 

# Climatic Effects on Rice Crop Productions in Bangladesh Using Multiple Regression Model and Measuring Production Efficiency Due to Climates Using Stochastic Frontier Model

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**Abstract**

The main objective of the study is to develop the best Multiple Regression Model for measuring the significance of climatic effects on rice crop production in Bangladesh and measuring the production efficiency due to climates by using Cobb-Douglas Stochastic Frontier Model. To perform this study, amount of land used corresponding to a year's production is an important variable which is sometimes used as a regressor variable and sometimes as weights to fit a Weighted Least Square Regression model. From the study, it is found that the Multiple R-squared values of Aus, Aman and Boro crop production are 0.9694, 0.9481 and 0.9544 respectively which are implied that these models can explain the most of the variability by the regressor variables, that is, these model are very good model. From the model validation test, it is obvious that these models are valid linear models. From the Stochastic Frontier model, Mean Efficiency of Aus, Aman and Boro production model are 0.8966353, 0.9159081 and 0.8540012 respectively. These results are indicated that there are huge opportunity to increase production by increasing technology.

**Keywords:** Climatic Effects, Rice Crop, Multiple Regression Model and Stochastic Frontier Model

## 1. Introduction

Bangladesh has a large agrarian base with 76 percent of total population is living in the rural areas and 90% of the rural population are directly related with agriculture. Increasing food production and attaining food security in Bangladesh require sustainable growth of agricultural sector. The Agro-Economic contribution is 20.83 percent of the Gross Domestic Product (Bangladesh Economics Review, 2009).

The dominant food crop of Bangladesh is rice, accounting for about 75 percent of agricultural land use (and 28 percent of GDP, Bangladesh Economics Review, 2009). Rice production increased every year in the 1980s (through 1987) except following year 1981, but the annual increases have generally been modest, barely keeping pace with the population. Rice production exceeded 15 million tons for the first time in following year 1986. In the mid-1980s, Bangladesh was the fourth largest rice producer in the world, but its productivity was low compared with other Asian countries, such as Malaysia and Indonesia.

High yield varieties of seed, application of fertilizer, and irrigation have increased yields, although these inputs also raise the cost of production and chiefly benefit the richer cultivators. The cultivation of rice in Bangladesh varies according to seasonal changes in the water supply. The largest harvest is Aman, occurring in November and December and accounting for more than half of annual production. Some rice for the Aman harvest is sown in the spring through the broadcast method, matures during the summer rains, and is harvested in the fall. The higher yielding method involves starting the seeds in special beds and transplanting during the summer monsoon. The second harvest is Aus, involving traditional strains but more often including high-yielding, dwarf varieties. Rice for the Aus harvest is sown in March or April, benefits from April and May rains, matures during in the summer rain, and is harvested during the summer. With the increasing use of irrigation, there has been a growing focus on another rice-growing season extending during the dry season from October to March. The production of this Boro rice, including high-yield varieties, expanded rapidly until the mid-1980s, when production leveled off at just below 4 million tons.

## 2. Climates and Rice Crop Productions

Different climatic factors affecting rice cultivation. There are many varieties of rice which are cultivated with differential response to climatic factors, such as:

Rainfall is the most important weather element for successful cultivation of rice. The distribution of rainfall in different regions is greatly influenced by the physical features of the terrain, the situation of the mountains and plateau.

Temperature is another climatic factor which has a favorable and in some cases unfavorable influence on the development, growth and yield of rice. Rice being a tropical and sub-tropical plant, requires a fairly high temperature, ranging from 20° to 40°C. The optimum temperature of 30°C during day season and 20°C during night season seems to be more favorable for the development and growth of rice crop. Rice cultivation is conditioned by temperature parameters at the different phases of growth. The critical mean temperature for

flowering and fertilization ranges from 16 to 20$^0$C, whereas, during ripening, the range is from 18 to 32$^0$C. Temperature beyond 35$^0$C affects grain filling.
Sunlight is very essential for the development and growth of the plants. In fact, sunlight is the source of energy for plant life. The yield of rice is influenced by the solar radiation particularly during the last 35 to 45 days of its ripening period. The effect of solar radiation is more profound where water, temperature and nitrogenous nutrients are not limiting factors. Bright sunshine with low temperature during ripening period of the crop helps in the development of carbohydrates in the grains.
Therefore, the rice growing seasons vary in different parts, depending upon temperature, rainfall, soil types, water availability and other climatic conditions. If the mean temperature is found favorable for rice cultivation throughout the year then, two or three crops of rice are grown in a year. Where rainfall is high and winter temperature is fairly low, only one crop of rice is grown.

## 3. Objective of the study

The main objective of the study is to develop the best Multiple Regression Model for measuring the significant of climatic effects on rice crop production in Bangladesh and measuring the production efficiency due to climates by using Stochastic Frontier Model.
The specific objectives of this study are:

- Developing a Multiple Regression Model for measuring the climatic effects on different types of rice crop named as Aus, Aman and Boro production in Bangladesh.
- Developing a Cobb-Douglas Stochastic Frontier Model measuring the productions efficiency due to Climates covering whole Bangladesh.

## 4. Review of Literature

A lots of work has been done to measure the climatic effects on agricultural crop production all over the world such as Mohammed Amir Hamjah (2014) has conducted an analysis to measure the climatic effects on Cotton and Tea production in Bangladesh by using Multiple Regression Model and here he also measure the production efficiency due to climates using Stochastic Frontier Model. Richard M. Adams, Brian H. Hurd, Stephanie Lenhart and Leary (Inter-Research, 1998) have conduct a study, which reviews the extant literature on these physical and economic effects and interprets this in terms of common themes or findings. Shafiqur Rahman (September, 2008) conduct an analysis by which he has shown the significant effects of temperature on agricultural production by using regression and correlation analysis. Hag Hamad Abdelaziz, Adam Abdelrahman, Abdalla and Mohmmed Alameen Abdellatif (2010) have shown that shed light on the main constraints of crop production in the traditional rainfed sector in Umkdada district, North Darfur State (Sudan). The study used descriptive statistics and regression for data analysis. The results of regression analysis revealed that the crops produced in season 2006 were significantly affected by some factors. Rahman, Mia and Bhuiyan (2012) has conducted a study in the year 2008-2009 to estimate the farm-size-specific productivity and technical efficiency fall rice crops. Farm-size-specific technical efficiency scores were estimated using stochastic production frontiers. There were wide of variations of productivity among farms, where large farms exhibited the highest productivity. The lowest net return or the highest cost of production was accrued from both the highest wage rate and highest amount of labour used in medium farms. Muhammad Fauzi Makki, Yudi Ferrianta, Rifiana and Suslinawati (2012) has conducted a study in Indonesia to evaluate the impact of climate change on productivity and technical efficiency paddy farms in tidal swamp land. The analysis showed Impact on productivity have not well because negative. Paulo Dutra Constantin and Diogenes Leiva Martin (2009) was conducted a study to apply a Cobb-Douglas Translog Stochastic Production Function and Data Envelopment Analysis in order to estimate inefficiencies over time as well as respective TFP (Total Factor Productivity) sources for main Brazilian grain crops-namely, rice, beans, maize, soybeans and wheat - throughout the most recent data available comprising the period 2001-2006.

## 5. Data source and Data manipulations

The climatic data sets are available from the Bangladesh Government's authorized websites www.barc.gov.bd. The crop data sets are also available from Bangladesh Agricultural Ministry's websites named as www.moa.gov.bd. These data set are available from 1972 to 2006. Climatic information were in the original form such that it is arranged in the monthly average information corresponding to the years from 1972 to 2006 according to the 30 climatic stations. The name of these stations are Dinajpur, Rangpur, Rajshahi, Bogra, Mymensingh, Sylhet, Srimangal, Ishurdi, Dhaka, Comilla, Chandpur, Josser, Faridpur, Madaripur, Khulna, Satkhira, Barisal, Bhola, Feni, MaijdeeCourt, Hatiya, Sitakunda, Sandwip, Chittagong, Kutubdia, Cox's Bazar, Teknaf, Rangamati, Patuakhali, Khepupara, Tangail, and Mongla. We take the month October, November, December, January and February as a "dry season" and March, April, May, June, July, August, September as a "summer season" considering the weather and climatic conditions of Bangladesh. Finally, we take average seasonal climatic information of 30 climatic station corresponding to the year from 1972 to 2006. We take the average of 30 climatic area because of focusing the overall country's situation and overall model fitting for whole Bangladesh.

## 6. Climatic Variables Under Study

**sun.sum** = Sunshine of the Summer Season, **sun.dry** = Sunshine of the Dry Season , **clo.sum** = Cloud Coverage of the Summer Season, **clo.dry** = Cloud Coverage of the Dry Season, **max.tem.dry** = Maximum Temperature of the Dry Season, **max.tem.sum** = Maximum Temperature of the Summer Season, **min.tem.dry** = Minimum Temperature of the Dry Season, **min.tem.sum** = Minimum Temperature of the Summer Season, **rain.dry**= Ammount of Rainfall of the Dry Season, **rain.sum** = Amount Rainfall of the Summer Season, **rh.dry** = Relative Humidity of the Dry Season, **rh.sum**= Relative Humidity of the Summer Season, **wind.dry** = Wind Speed of the Dry Season and **wind.sum** = Wind Speed of The Summer Season.

## 7. Used Software

This analysis has completely done by statistical programming based open source Software named as **R** with the version **2.15.1.** The additional library packages used for analysis is **lmtest, gvlma, car, frontier, etc.**

## 8. Methodology

### 8.1. Classical Linear Multiple Regression Model

The multiple classical linear regression model is given by

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} \dots\dots\dots \beta_q X_{qi} + \varepsilon_i \quad i = 1,2,3,\dots,N \qquad (1)$$

Here, Y = Dependent variable, $X_i$'s are independent variables, ε = stochastic error term, and $\beta_0$, $\beta_1$, $\beta_2$, … $B_q$ are the model's parameter which are to be estimated.

