Production Risk with Feasible Generalized Least Square

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Abstract. This study investigates production risk. A multistage stratified random sampling technique was adopted to select sampling unit. In between Cobb Douglas and Linear quadratic model, the linear quadratic model had been picked through feasible generalized least square method. The numerical model, we utilize the information from rice cultivating in Bangladesh. The results show that uneven socioeconomic and farm-specific inputs are creating risk in rice production. Input variables such as area, labour, and fertilizer and managerial factors, for example, experience, schooling, contact with extension, training, natural calamity, member and status indicated a significant impact on rice productions uncertainty. This indicated that both input and managerial factors were important for the rice production.

1. Introduction
Production risk is natural phenomena in agriculture especially for the emerging countries. Agricultural production faced extensive risks because of environmental factors, geological factors as well as diseases of crops, though farmers are generally risk averse [1-4]. As livelihood of farmers mostly depends on agriculture, the adverse outcomes have large consequences on their life. Through inputs and output, they try to mitigate the production risk.

Just and Pope [6] proposed a function to estimate production risk. Later, Griffiths and Anderson [7] extended the Just and Pope’s model (JP model) for panel data. Kumbhakar [8] extended the JP model for technical efficiency and used the modified model for cross-section in 2002 [9]. Sarkar et al. [5] express that it is necessity to estimate production risk in case of cross sectional research for Transplanted Aman rice, however, his study has limitation that it did not use cross sectional data. Therefore, this study is designed to give empirical insight into production risk of regional rice farmers. Objective of this study is to estimate production risk using production function with feasible generalized least square.

2. Methodology
2.1. Production Function
The general form of Just-Pope production function is
\[ y = f(x; \beta) + h(z; \delta) + \epsilon \]
Where:
\[ f(x; \beta) \] is the mean production function,
\( h(z;\delta) \) is the variance or risk function, 
\( x \) and \( z \) are the vectors of inputs, 
\( \beta \) and \( \delta \) are parameter vectors. 
\( E(\varepsilon) = 0 \) and \( V(\varepsilon) = \sigma^2 \) are the exogenous stochastic disturbances. Mean output can be represented as \( E(y) = f(x) + u \) and the variance of output can be represented as \( V(y) = V(u) = [h(z;\delta)]^2 \sigma^2 \). A positive sign on parameter \( h(z;\delta) \) implies an increase in the variability of production; on the other hand, a negative sign on the same function indicates a decrease in the variability.

2.2. Estimation Procedure: ML and FGLS
Maximum Likelihood (ML) and Feasible Generalized Least Square (FGLS) estimation procedure had been applied to estimate production risk [12 – 17]. The method of ML provides consistence and asymptotically fully efficient estimates of both mean production function and variance function, in a single stage [18] though, FGLS estimator is used in most empirical studies of production risk [16]. Therefore, both FGLS and ML were chosen for estimation in this study. The Cobb-Douglas (CD) production function and variance function respectively were estimated through the ML estimation procedure. The LQ mean function and variance function in Equations 2 and 3 respectively.

The FGLS procedure is given as follows. The general model in Equation (1) is used to describe conventionally. First, mean production function of Equation (1) was estimated by using ordinary least squares, which gives consistent estimates of the parameters \( \beta \). The predicted residuals were used as the output variable in the estimation of the output risk function.

\[
\hat{u} = y - f(x) = h(z;\delta) \cdot \varepsilon
\]

Second, Harvey [18] specified model was used for the output risk function

\[
\ln(\hat{u})^2 = z\delta + \nu
\]

where \( \nu \) is the error term. Estimated Equation (3) provided consistent estimates of the parameters \( \delta \) and the predicted value of the variance function \( \hat{h}(z;\delta) \). This predicted value was used to re-estimate the mean function for gaining efficient estimation

\[
y/\hat{h}(z;\delta) = f(x;\beta)/\hat{h}(z;\delta) + \varepsilon
\]

This weighted regression was corrected for heteroskedasticity and provided efficient estimates for the mean function \( f(x;\beta) \). Again, the estimated residual from Equation (4) was used to re-estimate the output risk function. Following the procedure of FGLS, the CD mean function and output variance function were estimated through the FGLS estimation procedure.

