters. Another reason for the higher production efficiency in the disaster-affected group may be the natural selection of more efficient farmers. In response to disasters, many households may have shifted away from agriculture to other livelihoods. Households that were more severely impacted by calamities and less efficient in production likely transitioned to different occupations, leaving behind a group of more efficient rice producers [25, 28, 33].

4.2.2. Estimation Results of Natural Disaster Experience on Productive Efficiency

One important contribution of this paper is the exploration of how the household's exposure to natural disaster-induced adverse impacts affected their productive efficiency. For the estimation of the marginal effects of production inputs and different household-level factors on technical efficiency, we considered two specifications. In one of the specifications, the interest variable "Experienced adverse effects" had been introduced in addition to the covariates of the Trans-log production function, and in the other specification, several other control factors were introduced to get a robust and unbiased estimate of the interest variable "Experienced adverse effects". Results from this analysis are presented in **Table 5**.

Our primary focus of **Table 5** is the marginal effects of the regressor "Experienced adverse effects" on the technical efficiency under two specifications. From Model-1, we can see a statistically significant impact of household's exposure to disaster during the past five years on their level of productive efficiency. Experiencing at least one natural calamity inducing detrimental impact during the years 2014–2018 reduces the household's technical inefficiency; in other words, it increases production efficiency by 18.8 percent. In order to ensure the robustness of this finding, in Model 2, we introduced several control variables. Results from Model 2 also indicate a statistically significant impact of "Experienced adverse effects" on technical inefficiency. According to the estimate of Model-2, on average, natural disaster-experiencing households are 19.8 percent more efficient compared to the group that did not experience such a calamity. Other factors, such as the average age of working-age household members and the size of households, are also statistically significant and increase productive efficiency by 1.3 percent and 5 percent, respectively. If the household has a member whose primary occupation is farming, productive efficiency increases by 54.42 percent; however, this impact has not been found statistically significant. Other household-specific factors that have statistically insignificant but positive effects on productive efficiency include "Household relies on agriculture," whose impacts are 5.4 percent. Additionally, if the agricultural land is owned by the household, productive efficiency declines by about 3.4 percent compared to the scenario where land is rented or leased. This result is also supported by our survey interviews, where it could be observed that households operating on leased agricultural lands or sharecroppers used more fertilizers and other inputs and exerted more effort in producing rice compared to the farmers producing on owned lands. While these practices of sharecroppers increased rice production, such practices might not be sustainable in the long run for soil fertility and can lead to overuse of agricultural land.

- Results' discussion:

One key finding from our econometric estimation of the SFA, under both specifications in **Table 5**, is that households experiencing adverse climatic shocks are observed to improve their production efficiency by 19% to 20%. This result supports Hypothesis-2. Several studies have shown that farmers in coastal areas that are negatively affected by meteorological hazards and other climatic shocks often adopt a wide range of climate-resilient agricultural practices [28, 30, 33]. Furthermore, rice producers who are more severely impacted by these shocks are more likely to adopt resilient practices such as planting new crop varieties, adjusting planting schedules, using organic fertilizers, and diversifying rice types. While the impact of these resilient practices might not be observed during a short span of time, in the long run, such practices make the production process more efficient [49–51]. Hence, the findings in this paper are consistent with the existing literature.

Another finding is that the age of household members involved in rice production is positively associated with technical efficiency. This result reflects the accumulation of farming experience, skills, and knowledge over time, which enhances better decision-making and resource allocation of the rice producers. The positive impact of producers age on the productive efficiency can also be observed in a number of studies [52–54]. Additionally, household size also positively impacts productive efficiency. Larger households may push rice producers to exert more labor to increase production, thus enhancing efficiency [53]. Finally, results from both Model-1 and

Table 5. Effects of disaster exposure and household-specific factors on inefficiency.