There are five critical assumptions relating to Classical Linear Multiple Regression Model. These assumptions required to show that the estimation technique, Ordinary Least Squares (OLS), has a number of desirable properties, and also so that the hypothesis tests regarding the coefficient estimates could validly be conducted. These assumptions are (1) E ( ε i ) = 0 , The errors have zero mean, (2) Var ( εi ) = $\sigma^2 < \infty$, The values variance of the error is constant and have finite over all values of $x_i$, (3) Cov ( ε i , ε j ) = 0, The errors are statistically independent of one another, (4) Cov ( ε ,i xi ) = 0, There is no relationship between the error and the corresponding x, (5) $\varepsilon_i \sim N(0, \sigma^2)$, $\varepsilon_i$ is normally distributed.

### 8.1.1 Shapiro–Wilk Normality Test

In statistics, the Shapiro–Wilk test tests the null hypothesis that a sample x1, ..., xn come from a normally distributed population. It was published in 1965 by Samuel Shapiro and Martin Wilk. The test statistic is:

$$w = \frac{(\sum_1^n a_i x_{(i)})^2}{\sum_1^n (x_i - \bar{x})^2} \qquad (2)$$

Where, $x_{(i)}$ (with parentheses enclosing the subscript index i) is the ith order statistic, i.e., the ith-smallest number in the sample; $\bar{x}$ is the sample mean; the constants, $a_{(i)}$ are given by (3)

$$(a_1, a_2, \quad a_n) = \frac{m^T V^{-1}}{(m^T V^{-1} V^{-1} m)^2} \qquad (3)$$

Where, $m = (m_1, m_2, \dots, m_n)^T$ and $m_1$, …., $m_n$ are the expected values of the order statistics of independent and identically distributed random variables sampled from the standard normal distribution, and **V** is the covariance matrix of those order statistics. The user may reject the null hypothesis if **W** is too small.

### 8.1.2. Box-Ljung Test

Ljung-Box (Box and Ljung, 1978) test can be used to check autocorrelation among the residuals. If a model fit well, the residuals should not be correlated and the correlation should be small. In this case the null hypothesis is $H_0 : \rho_1(e) = \rho_2(e) = \dots\dots = \rho_k(e) = 0$ is tested with the Box-Ljung statistic $Q^* = N(N+1) \sum_{i=1}^{k} (N-k) \ \rho_k^2(e)$

Where, N is the no of observation used to estimate the model. This statistic Q* approximately follows the chi-square distribution with (k-q) df, where q is the no of parameter should be estimated in the model. If Q* is large (significantly large from zero), it is said that the residuals autocorrelation are as a set are significantly different from zero and random shocks of estimated model are probably auto-correlated. So one should then consider reformulating the model.

### 8.1.3. Studentized Breusch-Pagan test

A formal test for detecting heteroscedasticity is Studentized Breusch-Pagan test (Breusch and Pagan, 1979) can be explained as for a given model, $Y = X^T\beta + €$
With $t = 1, 2, 3, \ldots, n$ and $X^T = [X_{1t}, X_{2t}, \ldots X_{kt}]$
We assume that heteroscedasticity takes the form: E (ut) = 0 for all t and $\boldsymbol{\sigma}^2 = E(ut^2) = h(Z_t^T, \alpha)$, where $Z^T = [Z_{1t}, Z_{2t, \ldots,} Z_{pt}]$ and $\alpha = [\alpha_1, \alpha_2, \ldots; \alpha_p]$ is a vector of unknown coecients and h(.) is some not specied function that must take only positive values. The null hypothesis (homoscedasticity) is then: $H_0 = \alpha_2 = \alpha_2 = \ldots = \alpha_p = 0$. Under the null we have $\boldsymbol{\sigma}^2_t = h(\alpha_1)$ (constant). The restricted model under the null is estimated by OLS, assuming disturbances are normally distributed. If the null hypothesis accepted then the error variance is homoscedastic.

### 8.1.4. Global Test of Validity Checking for a Linear Model

An easy-to-implement global procedure for testing the four assumptions of the linear model is proposed. The test can be viewed as a **Neyman smooth test** (1937) and it only relies on the standardized residual vector. If the global procedure indicates a violation of at least one of the assumptions, the components of the global test statistic can be utilized to gain insights into which assumptions have been violated. The procedure can also be used in conjunction with associated deletion statistics to detect unusual observations.
This distributional assumption, together with the linear link specification in are enumerated as four distinct assumptions:
(A1) (*Linearity*) $\mathbf{E}\{Y_i|\mathbf{X}\} = \mathbf{x}_i\beta$, where $\mathbf{x}_i$ is the $i$th row of $\mathbf{X}$;
(A2) (*Homoscedasticity*) $\mathbf{Var}\{Y_i|\mathbf{X}\} = \sigma^2$, $i = 1,2,\ldots,n$;
(A3) (*Uncorrelatedness*) $\mathbf{Cov}\{Y_i,Y_j|\mathbf{X}\} = 0, (i \neq j)$; and
(A4) (*Normality*) $(Y_1,Y_2,\ldots,Y_n)|\mathbf{X}$ have a multivariate normal distribution.

Assumptions (A3) and (A4) imply that, given $\mathbf{X}$, $Y_i$, $i = 1, 2, \ldots, n$ are independent normal random variables. Without loss of generality, we assume that $\mathbf{X}$ is of full rank with $n > p$, so rank($\mathbf{X}$) = $p$. Under (A1)–(A4),the maximum likelihood (ML) estimators of β and $\sigma^2$ are given, respectively, by
$\mathbf{b} = \hat{\beta} = (\mathbf{XtX})^{-1}\,\mathbf{XtY}$ and $s^2 = \boldsymbol{\sigma}^2 = \ln\mathbf{Y}t(\mathbf{I}-\mathbf{P}[\mathbf{X}])Y$;
Assessment of whether assumptions (A1)–(A4) are satisfied, based on the data (**Y**, **X**), has received considerable attention. Assessment procedures typically involve the standardized residuals **R**, herein defined according to

$$\boldsymbol{R_i} = \frac{(\boldsymbol{Y_i} - \hat{\boldsymbol{Y}})}{\boldsymbol{s}}$$

Where, $\hat{Y_i}$ is the fitted value of $Y_i$
Formal significance tests for (A1)–(A4) involve testing the null hypothesis ($H_0$) versus the alternative hypothesis ($H_1$), where
$H_0$ : Assumptions (A1)−(A4) all hold
$H_1$ : At least one of (A1)−(A4) does not hold.
The first and second components for the test is given by

$$S_1 = \left\{\frac{1}{\sqrt[2]{6n}}\sum_{i=1}^{n} R^3{}_i\right\}^2$$

$$S_2 = \left\{\frac{1}{\sqrt[2]{24n}}\sum_{i=1}^{n} (R^4{}_i - 3)\right\}^2$$

The third component for the test is given by

$$S_3 = \frac{\{\frac{1}{\sqrt{n}}\sum_{i=1}^{n}(Y_i - \hat{Y})^2 R_i\}^2}{(\hat{\Omega} - b^t\hat{\sum}_x b - \Gamma\hat{\sum}_x{}^{-1}\Gamma)}$$

Where, $\hat{\Omega} = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y})^4$ and $\hat{\sum}_x = \sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})$

$$\Gamma = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y})^2(X_i - \bar{X})$$

The Fourth component for the test is given by(the fourth component statistic requires a user-supplied n × 1 vector V, which by default is set to be the time sequence $V = (1, 2, \ldots, n)^t$.)

$$S_4 = \frac{1}{\sqrt{2\,\hat{\sigma}^2\,n}}\sum_1^n(V_i - \bar{V})(R_i{}^2 - 1)$$

Where $\hat{\sigma}^2 = \frac{1}{n}\sum_1^n(V_i - \bar{V})^2$

The global test statistics is given by $G^2 = S_1 + S_2 + S_3 + S_4$
Now reject $H_0$, if $G^2 > G^2_{\alpha,4}$

### 8.2. Stochastic Frontier Model

#### 8.2.1 The Production Frontier: Theoretical Framework

The standard definition of a production function is that it gives the maximum possible output for a given set of inputs, the production function therefore defines a boundary or a frontier. All the production units on the frontier will be fully efficient. Efficiency can be of two kinds: technical and allocative. Technical efficiency is defined either as producing the maximum level of output given inputs or as using the minimum level of inputs given output Allocative efficiency occurs when the marginal rate of substitution between any of the inputs equals the corresponding input price ratio. If this equality is not satisfied, it means that the country is not using its inputs in the optimal productions. A production frontier model can be written as:

$$y_i = f(x_i;\ \beta)\ TE_i \qquad (4)$$

Where, $y_i$ is the output of producer i (i = 1, 2,…, N ); $x_i$ is a vector of M inputs used by producer i; $f(x_i;\ \beta)$ is the production frontier and β is a vector of technology parameters to be estimated. Let $TE_i$ be the technical efficiency of producer i,

$$TE_i = \frac{y_i}{f(x_i;\ \beta)} \qquad (5)$$

In the case, $TE_i = 1$, $y_i$ achieves its maximum feasible output of $f(x_i;\ \beta)$. If $TE_i < 1$, it measures technical inefficiency in the sense that observed output is below the maximum feasible output. The production frontier $f(x_i;\ \beta)$ is deterministic.We have to specify the stochastic production frontier

$$y_i = f(x_i;\ \beta)\exp(v_i)\ TE_i \qquad (6)$$

Where, $f(x_i;\ \beta)\exp(v_i)$ is the stochastic frontier, which consists of a deterministic part $f(x_i;\ \beta)$ common to all producers and a producer-specific part which $\exp(v_i)$ captures the effect of the random shocks to each producer $TE_i$ can be computed for Stocahastic Fromntier production of i$^{th}$ producer

$$TE_i = \frac{y_i}{f(x_i;\ \beta)\exp(v_i)} \qquad (7)$$

#### 8.2.2. Stochastic Frontier Productions Function

The econometric approach to estimate frontier models uses a parametric representation of technology along with a two-part composed error term. Under the assumption that is of $f(x_i;\ \beta)$ is of Cobb-Douglas type, the stochastic frontier model in equation (7) can be written as

$$Y_i = \alpha + \beta X_i + \varepsilon_i \qquad (8)$$

Where, $\varepsilon_i$ is an error term with $\varepsilon_i = v_i - u_i$

The economic logic behind this specification is that the production process is subject to two economically distinguishable random disturbances: statistical noise represented by $v_i$ and technical inefficiency represented by $u_i$