3. Numerical Example

3.1. Materials
In this cross sectional study, a structured questionnaire was used to collect data from farmers. T. Aman rice cropping farmers were included for interview. Data were collected immediately after the rice harvested to minimize errors arising from recall. A multistage stratified sampling technique was designed to select rice farm household in which a union (smallest administrative unit of Government of Bangladesh) was considered as a strata. The respondents had freedom to withdrawal him/herself from the interview at any time.

The sample size was calculated using the following formula given by Islam [10]:

\[
n = z^2 \left[ P(1-P)/d^2 \right] * D_{eff}
\]

Where:
\( n \) is the size of the sample, 
\( z \) is two-sided normal variate at 95% confidence level (1.96),
\( P \) is the percentage of indicator,
\( d \) denotes the precision,
\( D_{\text{eff}} \) is the design effect.

To obtain data on indicators at a 10% precision and 95% confidence interval, assuming a design effect of 2.20 and the most conservative estimate of indicator percentage (50%), the sample size required was 200. Therefore, 200 farm households were required to measure the efficiency of rice growing farmers from each division. Regional difference varies due to farm manager’s personal qualification, farming practice, availability of irrigation facility, favourable climate, and soil etc. Bangladesh consists of 30 agro-ecological zones (AEZ). That is overlapping with each other. A total number of 7 mutually exclusive regions were considered for the data set and presented in Appendix (Table A1). The description of the data sets has been given in Appendix (Table A2). The descriptive statistics of input, output, socio-economic, and farm-specific variables are given in Appendix (Table A3). This study followed the categorization of variables of Sherlund et al. [11].

3.2. Log Quadratic (LQ) Production Function for the Study

The empirical LQ mean function of Equation (1) is given as

\[
\ln y_{it} = \beta_0 + \beta_1 \text{Area}_{it} + \beta_2 \text{Labor}_{it} + \beta_3 \text{Seed}_{it} + \beta_4 \text{Pesticide}_{it}
+ \frac{1}{2}(\beta_5 \text{Area}_{it} \times \text{Area}_{it} + \beta_6 \text{Labor}_{it} \times \text{Labor}_{it} + \beta_7 \text{Seed}_{it} \times \text{Seed}_{it}
+ \beta_8 \text{Fertilizer}_{it} \times \text{Fertilizer}_{it} + \beta_9 \text{Pesticide}_{it} \times \text{Pesticide}_{it}) + \beta_{10} \text{Labor}_{it}
+ \beta_{11} \text{Area}_{it} \times \text{Seed}_{it} + \beta_{12} \text{Fertilizer}_{it} \times \text{Labor}_{it} + \beta_{13} \text{seed}_{it} \times \text{Pesticide}_{it}
+ \beta_{14} \text{Fertilizer}_{it} \times \text{Seed}_{it} + \beta_{15} \text{Seed}_{it} \times \text{Fertilizer}_{it} + \beta_{16} \text{Pesticide}_{it} \times \text{Seed}_{it} + u_{it} (6)
\]

3.3. LQ Variance Function

Variance functions can be represented as a special case of variance function specification given by Harvey [18]: 
\( V(u) = \exp[\delta z] \), where \( z \) is the input level or transformation of input and can also be a managerial variable. The production variability might also be related to the farmers’ educational background and experience, which had been included in this empirical analysis. The interaction term is omitted from LQ model in variance function.