	Model-1: SFA with Disaster-Exposure	Model-2: SFA with Disaster-Exposure and Household-Specific Factors
	Coefficients/Marginal Effect	Coefficients/Marginal Effect
Production frontier		
Log of land size (in percent)	0.121	0.04
Log of seeds used (in percent)	0.051**	0.045**
Log of fertilizer used (in percent)	0.275***	0.159**
Log of pesticides used (in percent)	−0.005	0.006
Log of irrigation cost (in percent)	0.01	0.008
Land* fertilizer	−0.056***	−0.034**
Land-squared	0.026**	0.020**
Constant term	3.342***	3.873***
Marginal effects on technical inefficiency		
Experienced adverse effects (1 = yes, 0 = no)	−0.188**	−0.198**
Member's primary occupation farming (1 = yes, 0 = no)		−0.544
Own agricultural land (1 = yes, 0 = no)		0.034
Household relies on agriculture (1 = yes, 0 = no)		−0.054
Average age of working-age members (in years)		−0.013*
Members' age * members' occupation farming		0.006
Household's size (in numbers)		−0.050***
Constant term	−0.712***	4.725***
No. of Obs.	196	194
Log-likelihood value	−137.65	−118.51
Information Criteria	297.29	273.03

Note: *, **, and *** indicate a significance at 10%, 5%, and 1% level, respectively.
Source: Authors' estimation using the collected dataset.

Model-2 of SFA indicate that the input elasticities of production are statistically significant for seeds and fertilizer and have a positive impact on productive efficiency. However, the marginal effect of fertilizer declines as the size of the agricultural land is larger. These findings align with the effects found in the literature [15, 28].

The results found in this paper are insightful in nature. However, the paper has a few limitations due to the nature of the dataset. The dataset used for this paper was a cross-sectional dataset. Should we have a longitudinal dataset, we could analyze the dynamic adjustment in the technical efficiency resulting from the disaster experiences of the rice producers in the disaster-prone coastal areas. Additionally, the findings obtained in this paper cannot be generalized for the types of natural disaster experiences, such as flood and river erosion, that were not covered during the questionnaire survey.

5. Conclusions and Policy Recommendations

Our findings indicate that rice production in the coastal areas of Bangladesh exhibits a lower level of production efficiency compared to other regions of the country. While technical efficiency in these coastal areas shows considerable potential for improvement, rice producers who have faced recent disaster-induced shocks demonstrate a higher level of resilience through adaptive agricultural practices. These practices, in turn, lead to greater production efficiency compared to their counterparts who have not experienced such shocks. Specifically, households adversely affected by disasters were found to have, on average, 20 percent higher technical efficiency in rice production compared to unaffected households, controlling for other confounding factors. A possible explanation for this result is that exposure to natural hazards drives these households to adopt more resilient farming techniques and utilize their productive capacities more intensively in anticipation of future risks. The experience of disaster encourages farmers to innovate and adapt, enhancing their overall efficiency.

Understanding the resilient practices employed by these disaster-affected households offers valuable insights for improving rice production across all coastal communities. Observing the strategies that contribute to their increased efficiency could inform broader agricultural policies. Government interventions, such as agricultural extension services or targeted subsidies, could incorporate these resilience-building practices to support rice producers in disaster-prone coastal regions. Such policy measures would not only improve production efficiency but also enhance the sustainability of rice farming in these vulnerable areas.

Despite several issues and constraints in the production of rice, a large portion of coastal farmers engage in rice production for their livelihood. Results obtained from this research paper can provide important policy insights to enhance the usage of adaptive measures and required support mechanisms for the coastal population that is based on the agricultural activities involving rice production for their livelihood.

Author Contributions

S.M.A.E., Conceptualization, Methodology, Formal Analysis, Writing—Original Draft, Writing—Review and Editing. M.J., Conceptualization, Methodology, Writing—Original Draft, Writing—Review and Editing, Supervision. M.S.A., Investigation. S.S., Writing—Review and Editing. M.A.S., Conceptualization. D.A., Conceptualization.

Funding

This research was supported and funded by the Climate Change Trust Fund (CCTF), the Government of the People's Republic of Bangladesh, and the Department of Environment (DoE).

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of North South University, Bangladesh.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The dataset and the STATA-do files can be made available upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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