There are some assumptions necessary on the characteristics of these components. The errors $v_i$ are assumed to have a symmetric distribution, in particular, they are independently and identically distributed as N (0, $\sigma_v^2$) The component $u_i$ is assumed to be distributed independently of $v_i$ and to satisfy $u_i \geq 0$ (e.g. it follows a one-sided normal distribution $N^+$ (0, $\sigma_v^2$). The non-negativity of the technical inefficiency term reflects the fact that if $u_i > 0$ the country will not produce at the maximum attainable level. Any deviation below the frontier is the result of factors partly under the production unit's control, but the frontier itself can randomly vary across firms, or over time for the same production unit. This last consideration allows the assertion that the frontier is stochastic, with a random disturbance $v_i$ being positive or negative depending on favorable or unfavorable external events.

It is important to note that given the non-negativity assumption on the efficiency term, its distribution is non-normal and therefore the total error term is asymmetric and non-normal. This implies that the least squares estimator is inefficient. Assuming that $v_i$ and $u_i$ are distributed independently of $x_i$, estimation of (8) by OLS provides consistent estimators of all parameters but the intercept, since $E(\varepsilon_i) = -E(u_i) \leq 0$. Moreover, OLS does not provide an estimate of producer-specific technical efficiency. However, it can be used to perform a simple test based on the skewness of empirical distribution of the estimated residuals. Schmidt and Lin (1984) propose the test statistic

$$b^{1/2} = \frac{m_3}{m_2^{3/2}} \qquad (9)$$

Where, $m_2$ and $m_3$ are the second and the third moments of the empirical distribution of the residuals. Since $v_i$ is symmetrically distributed, $m_3$ is simply the third moment of the distribution of $u_i$.
The case $m_3 < 0$ implies that OLS residuals are negatively skewed, and that there is evidence of technical inefficiency. In fact, if $u_i > 0$ then $\varepsilon_i = v_i - u_i$ is negatively skewed. The positive skewness in the OLS residuals, i.e. m3 > 0, suggests that the model is mis-specified. Coelli (1995) proposed an alternative test statistic

$$b^{1/2} = \frac{m_3}{(6m_2^3/N)^{1/2}} \qquad (10)$$

Where, N is equal to the number of observations. Under the null hypothesis of zero skewness in the OLS residuals, $m_3=0$, the third moment of OLS residuals is asymptotically distributed as a normal random variable with mean zero and variance $6m_2^3/N$. This implies that the test statistic (10) is asymptotically distributed as a standard normal random variable N (0,1).
Coelli (1995) presents Monte Carlo experiments where these tests have the correct size and good power. The asymmetry of the distribution of the error term is a central feature of the model. The degree of asymmetry can be represented by the following parameter:

$$\lambda = \frac{{\sigma_u}^2}{{\sigma_v}^2} \qquad (11)$$

The larger λ is, the more pronounced the asymmetry will be. On the other hand, if λ is equal to zero, then the symmetric error component dominates the one-side error component in the determination of $\varepsilon_i$. Therefore, the complete error term is explained by the random disturbance $v_i$, which follows a normal distribution. $\varepsilon_i$ therefore has a normal distribution. To test the hypothesis that λ = 0, we can compute a Wald statistic or likelihood ratio test both based on the maximum likelihood estimator of λ Coelli (1995) tests as equivalent hypothesis γ = 0 against the alternative γ > 0, where

$$\gamma = \frac{{\sigma_u}^2}{{\sigma_u}^2 + {\sigma_v}^2} \qquad (12)$$

A value of zero for the parameter γ indicates that the deviations from the frontier are entirely due to noise, while a value of one would indicate that all deviations are due to technical inefficiency. The Wald statistic is calculated as

$$W = \frac{\hat{\gamma}}{\widehat{\sigma_\gamma}} \qquad (13)$$

Where, $\hat{\gamma}$ is maximum likelihood estimate of γ and $\widehat{\sigma_\gamma}$ is its estimated standard error. Under $H_0$: γ = 0 is true, the test statistic is asymptotically distributed as a standard normal random variable. However, given that γ cannot be negative, the test is performed as a one-sided test. The likelihood test statistic is

$$LR = -2[Log(L_0) - Log(L_1)] \qquad (14)$$

Where, log ($L_0$) is the log-likelihood valued under the null hypothesis and log ($L_1$) is the log-likelihood value under the alternative. This test statistic is asymptotically distributed as chi-square random variable with degrees of freedom equal to the number of restrictions. Coelli (1995) notes that under the null hypothesis γ = 0, the statistic lies on the limit of the parameter space since γ cannot be less than zero. He therefore concludes that the likelihood ratio statistic will have an asymptotic distribution equal to a mixture of chi-square distributions ($\frac{1}{2}\chi_0^2 + \frac{1}{2}\chi_1^2$).

## 9. Results and Disscussions

### 9.1. Multiple Regression Modeling of Aus Production

we try to fit the Multiple Regression model by using Box-Cox transformation to adjust the response variable (Aus production) with $\lambda = 0.00006611$); and to fit a linear rgeression model. At the same time, Log-transformation is used in the regressor variable “wind.sum” because of avoiding the unusual patern in the “residusal versus regressor” plots and it does not create a horizontal band without transformation. The parameter estimates of the fitted Multiple Regression model for measuring the climatic effects on Aus production are given in Table 1.

***Table 1**: Summary Statistics of the Aus Production Model*

| Coefficients | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 1.00e+00 | 2.96e-04 | 3375.522 | < 0.0001 |
| aus.area | 3.09e-08 | 3.56e-09 | 8.659 | < 0.0001 |
| sun.sum | -4.98e-06 | 6.52e-06 | -0.763 | 0.455 |

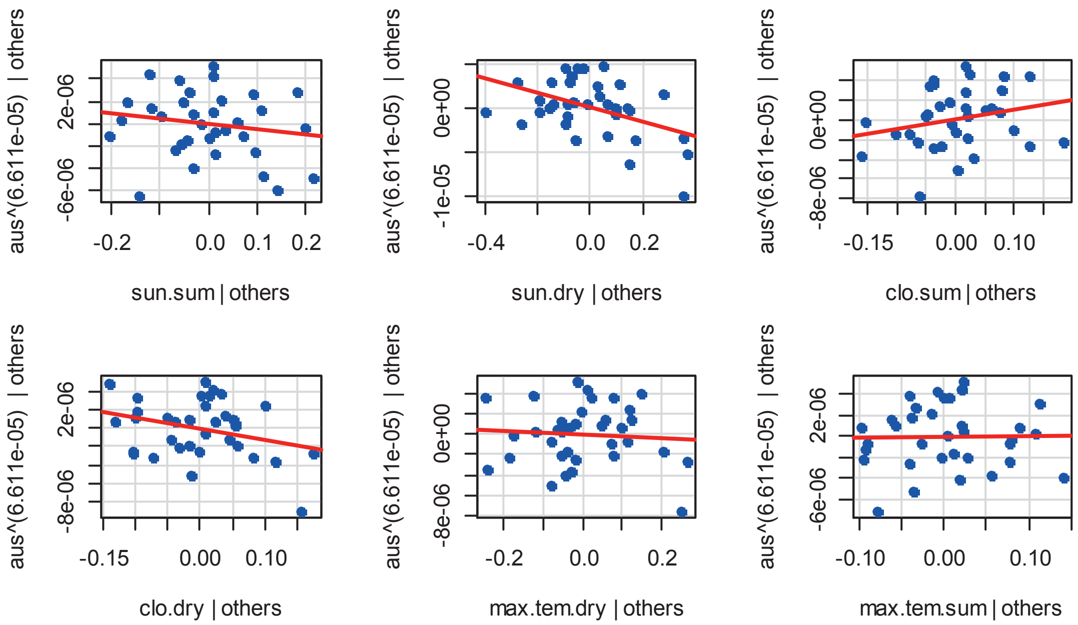
| | | | | |
|---|---|---|---|---|
| sun.dry | -8.33e-06 | 3.78e-06 | -2.204 | 0.040 |
| clo.sum | 9.34e-06 | 8.84e-06 | 1.057 | 0.304 |
| clo.dry | -1.24e-05 | 8.77e-06 | -1.416 | 0.173 |
| max.tem.dry | -1.93e-06 | 5.47e-06 | -0.353 | 0.728 |
| max.tem.sum | 7.03e-07 | 1.05e-05 | 0.067 | 0.947 |
| min.tem.dry | 1.57e-06 | 5.98e-06 | 0.263 | 0.796 |
| min.tem.sum | -2.81e-06 | 7.74e-06 | -0.363 | 0.721 |
| rain.dry | -2.09e-08 | 6.55e-08 | -0.32 | 0.753 |
| rain.sum | -1.64e-08 | 3.24e-08 | -0.506 | 0.619 |
| rh.dry | 1.19e-06 | 1.24e-06 | 0.966 | 0.346 |
| rh.sum | -1.73e-06 | 2.60e-06 | -0.665 | 0.514 |
| wind.dry | -5.68e-06 | 1.73e-05 | -0.328 | 0.747 |
| log(wind.sum)* | -2.65e-05 | 1.39e-05 | -1.905 | 0.072 |

*log(wind.sum) = Log-transformation of wind.sum

From the Table 1, we observe that aus.area, clo.sum, max.tem.sum, min.tem.dry and rh.dry have positive effects on Aus productions; and sun.sum, sun.dry, clo.dry, max.tem.dry, min.tem.sum, rain.dry, rain.sum, rh.sum, wind.dry and log (wind.sum) have negative effects on Aus productions. Again, aus.area, sun.dry and log (wind.sum) have statistically significant effects on Aus crop production at 10% level of significance.