The LQ model output risk function of Equation (1) is

\[
V(u_{it}) = \exp(\delta_0 + \delta_1 \text{Area}_{it} + \delta_2 \text{Labor}_{it} + \delta_3 \text{Seed}_{it} + \delta_4 \text{Fertilizer}_{it}
+ \delta_5 \text{Pesticide}_{it} + \delta_6 \text{ST}_{it} + \delta_7 \text{MEM}_{it} + \delta_8 \text{EDU}_{it} + \delta_9 \text{EXP}_{it} + \delta_{10} \text{TRAIN}_{it} + \delta_{11} \text{CEO}_{it}
+ \delta_{12} \text{PS}_{it} + \delta_{13} \text{ST}_{it} + \delta_{14} \text{IS}_{it} + \delta_{15} \text{CL}_{it} + \delta_{16} \text{DSE}_{it} + \delta_{17} \text{NCL}_{it} ) (7)
\]

The marginal output risk in input \( k \) is given by

\[
\frac{\partial \text{var}(y_{it})}{\partial z_k} = \frac{\partial \text{var}(u_{it})}{\partial z_k} = \exp \left\{ \delta_0 + \delta_1 \text{Area}_{it} + \delta_2 \text{Labor}_{it} + \delta_3 \text{Seed}_{it} + \delta_4 \text{Fertilizer}_{it}
+ \delta_5 \text{Pesticide}_{it} + \delta_6 \text{ST}_{it} + \delta_7 \text{MEM}_{it} + \delta_8 \text{EDU}_{it} + \delta_9 \text{EXP}_{it}
+ \delta_{10} \text{TRAIN}_{it} + \delta_{11} \text{CEO}_{it} + \delta_{12} \text{PS}_{it} + \delta_{13} \text{ST}_{it} + \delta_{14} \text{IS}_{it} + \delta_{15} \text{CL}_{it} + \delta_{16} \text{DSE}_{it} + \delta_{17} \text{NCL}_{it} \right\}
\frac{\partial z_k}{\partial z_k} 
\exp \left\{ \delta_0 + \delta_1 \text{Area}_{it} + \delta_2 \text{Labor}_{it} + \delta_3 \text{Seed}_{it} + \delta_4 \text{Fertilizer}_{it}
+ \delta_5 \text{Pesticide}_{it} + \delta_6 \text{ST}_{it} + \delta_7 \text{MEM}_{it} + \delta_8 \text{EDU}_{it} + \delta_9 \text{EXP}_{it}
+ \delta_{10} \text{TRAIN}_{it} + \delta_{11} \text{CEO}_{it} + \delta_{12} \text{PS}_{it} + \delta_{13} \text{ST}_{it} + \delta_{14} \text{IS}_{it} + \delta_{15} \text{CL}_{it} + \delta_{16} \text{DSE}_{it} + \delta_{17} \text{NCL}_{it} \right\}
\]

The output variance elasticity with respect to input \( k \) is given by

\[
\text{VE}_{it}^{(k)} = \frac{\partial \text{var}(y_{it})}{\partial z_k} \frac{\partial z_k}{\partial \text{var}(y_{it})} = \delta_k z_k (8)
\]
The first element of \( z \), \( z_0 \) is taken as unity. This implies \( \text{var}(\varepsilon) = \exp(\delta_b) \).

If \( V \)E is greater (less) than zero, then input \( k \) is risk-increasing (risk-decreasing). The total output variance elasticity in inputs and managerial is defined as

\[
TVE(z) = \sum \text{VE}^{z_{ij}}
\]

If \( TVE \) is greater (smaller) than zero, then a factor neutral expansion of input levels will lead to an increase (decrease) in the variance of output.

The output variance elasticity’s are given in Table 5. The estimated output risk model confirmed that there were both risk-accumulating and risk-diminishing inputs. For DHR, RAJR, SYR negative variance elasticity found by labor input. In this case, the variance elasticity implied that labor input played a risk-diminishing role which is similar with the study of Tveteras and Wan [14]. Labor input elasticity was positive for CHR, KHR, BAR and RANGR that is, in these regions labor is risk increasing factor. However, the value indicates inelasticity which is very small as well as there is no alternate substitution. Total output variance elasticity (TVE) is higher than one for the regions SYR (-1.254) and CHR (-1.11) which reflect that there is flexible substitution of inputs. RANGR is very close to one (-0.931) as can consider as elastic. TVE is negative in DHR, CHR, BAR, SYR and RANGR that is, the production variability is decreasing. On the other hand, TVE were inelastic in the farm of RAJR (0.178) and KHR (0.115).

3.4. Data Validation

3.4.1. Normality Test

The normality test statistics of Jarque Berra for \( JB_{DHR}, JB_{CHR}, JB_{RAJR}, JB_{KHR}, JB_{SYR}, JB_{RANGR} \) are less than \( \chi^2_{\text{critical}} \) at 1% level of significance. The test statistics \( JB_{BAR} \) is less than \( \chi^2_{\text{critical}} \) at 10% level of significance (Table 1). Therefore, there is no evidence to reject the null hypothesis that residuals were normally distributed.

3.4.2. Multicollinearity Test

To test the multicollinearity among the output and input variables a Variance Inflation Factor test was run. Multicollinearity test showed that there was no high multicollinearity among the input variables (Table 2).

3.5. Feasible Generalized Least Square

The estimation of Likelihood value of C-D and LQ production function for the two methods ML and FGLS have presented in Table 3. Between the estimation methods, the likelihood value of FGLS is higher compare to the method of ML for all the regions. LQ production function is more appropriate to estimate the output variable than C-D production function for all the regions except Dhaka region (DHR). C-D production function is more appropriate for DHR. LQ model was adequately fit data; hence former results have been shown from LQ model through FGLS method (Table 4).

Area and labor are risk decreasing inputs for rice production in DHR by FGLS method. This result was supported by Picazo-Tadeo and Wall [16]. Picazo-Tadeo and Wall [16] also estimated the parameter in the context of Spanish rice farm by FGLS method.

In CHR, seed, fertilizer and pesticide were risk reducing. In RAJR, except pesticide rest of the input, area, labor, seed, fertilizer were risk reducing. In KHR, only area and pesticide was risk reducing input, but labor and seed were risk increasing input. Area, seed and fertilizer in BAR farms were risk decreasing input. Labor, fertilizer, and pesticide were working as risk reducing in SYR farms. Seed, fertilizer, and pesticide were showing risk reducing input in RANGR.

The inclusion of socioeconomic and farm-specific variables was strongly supported by likelihood ratio test. Socioeconomic and farm specific variables give negative relation with production risk. In case of DHR, input experience was negatively associated with output risk. Coelli, Rahman, and Thirtle [19] stated that more experienced farmers have more knowledge about traditional management system. Older farm managers are reluctant about to adopt risk in production. Training was positively associated with
production risk. Poor farm managers’ rarely received training in Bangladesh. In this condition, it is noted that uneven socioeconomic and farm-specific inputs are creating risk in production.

4. Discussion

The study identified the general causes of production variability in the T. AMAN rice farms. The obtained results showed that the chosen LQ model provided the best fit for the selected farms of T. AMAN rice over a cross-sectional period.

The results suggested that the input variables such as area, labor, and fertilizer had a significant influence on T. AMAN rice production. On the other hand, the managerial variables, such as experience, schooling, contact with extension, training, natural calamity, member status showed a significant positive impact on T. AMAN production uncertainty. This indicated that both input and managerial variables were important for better T. AMAN production, and required proper guidelines of input use. The main motivation was to show the level of inputs and other farm-specific factors affect T. AMAN production technologies in Bangladesh. The higher amount of labor input per farm increases the output variability, but these empirical results showed that labor was a reducing variability, similar to Gardebroek et al [20]. Better training of the farm manager was found to reduce inefficiency in production. This empirical study showed similar result with Tveteras et al. [21]. It can be recommended on the basis of findings that the farmer may after have received some vocational schooling can optimize his return based on an enhanced ability to evaluate the associated risks and opportunities for him. Moreover, agricultural production are generally uncertain, as natural disasters such as the weather, pests, diseases, and other production calamities affect the farm output. Even slight changes in the input conditions may produce serious impact on farm production, leading to a loss of part or all of the crop’s produce. Many small farmers can be considered as risk-averse in this case. If experienced farmers know the specific risk profiles for their agricultural products and try to manage these risks, then they may have a golden opportunity to increase their production as well as their living standard by means of the limited available land.