Again, from the fitted Multiple Regression model, Multiple R-squared is 0.9694, which implies that 96.94% of the total variations can be explained by the regressor variables and Adjusted R-squared is 0.9452, which implies that 94.52 % variation can be explained by the regressor variables after adjustments and from the overall test, $Pr(|F_{(15, 19)}| \geq 40.11) < 0.00001$ implies that all the variables are not eqully significant effects on Aus production at 5% level of significance.

Added Variable Plots for the Aus production model are shown in the Figure 1



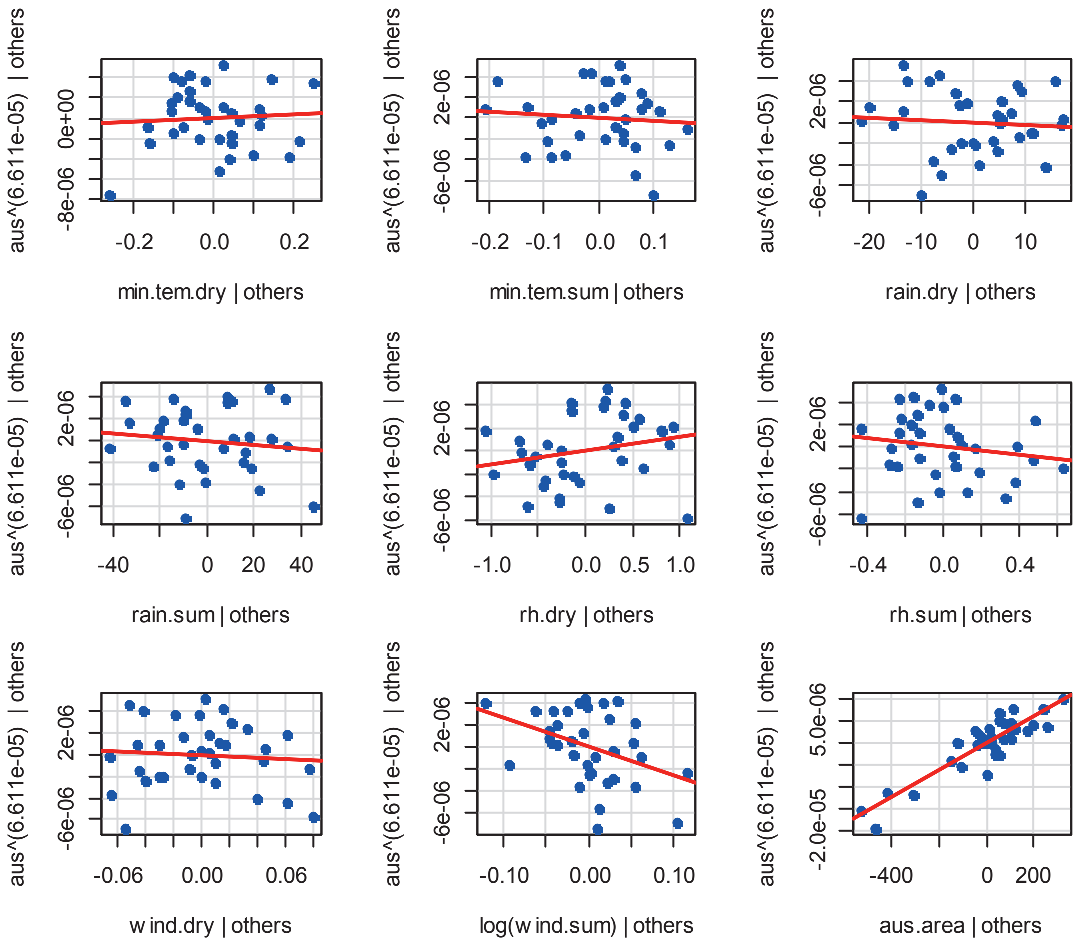
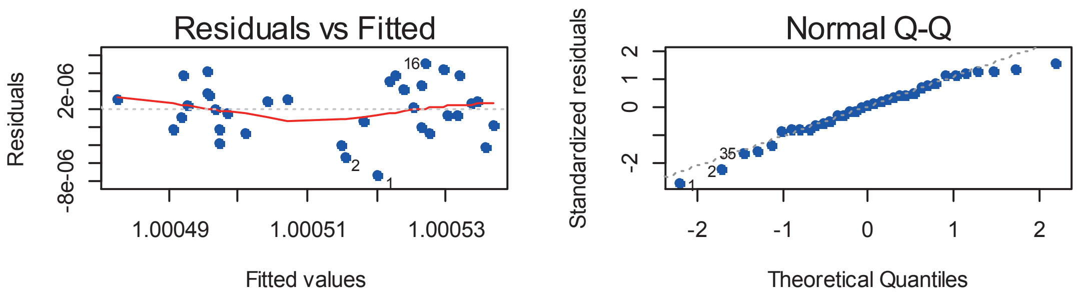



***Figure 1:*** *Added Variable Plots for Aus Productions Model*

From the Figure 1, which displays the partial relationship between the response (Aus) residuals and each of the predictor's residuals for Aus production model. All plots show that they follow a staright line with non-zero slopes and there is no curvature relationship ammong the predictor's residuals and response residuals. That is why, it can be said that each of the predictor variabls are added to the model with maintaining a linear relation, that is, this model is going to make a linear relationship between the response variable and the predictor variables to measure the climatic effects on Aus production in Bangladesh.

**9.1.1. Residuals Diagnostics for Aus Production Model**

Residuals Diaagonstics Plots for measuring the climatic effects on Aus production model are shown in the Figure 2



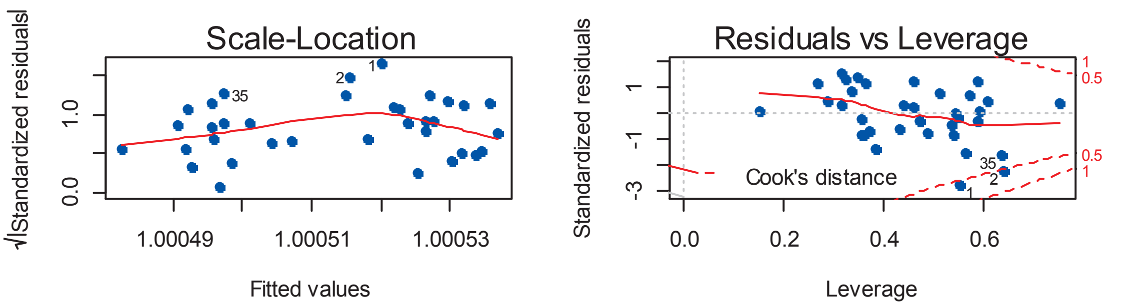



***Figure 2:** Residuals Diagonstics for Aus Production Model*

From the Figure 2, we observe that,

- all of the points are lied around the horizontal line and they try to create a horizontal band, which implies constant variance among the residuals of the Aus production model (top-left).
- almost all of the points try to create a horizontal band which indicates that residals have constant variance of the Aus production model (bottom-left).
- although there are two leverage point, according to the cook's distance, they are approximately on the 50% Cook's interval of the leverage points, which has small amount of influence on the model properties of the Aus production model (bottom-right).
- almost all of the points are very closed to Q-Q line or on the Q-Q line, which suggests that residuals are normally distributed of the Aus production model (top-right).

To check different assumptions by using formal test of Aus production model are shown in the Table 2

***Table 2:** Residuals Diagnostic Test for Assumptions Checking*

| Residuals Diagnostic | Test Name | P-value |
|---|---|---|
| Constant Variance test | Breusch-Pagan | Pr($\|\chi^2_{(14)}\|$ ≥ 19.546 ) = 0.19 |
| Auto-correlation test | Box-Ljung test | Pr($\|\chi^2_{(1)}\|$ ≥ 0.7883) = 0.3746 |
| Normality Test | Shapiro-Wilk | Pr($\|\chi^2_{(35)}\|$ ≥ 0.9818) = 0.8166 |

From the Table 2, it is clear that residuals of the fitted Multiple Regression model for Aus production have constant variance, have no auto-correlation problem and they follow normal distribution at 5% level of significance which are implied that the fitted model's assumptions are very well managed. These all test are made based on Chi-square test.

### 9.1.2. Global Validation Checking for Aus Production Model

Global model validation test is used to check whether Aus production model is valid or not. The test is performed at 5% level of significance on 4 degrees of freedom. The results from the test are shown in the Table 3.

***Table 3:** Global Validation Checking for Aus Production Model*

| Test Statistics | Value | p-value | Decision |
|---|---|---|---|
| Global Stat | 6.0322 | 0.19675 | Assumptions acceptable |
| Skewness | 0.5032 | 0.47812 | Assumptions acceptable. |
| Kurtosis | 0.2431 | 0.62197 | Assumptions acceptable. |
| Heteroscedasticity | 3.4571 | 0.06298 | Assumptions acceptable. |

From the Table 3, we observe that the p-value of Global stat is 0.19675, which suggests that linearity of parameters, Homoscedasticity, Autocorrelation and Normality test are very well managed in the fitted model, that is, the fitted model is a valid linear model. Again, Skewness and Kurtosis of the fitted model are 0.5032 and 0.2431 respectively and their corresponding p-values for testing hypothesis are 0.47812 and 0.62197, which are suggested that the assumptions of the skewness and kurtosis are very well accepted to fit a linear model. At the same time, the heteroscedasticity assumptions is also accepted with the p-value of 0.06298, which suggests homoscedasticity of variance. We can easily say that the fitted model is the best fitted Multiple Linear Regression model for measuring the climatic effects on Aus production in Bangladesh.