5. Conclusions

In this study, the C-D and LQ models were employed to estimate the production risk technologies on a cross-sectional data of Bangladesh T. AMAN rice farms. However, relatively little attention has been paid to the possibility of the production risk, associated with input variable characteristics which have the potential to alter findings regarding farm inefficiency and through this policy conclusion regarding the applicable and focus in rural development efforts in the area. The two systems of approaches, FGLS and ML were applied to give a clear picture of production risk in T. AMAN rice farms. In farmed T. AMAN rice production, risk plays an important part. Consequently, it is important to know which inputs are risk increasing or decreasing. For this we estimate the partial derivatives of the production risk, function. Typically small-scale farmers always face severe financial constraints. The financial constraint problem is most severe among farmers in developing country like Bangladesh. Thus the relative risk is higher than well diversified financially strong investors. The results of this study are of great concern to academics, agriculturists, policymakers, as well as government. Furthermore, these findings have important applied implications to different agricultural farms. The presence of heterogeneity of T. AMAN rice farm indicates to the regulators and policymakers that appropriate measures should be taken to increase the production through proper utilization of input in the farm. In addition, the extent and direction of government involvement is also an important factor in rice farm evolution. Government involvement must be continued to avoid most production risks.

Research on production risk is therefore of great importance, especially for small-scale farming systems in developing countries, where farmers are more vulnerable to risk.

This shows that different climate zones can be impacted differently by climate change. Therefore, the severity of climate change effects on rice yields may vary between climate zones. Our results suggest that region-specific or climate zone specific awareness policies should be implemented.

This will enable the development of local or micro-level adaptation policies for reducing yield variability, and ensuring food security in the presence of climate change.
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### Table 1: Value of Test Statistic for Jarque-Bera Normality Test

| REGION  | CHI-SQUARE TEST | TEST STATISTICS |
|---------|-----------------|-----------------|
| DHR     | 2.6993**        |                 |
| CHR     | 2.4813**        |                 |
| RAJR    | 2.4473**        |                 |
| KHR     | 2.8343**        |                 |
| BAR     | 7.5737*         |                 |
| SYR     | 0.8071***       |                 |
| RANGR   | 1.6204***       |                 |

Note. ***, **, * represents statistically significant at 1%, 5%, and 10% respectively

### Table 2: Multicollinearity test between input variables

| Description of Variable | Symbol of the Variable | VIF-Score |
|-------------------------|-------------------------|-----------|
| Production of T. AMAN   | (y)                     | 3.020274  |
| Area                    | (x₁)                    | 2.548984  |
| Labor                   | (x₂)                    | 1.858775  |
| Seed                    | (x₃)                    | 2.424339  |
| Fertilizer              | (x₄)                    | 2.065635  |
| Pesticide               | (x₅)                    | 1.393408  |
| Status                  | (z₁)                    | 1.290092  |
| Member                  | (z₂)                    | 1.090466  |
| Education               | (z₃)                    | 1.196204  |
| Experience              | (z₄)                    | 1.126743  |
| Contact with extension  | (z₅)                    | 1.374852  |
| Officer                 | (z₆)                    | 1.483119  |
| Training                | (z₇)                    | 1.197550  |
| Plough System           | (z₈)                    | 1.217695  |
| Seed Type               | (z₉)                    | 1.262293  |
| Irrigation System       | (z₁₀)                   | 1.249655  |
| Condition of Land       | (z₁₁)                   | 1.347588  |
| Natural Calamity        | (z₁₂)                   | 1.019288  |
Table 3. Hypothesis Test for Selecting Appropriate production function and method for estimation