**Finally,** from all of the test, assumptions of residuals like Homoscedasticity, Autocorrelation Normality are very well satisfied and model validation test "Global Tesst" also satisfied all of the assuptions of a linear model and the fitted model is a valid linear regression model. Without any kind of loss of generality, it can be said that this fitted model is the best fitted Multiple Regression Model for measuring the climatic effects on Aus production based on the sample data.

### 9.2. Stochastic Frontier Modeling for Aus Production

The Parameter estimates of the fitted Cobb-Douglas Stochastic Frontier model for the Aus production are given in the Table 4.

***Table 4:*** *Summary Statistics of the Frontier Model for Aus Productions Model*

| Coefficients | Estimate | Std. Error | z value | Pr(>\|z\|) |
|---|---|---|---|---|
| (Intercept) | 92.160779 | 0.996048 | 92.5265 | <0.00001 |
| sun.sum | -0.173765 | 0.985161 | -0.1764 | 0.8599939 |
| sun.dry | 0.436326 | 0.972718 | 0.4486 | 0.653746 |
| clo.sum | -0.178892 | 0.990753 | -0.1806 | 0.8567114 |
| clo.dry | 0.092154 | 0.983585 | 0.0937 | 0.9253542 |
| max.tem.dry | 3.303501 | 0.95477 | 3.46 | 0.0005402 |
| max.tem.sum | -20.038424 | 0.952193 | -21.0445 | <0.00001 |
| min.tem.dry | -2.874055 | 0.968015 | -2.969 | 0.0029875 |
| min.tem.sum | 7.703994 | 0.959232 | 8.0314 | <0.00001 |
| rain.dry | -0.044953 | 0.410594 | -0.1095 | 0.9128187 |
| rain.sum | 0.293467 | 0.85238 | 0.3443 | 0.7306275 |
| rh.dry | 4.519542 | 0.924509 | 4.8886 | <0.00001 |
| rh.sum | -14.537637 | 0.921416 | -15.7775 | <0.00001 |
| wind.dry | 0.122232 | 0.678237 | 0.1802 | 0.8569791 |
| wind.sum | 0.370191 | 0.767708 | 0.4822 | 0.6296615 |
| sigmaSq | 0.022407 | 0.067803 | 0.3305 | 0.7410384 |
| gamma | 0.974857 | 0.907663 | 1.074 | 0.2828091 |

From the Table 4, it is obvious that max.tem.dry, max.tem.sum, min.tem.dry, min.tem.sum, rh.dry and rh.sum have statistically significant effects on frontier Aus production due to Climates covering the whole Bangladesh at 5% level of significance.

From the Analysis, Average Technical Efficiency is 0.8966353. The highest value of the efficiency is 0.9864567, which occurred in the year 1986, that is, in that year, Bangladesh achieves maximum Aus production and the lowest is 0.6536779, which occurs in the year 1973, that is, in that year, Bangladesh achieves minimum Aus production due to climates. These results are indicated that the majority of years are relatively not well in achieving maximum Aus production due to climates. Efficiency rate approximately 90% gives sense that almost all of the year achieve maximum Aus production due to climates. At the same time, according to the Coelli's test $\boldsymbol{H_0{:}\gamma = 0}$, gives the value of gamma is 0.974857and it's p-value for testing the hypothesis is 0.2828091which indicates insignificant implying that all of the deviations are arisen due to inefficiency. It also means that there is a huge opportunity to increase Aus production in the Bangladesh due to climates by increasing Technology. Again, from the likelihood ratio test, it is found that the Pr($|\chi^2_{(1)}| \geq 9.9338$) = 0.0008113, which implies to reject the null hypothesis that there is no production inefficiency, that is, there exist some inefficiencies of the Aus production in Bangladesh due to climates.

### 9.3. Multiple Regression Modeling of Aman Production

we try to fit the Multiple Regression model, where Log-transformation is used in the regressor variable "clo.dry" because of avoiding the unusual patern in the "residusal versus regressor" plots and it does not create a horizontal band without transformation. The parameter estimates of the fitted Multiple Regression model for measuring the climatic effects on Aman production are given in Table 5.

***Table 5:*** *Summary Statistics of the Aman Production Model*

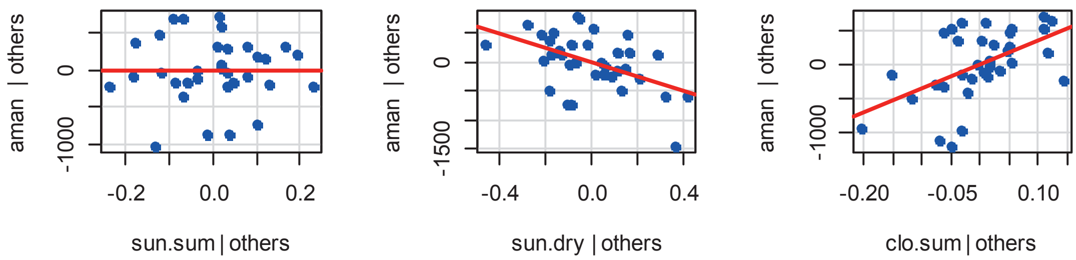
| Coefficients | Estimate | Std. Error | t - value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | -34554.2017 | 39211.21083 | -0.881 | 0.3892 |
| aman.area | 2.42556 | 0.709322 | 3.42 | 0.00287 |
| sun.sum | 34.852807 | 909.112807 | 0.038 | 0.96982 |
| sun.dry | -1222.39498 | 507.479251 | -2.409 | 0.02632 |
| clo.sum | 3483.03007 | 1277.997023 | 2.725 | 0.01343 |
| log(clo.dry)* | -2301.57968 | 2064.482467 | -1.115 | 0.27882 |
| max.tem.dry | 631.075145 | 806.098863 | 0.783 | 0.44335 |
| max.tem.sum | 990.795388 | 1339.114617 | 0.74 | 0.46841 |
| min.tem.dry | -785.319059 | 886.228044 | -0.886 | 0.38662 |
| min.tem.sum | -300.740357 | 1084.829896 | -0.277 | 0.7846 |
| rain.dry | 11.024276 | 9.213635 | 1.197 | 0.24621 |
| rain.sum | -6.902198 | 4.604804 | -1.499 | 0.15033 |
| rh.dry | 165.714079 | 179.879178 | 0.921 | 0.36847 |
| rh.sum | -147.72443 | 348.107315 | -0.424 | 0.67607 |
| wind.dry | -2880.72226 | 2463.42711 | -1.169 | 0.25671 |
| wind.sum | -2232.1388 | 1142.987676 | -1.953 | 0.06572 |

*log(clo.dry) = Log-transformation of clo.dry

From the Table 5, we observe that aman.area, sun.sum, clo.sum, max.tem.dry, max.tem.sum, rain.dry and rh.dry have positive effects on Aman production; and sun,dry, log(clo.dry), min.tem.dry, min.tem.sum, rain.sum, rh.sum, wind.dry and wind.dry have negative effects on Aus productions. Again, aman.area, sun.dry, sun.sum and wind.sum have statistically significant effects on Amn production at 5% level of significance.

Again, from the fitted Multiple Regression model, Multiple R-squared is 0.9481, which implies that 94.81% of the total variations can be explained by the regressor variables and Adjusted R-squared is 0.9072, which implies that 90.72 % of the total variations can be explained by the regressor variables after adjustments and from the overall test, $Pr(|F_{(15, 19)}| \geq 23.15) < 0.00001$ implies that all the regressor variables are not eqully significant effects on Aman production at 5% level of significance.

Added Variable Plots for the Aman production model are shown in the Figure 3



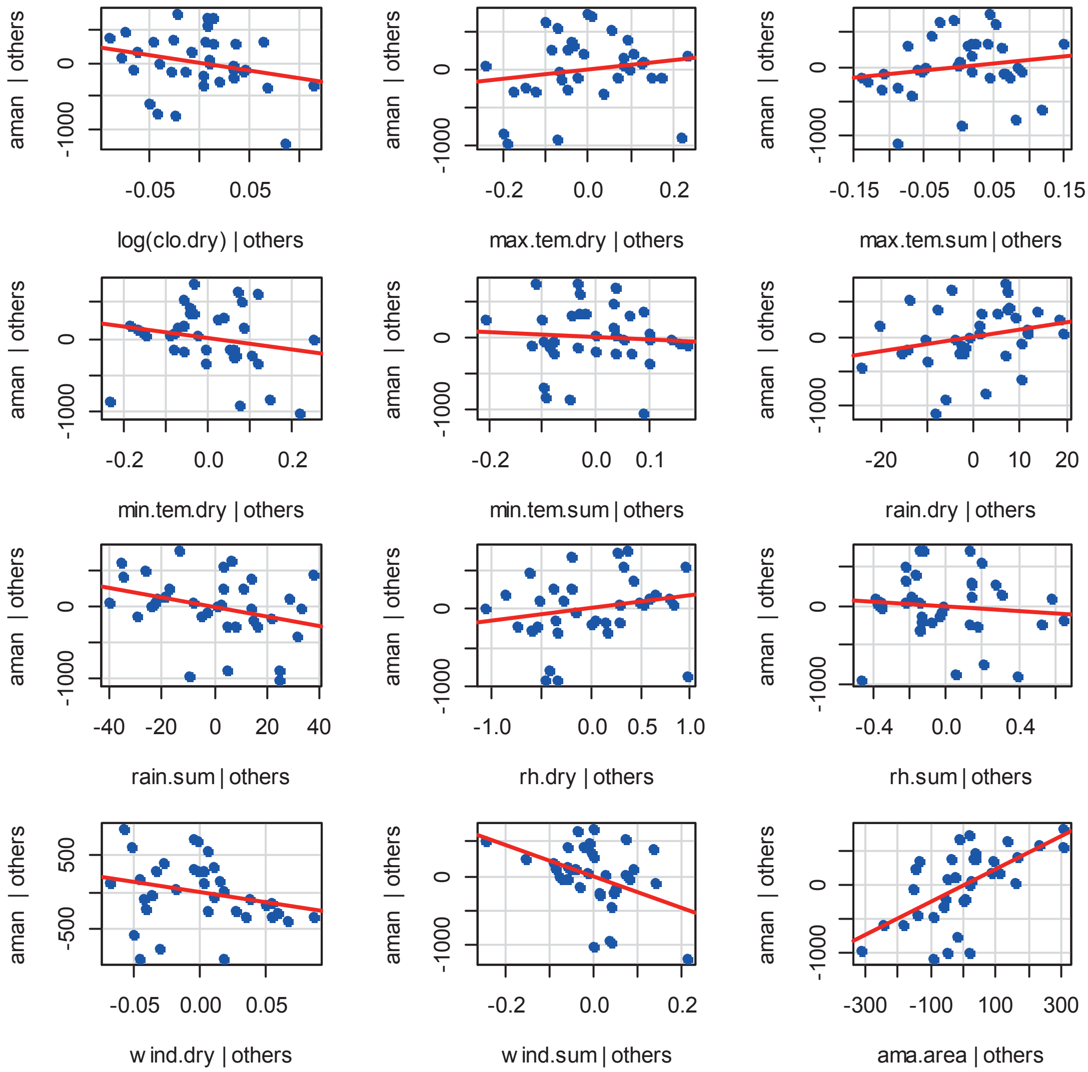
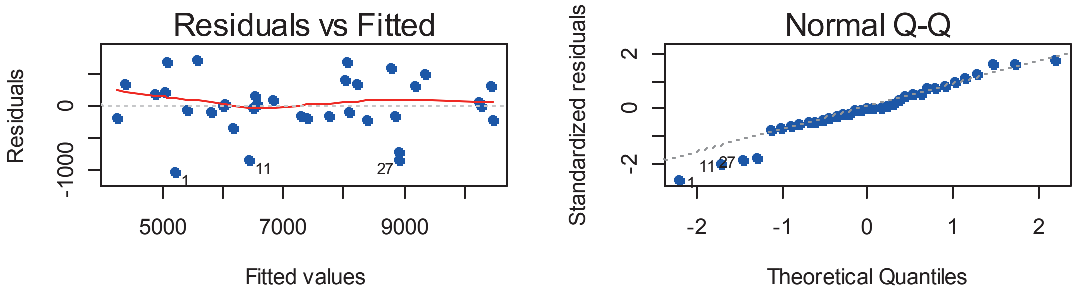



***Figure 3:** Added Variable Plots for Wheat Production Model*

From the Figure 3, which displays the partial relationship between the response (Aman production) residuals and each of the predictor's residuals for Aman production model. All plots show that they follow a staright line with non-zero slopes and there is no curvature relationship ammong the predictor's residuals and response residuals. That is why, it can be said that each of the predictor variabls are added to the model with maintaining a linear relation, that is, this model is going to make a linear relationship between the response variable and the predictor variables to measure the climatic effects on Aman production in Bangladesh.

### 9.3.1. Residuals Diagnostics for Aman Production Model

Residuals Diaagonstics Plots for measuring the climatic effects of Aman production model are shown in the Figure 4.



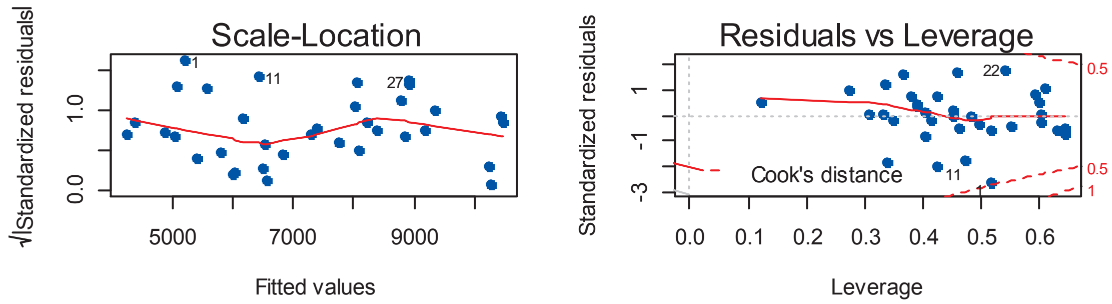



***Figure 4:*** *Residuals Diagonstics for Aman Production Model*

From the Figure 4, we observe that,

- all of the points are lied around the horizontal line and they try to create a horizontal band, which implies constant variance among the residuals of the Aman production model (top-left).
- almost all of the points try to create a horizontal band which indicates that residals have constant variance of the Aman production model (bottom-left).
- although there is a single leverage point, according to the cook's distance it is approximately on the 50% Cook's interval of the leverage points, which has small amount of influence on the model properties of the Aman production model (bottom-right).
- almost all of the points are very closed to Q-Q line or on the Q-Q line, which suggests that residuals are normally distributed of the Aman production model (top-right).

To check different assumptions by using formal test for Aman production model are shown in the Table 6

***Table 6:*** *Residuals Diagnostic Tests for Assumptions Checking*

| Residuals Diagnostic | Test Name | P-value |
|---|---|---|
| Constant Variance test | Breusch-Pagan | $Pr(\lvert\chi^2_{(14)}\rvert \geq 11.9815) = 0.6804$ |
| Auto-correlation test | Box-Ljung test | $Pr(\lvert\chi^2_{(1)}\rvert \geq 0.6069) = 0.4359$ |
| Normality Test | Shapiro-Wilk | $Pr(\lvert\chi^2_{(35)}\rvert \geq 0.9486) = 0.1029$ |

From the Table 6, it is clear that residuals of the fitted Multiple Regression model for Aman production have constant variance, have no auto-correlation problem and they follow normal distribution at 5% level of significance which implies the fitted model's assumptions are very well managed. These all test are made based on Chi-square test.

### 9.3.2. Global Validation Checking for Aman Production Model

Global model validation test is used to check whether Aman production model is valid or not. The test is performed at 5% level of significance on 4 degrees of freedom. The results from the test are shown in the Table 7.

***Table 7:*** *Global Validation Checking for Aman Production Model*

| Test Statistics | Value | p-value | Decision |
|---|---|---|---|
| Global Stat | 3.4884 | 0.4796 | Assumptions acceptable |
| Skewness | 1.4706 | 0.2253 | Assumptions acceptable. |
| Kurtosis | 0.0593 | 0.8076 | Assumptions acceptable. |
| Heteroscedasticity | 0.6698 | 0.4131 | Assumptions acceptable. |

From the Table 7, we observe that the p-value of Global Stat is 0.4796, which suggests that linearity of parameters, Homoscedasticity, Autocorrelation and Normality test are very well managed in the fitted regression model, that is, the fitted model for Aman production is a valid linear model. Again, Skewness and Kurtosis of the fitted model are 1.4706 and 0.0593 respectively and their corresponding p-values for testing hypothesis are 0.2253 and 0.8076, which are suggested that the assumptions of the skewness and kurtosis are very well accepted to fit a linear model. At the same time, the heteroscedasticity assumptions is also accepted with the p-value = 0.4131suggesting homoscedasticity of variance. We can easily say that the fitted model is the best fitted Multiple Linear Regression model for measuring the climatic effects on Aman production in Bangladesh.

**Finally,** from all of the test, assumptions of residuals like Homoscedasticity, Autocorrelation and Normality are very well satisfied and model validation test "Global Tesst" also satisfied all of the assuptions of the linear model and the fitted model is a valid linear model. Without any kind of loss of generality, it can be said that this fitted model is the best fitted Multiple Regression Model for measuring the climatic effects on Aman production based on the sample data.

### 9.4. Stochastic Frontier Modeling for Aman Production

The Parameter estimates of the Cobb-Douglas Stochastic Frontier Model for the Boro production are given in the Table 8.

***Table 8:*** *Summary Statistics of the Frontier Model for Aman Productions Model*

| Coefficients | Estimate | Std. Error | z value | Pr(>\|z\|) |
|---|---|---|---|---|
| (Intercept) | 1.0957603 | 0.9917341 | 1.1049 | 0.2692058 |
| sun.sum | -1.1965307 | 0.6502877 | -1.84 | 0.0657679 |
| sun.dry | -1.492296 | 0.5937395 | -2.5134 | 0.0119579 |
| clo.sum | 0.0772077 | 0.6107033 | 0.1264 | 0.8993961 |
| clo.dry | -0.2986345 | 0.3039728 | -0.9824 | 0.3258841 |
| max.tem.dry | -0.339906 | 0.9455599 | -0.3595 | 0.7192391 |
| max.tem.sum | 6.3653451 | 0.9007222 | 7.0669 | <0.0001 |
| min.tem.dry | 1.6468955 | 0.8000501 | 2.0585 | 0.0395431 |
| min.tem.sum | -5.3480922 | 0.9237925 | -5.7893 | <0.0001 |
| rain.dry | 0.0134537 | 0.057745 | 0.233 | 0.8157731 |
| rain.sum | -0.1970913 | 0.1597458 | -1.2338 | 0.2172847 |
| rh.dry | -1.3169369 | 0.847432 | -1.554 | 0.1201767 |
| rh.sum | 2.5972418 | 0.7447202 | 3.4875 | 0.0004875 |
| wind.dry | -0.2880678 | 0.4698982 | -0.613 | 0.539848 |
| wind.sum | -0.4007069 | 0.4477095 | -0.895 | 0.3707789 |
| sigmaSq | 0.0132774 | 0.0033777 | 3.9309 | <0.0001 |
| gamma | 0.9811439 | 0.0475385 | 20.6389 | <0.0001 |

From the Table 8, it is clear that sun.sum, sun.dry, max.tem.sum, min.tem.dry, min.tem.sum and rh.sum have statistically significant effects on frontier Aman production due to Climates covering the whole Bangladesh at 5% level of significance.

From the fitted model, Average Technical Efficiency is 0.9159081. The highest value of the efficiency is 0.9925343, which occurred in the year 1987, that is, in that year, Bangladesh achieves maximum Aman production and the lowest is 0.7527511, which occurred in the year 1982, that is, in that year, Bangladesh achieves minimum Aman production. These result indicate the majority of year are relatively not well in achieving maximum Aman production. Efficiency rate approximately 91% gives sense that most of the year can achieve maximum Aman production. At the same time, according to the Coelli's test $H_0: \gamma = 0$, gives the value of gamma is 0.9811439 and it's p-value for testing the hypothesis is < 0.0001 indicating highly significant, which implies that all of the deviations are arisen due to technical inefficiency. It also means that there is a huge opportunity to increase Aman production in the Bangladesh by increasing technology. Again, from the likelihood ratio test, it is found that the $\Pr(|\chi^2_{(1)}| \geq 6.8844) = 0.004348$, which implies to reject the null hypothesis that there is no production inefficiency, that is, there exist inefficiency of the Aman production due to climates in Bangladesh.

### 9.5. Weighted Multiple Regression Modeling of Boro Production

We select Weighted Least Squares (WLS) methods because of avoiding the outlier and influential observations which have very bad effects on fitted model's properties by using Ordinary Least Square (OLS) method, where amounts of land area are used for Boro production as a weights because the amount of land area increases or decreases in corresponding year's production proportionately. Also without Weighted Least Squares the assumption of Autocorrelation is violated. The parameter estimates of the fitted Weighted Multiple Regression model for measuring the climatic effects on Boro production are given in the Table 9.

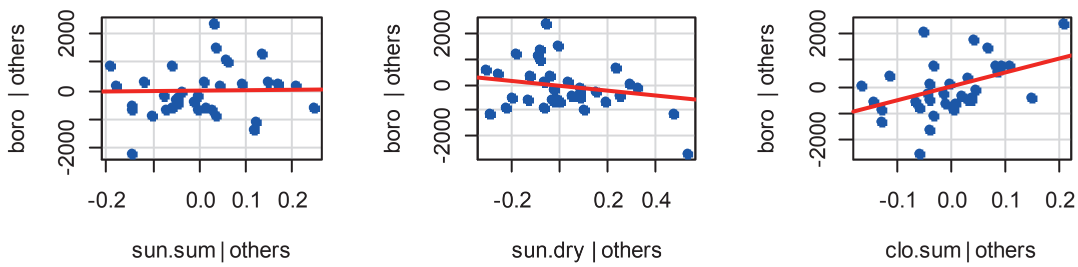
***Table 9**: Summary Statistics of the Boro Production Model*

| Coefficients | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | -84602.979 | 77591.13 | -1.09 | 0.2885 |
| sun.sum | 268.036 | 1877.38 | 0.143 | 0.8879 |
| sun.dry | -976.092 | 1028.063 | -0.949 | 0.3537 |
| clo.sum | 5135.426 | 2427.188 | 2.116 | 0.0471 |
| clo.dry | -1474.242 | 2586.465 | -0.57 | 0.575 |
| max.tem.dry | 1790.703 | 1556.702 | 1.15 | 0.2636 |
| max.tem.sum | 1787.945 | 2790.252 | 0.641 | 0.5289 |
| min.tem.dry | -1887.299 | 1828.237 | -1.032 | 0.3143 |
| min.tem.sum | 879.533 | 2305.861 | 0.381 | 0.7069 |
| rain.dry | 27.43 | 19.141 | 1.433 | 0.1673 |
| rain.sum | 5.049 | 9.736 | 0.519 | 0.6098 |
| rh.dry | 305.12 | 360.569 | 0.846 | 0.4074 |
| rh.sum | -406.147 | 693.217 | -0.586 | 0.5645 |
| wind.dry | -6697.18 | 5169.133 | -1.296 | 0.2099 |
| wind.sum | -5982.886 | 2541.914 | -2.354 | 0.0289 |

From the Table 9, we observe that sun.sum, clo.sum, max.tem.dry, max.tem.sum, min.tem.sum, rain.dry, rain.sum and rh.dry have positive effects on Boro production; and sun,dry, clo.dry, min.tem.dry, rh.sum, wind.dry and wind.dry have negative effects on Boro production. Again, clo.sum and wind.sum have statistically significant effects on Boro production at 5% level of significance.

Again, from the fitted Multiple Regression model, Multiple R-squared is 0.9544, which implies that 95.44% variation can be explained by the regressor variables and Adjusted R-squared is 0.9225, which implies that 92.25 % variation can be explained by the regressor variables after adjustments; and from overall test, $Pr(|F_{(15, 19)}| \geq 29.92) < 0.00001$, which implies that all the variables are not eqully significant effects on Boro productions at 5% level of significance.

Added Variable Plots for the Boro production model are shown in the Figure 5.



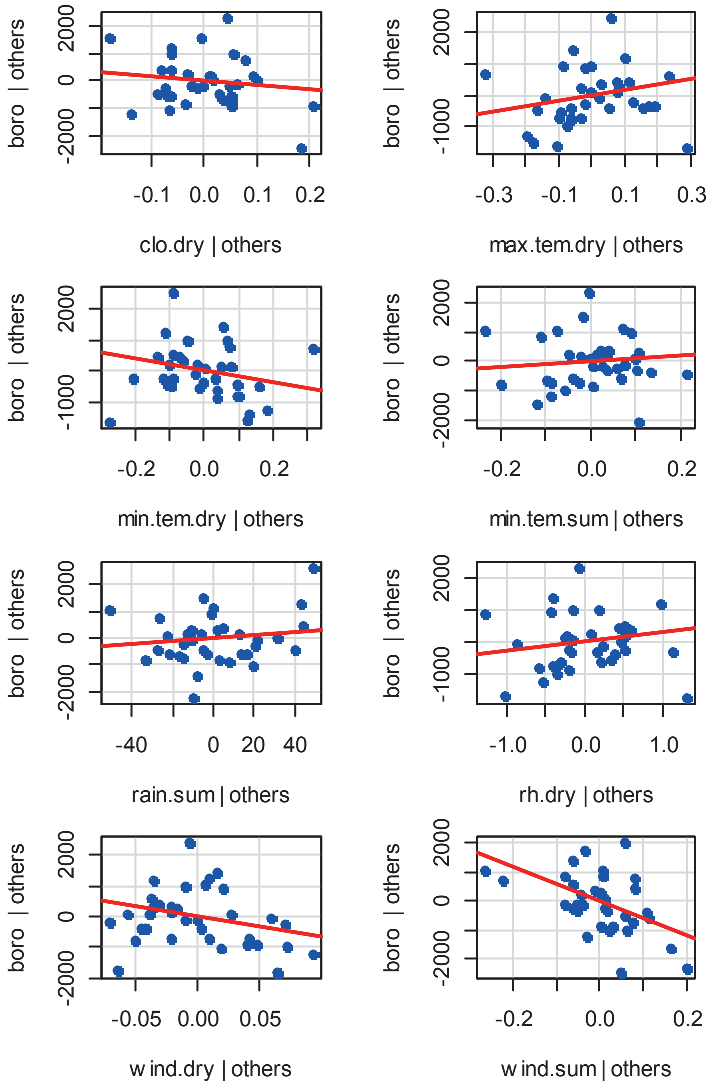
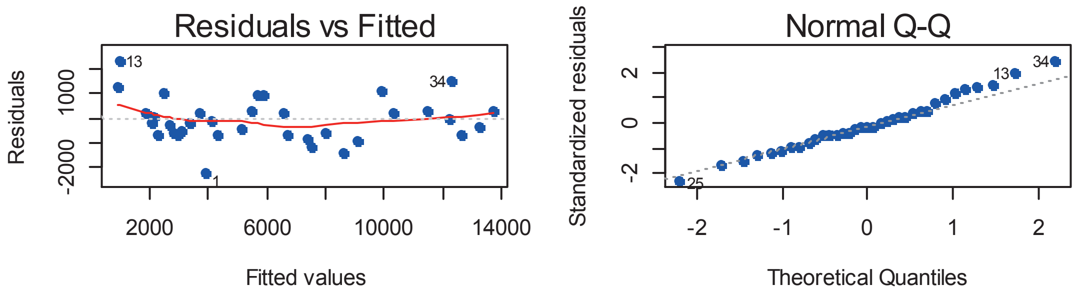



***Figure 5:*** *Added Variable Plots for Boro Productions Model*

From the Figure 5, which displays the partial relationship between the response (Boro production) residuals and each of the predictor's residuals for Boro production model. All plots show that they follow a staright line with non-zero slopes and there is no curvature relationship ammong the predictor's residuals and response residuals. That is why, it can be said that each of the predictor variabls are added to the model with maintaining a linear relationship, that is, this model is going to make a linear relationship between the response variable and the predictor variables to measure the climatic effects on Boro production in Bangladesh.

### 9.5.1. Residuals Diagnostics for Boro Production Model

Residuals Diaagonstics Plots for measuring the climatic effects on Boro production model are shown in the Figure 6.



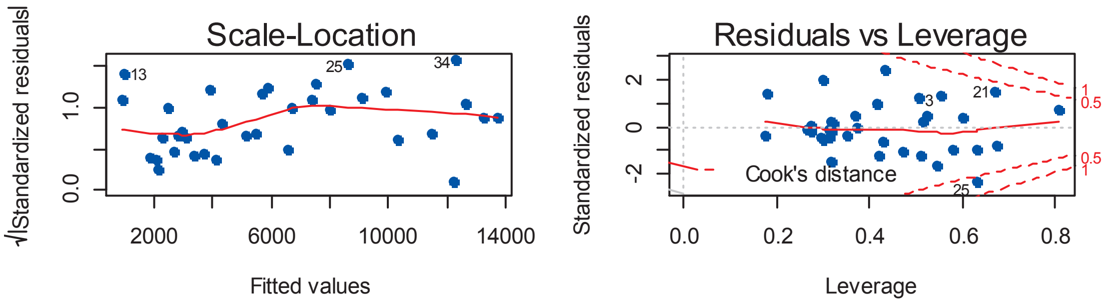



***Figure 6:** Residuals Diagonstics for Boro Production Model*

From the Figure 6, we observe that,

- all of the points are lied around the horizontal line and they try to create a horizontal band, which implies constant variance among the residuals of the Boro production model (top-left).
- almost all of the points try to create a horizontal band which indicates that residals have constant variance of the Boro production model (bottom-left).
- although there is a single leverage point, according to the cook's distance it is approximately on the 50% Cook's interval of the leverage points, which has small amount of influence on the model properties of the Boro production model (bottom-right).
- almost all of the points are very closed to Q-Q line or on the Q-Q line, which suggests that residuals are normally distributed of the Boro production model (top-right).

To check different assumptions by using formal test for Boro production model are shown in the following Table 10

***Table 10:** Residuals Diagnostic Tests for Assumptions Checking*

| Residuals Diagnostic | Test Name | P-value |
|---|---|---|
| Constant Variance test | Breusch-Pagan | $Pr(\|\chi^2_{(14)}\| \geq 13.8719) = 0.4593$ |
| Auto-correlation test | Box-Ljung test | $Pr(\|\chi^2_{(1)}\| \geq 1.5586) = 0.2119$ |
| Normality Test | Shapiro-Wilk | $Pr(\|\chi^2_{(35)}\| \geq 0.9691,) = 0.4185$ |

From the Table 10, it is clear that residuals of the fitted Multiple Regression model for Boro production have constant variance, have no auto-correlation and they follow normal distribution at 5% level of significance which implies the fitted model's assumptions are very well managed. These all test are made based on Chi-square test.

### 9.5.2. Global Validation Checking for Boro Production Model

Global model validation test is used to check whether Boro production model assumption are valid or not. The test is performed at 5% level of significance on 4 degrees of freedom. The results from the test are shown in the Table 11.

***Table 11:** Global Validation Checking for Boro Production Model*

| Test Statistics | Value | p-value | Decision |
|---|---:|---|---:|
| Global Stat | 5.6819 | 0.22420 | Assumptions acceptable |
| Skewness | 0.1895 | 0.66331 | Assumptions acceptable. |
| Kurtosis | 0.4044 | 0.52485 | Assumptions acceptable. |
| Heteroscedasticity | 0.9137 | 0.33914 | Assumptions acceptable. |

From the Table 11, we observe that the p-value of Global Stat is 0.22420, which suggests that linearity of parameters, Homoscedasticity, Autocorrelation and Normality test are very well managed in the fitted regression model, that is, the fitted model for Boro production is a valid linear model. Again, Skewness and Kurtosis of the fitted model are 0.1895 and 0.4044 respectively and their corresponding p-values for testing hypothesis are 0.66331 and 0.52485, which are suggested that the assumptions of the skewness and kurtosis are very well accepted to fit a linear model. At the same time, the heteroscedasticity assumptions is also accepted with the p-value = 0.33914, which suggests homoscedasticity of variance. It can easily be said that the fitted model is the best fitted Multiple Linear Regression model for measuring the climatic effects on Boro production in Bangladesh.

**Finally,** from all of the Graphical and Formal test of assumptions checking of residuals like Homoscedasticity, Autocorrelation and Normality are very well managed and model validation test "Global Test" also satisfied all of the assuptions of a linear model and the fitted model is a valid linear model. So, without any kind of loss of generality, it can be said that this fitted model is the best fitted Multiple Regression Model for measuring the climatic effects on Boro production based on the sample data.

### 9.6. Stochastic Frontier Modeling of Boro Production

The Parameter estimates of the Cobb-Douglas Stochastic Frontier Model for the Boro production are given in the Table 12.

***Table 12:*** *Summary Statistics of the Frontier Model for Boro Productions Model*

| Coefficients | Estimate | Std. Error | z value | Pr(>\|z\|) |
|---|---|---|---|---|
| (Intercept) | -99.7681 | 1.010599 | -98.7218 | < 0.00001 |
| sun.sum | -0.59988 | 0.585969 | -1.0237 | 0.3059603 |
| sun.dry | -3.16171 | 0.638472 | -4.952 | < 0.00001 |
| clo.sum | 2.233974 | 0.730229 | 3.0593 | 0.0022187 |
| clo.dry | -0.93814 | 0.290893 | -3.225 | 0.0012596 |
| max.tem.dry | 3.137814 | 0.925431 | 3.3906 | 0.0006973 |
| max.tem.sum | 26.86868 | 0.886917 | 30.2945 | < 0.00001 |
| min.tem.dry | -1.49288 | 0.880928 | -1.6947 | 0.0901386 |
| min.tem.sum | -10.014 | 0.934246 | -10.7188 | < 0.00001 |
| rain.dry | 0.31812 | 0.081432 | 3.9066 | 0.000095 |
| rain.sum | -0.10498 | 0.24101 | -0.4356 | 0.6631415 |
| rh.dry | -1.52947 | 1.099871 | -1.3906 | 0.1643508 |
| rh.sum | 11.84676 | 1.033388 | 11.464 | < 0.00001 |
| wind.dry | -0.20573 | 0.430453 | -0.4779 | 0.6326897 |
| wind.sum | -1.1007 | 0.442269 | -2.4888 | 0.0128188 |
| sigmaSq | 0.05024 | 0.016491 | 3.0465 | 0.0023152 |
| gamma | 1 | 0.000002 | 468283.4719 | < 0.00001 |

From the Table 12, it is obvious that sun.dry, clo.dry, clo.sum, max.tem.sum, max.tem.dry, min.tem.dry, min.tem.sum, rain.dry, rh.sum, and wind.sum have statistically significant effects on frontier Boro production due to Climates covering the whole Bangladesh at 5% level of significance.

From the fitted model, Average Technical Efficiency is 0.8540012. The highest value of the efficiency is 0.9997242, which occurred in the year 1987, that is, in that year, Bangladesh achieves maximum Boro production and the lowest value is 0.5522312, which occurred in the year 1972, that is, in that year, Bangladesh achieves minimum Boro production. These result are indicated that majority of year are relatively not well in achieving maximum Boro production. Efficiency rate approximately 85% gives sense that most of the year did not achieve maximum frontier Boro production. At the same time, according to the Coelli's test $H_0: \gamma = 0$, which gives the value of gamma is 1 and it's p-value for testing the hypothesis is < 0.00001 indicating highly significant, which implies that all of the deviations are arisen due to technical inefficiency. It also means that there is a huge opportunity to increase frontier Boro production in Bangladesh by increasing technology. Again, from the likelihood ratio test, it is found that the Pr($|\chi^2_{(1)}|$ ≥ 14.286) = 0.00005, which implies to reject the null hypothesis that there is no production inefficiency, that is, there exist inefficiency of the frontier Boro production due to climates in Bangladesh.

**Conclusion and Recommendation**

The main objective of the study is to develop the best Multiple Regression Model for measuring the climatic effects on rice crop productions in the Bangladesh and measuring the production efficiency due to climates by using Cobb-Douglas Stochastic Frontier Model. To serve this purpose, Climatic information are divided into two season to measure the effects seasonally effects named as dry season which covers the months October, November, December, January and February; and summer season which covers the months March, April, May, June, July, August and September considering the climatic condition of Bangladesh.

From the fitted Multiple Regression Model of Aus production, the value of Multiple R-squared is 0.9694, which implies that 96.94% variation can be explained by the regressors variable. Similarly, for the Aman production model, the value of Multiple R-squared is 0.9481, which implies that 94.81% variation can be explained by the regressors variable. At the same time, from the Boro production model, the value of Multiple R-squared is 0.9544, which implies that 95.44% variation can be explained by the regressors variable. From each of the fitted model, it can be said that these models are very good representative and can explain the practical situations very well. Again, the p-values for Global Stat of Aus, Aman and Boro production models are 0.19675, 0.4796 and 0.22420 respectively, implying all are valid linear model.

From the fitted Model, it is observed that aus.area ,sun.dry and log(wind.sum) have statistically significant effects on Aus production. Again, aman.area, sun.dry, sun.sum and wind.sum have statistically significant effects on Amn production. At the same time, clo.sum and wind.sum have statistically significant effects on Boro production.

Again, from the Stochastic Frontier model, Mean Efficiency of Aus production due to climates is 0.8966353, indicating majority of years are relatively not well in achieving maximum Aus production. Similarly, Mean Efficiency of Aman production due to climates is 0.9159081, implying most of the year did not achieve maximum production. Again, From the Boro production model, Average Technical Efficiency is 0.8540012, indicating most of the year did not achieve maximum frontier Boro productions. From all model, it is obvious that there are huge opportunity to increase productions by increasing technology and all of deviations are arisen due to inefficiencies.

After conducting these analyses, the following recommendations can be made such as

- The policy makers and researchers could use these model to make a decision for agricultural productions under consideration of climatic and hydrological effects on agricultural productions.
- Similar regional models could be further studied to find variations of the models.
- The climatic zone similar to Bangladesh could also be compared in the future studies.

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