| Region | Log-likelihood C-D | Log-likelihood LQ | FGLS estimates C-D | FGLS estimates LQ | Accepted Decision |
|--------|------------------|------------------|-------------------|------------------|------------------|
| DHR    | -970.104         | -931.884         | -418.213          | -436.563         | CD               |
| CHR    | -902.108         | -927.844         | -421.802          | -416.358         | FGLS             |
| RAJR   | -982.826         | -926.151         | -457.310          | -424.672         | LQ               |
| KHR    | -985.719         | -932.754         | -437.598          | -423.578         | FGLS             |
| BAR    | -994.339         | -937.716         | -434.368          | -410.372         | LQ               |
| SYR    | -985.471         | -889.250         | -408.532          | -360.436         | FGLS             |
| RANGR  | -1009.03         | -975.683         | -435.436          | -418.753         | LQ               |

Note: *, ** and *** is statistically significant at 1%, 5% and 10% level of significance.

Table 4. Feasible Generalized Least Square Estimation for Output Risk in Linear Quadratic Production

| Variables | DHR  | CHR  | RAJR | KHR  | BAR  | SYR  | RANGR |
|-----------|------|------|------|------|------|------|-------|
| Constant  | (δ₀) | 7.30*| 11.51*| 4.43***| 4.99*| 7.17*| 14.39*| 9.62* |
| Area      | (δ₁) | 3.64| 3.40| 3.35| 3.35| 3.35| 3.35| 3.35 |
| Labor     | (δ₂) | -0.83*| 0.25| -0.00| 0.11| 0.00| -0.35| 0.62 |
| Seed      | (δ₃) | 0.69| -0.37| -0.13| 0.21| -0.10| 0.17| -0.10 |
| Fertilizer| (δ₄) | -0.07| -0.70***| -0.12| 0.37| -0.03| -0.43| -0.31 |
| Pesticide | (δ₅) | -0.08| -0.28| 0.22**| -0.00| 0.03| -0.18| -0.85*|
| STS       | (δ₆) | 0.00| 0.00| -0.00| -0.00**| 0.00| 0.00| 0.08 |
| MEM       | (δ₇) | 0.03| -0.19| -0.37| -0.38| -0.45| -1.80| 0.20*** |
| EDU       | (δ₈) | 0.07| -0.06| 0.05| 0.03| 0.05| 0.06| 0.05 |
| EXP       | (δ₉) | 0.01| -0.07| -0.00| -0.00| 0.01| 0.01**| 0.02 |
| CEO       | (δ₁₀)| 0.04| 0.04| -0.00| 0.01| 0.01**| 0.02| 0.34 |
| TR        | (δ₁₁)| -0.12| 0.01| 0.01| -0.00| 0.17| 0.41| 0.11 |
| PS        | (δ₁₂)| -0.00| -0.50| 0.46| -0.44| 0.17| 0.41| 0.11 |
| ST        | (δ₁₃)| -0.29| -0.33| 0.04| -0.83| -0.00| -0.37| -0.31 |
| IS        | (δ₁₄)| 0.04| 0.07| 0.39| 0.01| 0.11| 0.03| 0.03 |
| CL        | (δ₁₅)| -0.04| -0.37| -0.75***| 0.03| -0.24| -0.34| 1.36 |
| DSE       | (δ₁₆)| 0.00| 0.69**| 0.36| -0.47| -0.34| -1.11**| 0.47 |

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Table 5. Output Variance Elasticity from LQ model by Feasible Generalised Least Square

| VARIABLES | DHR | CHR | RAJR | KHR | BAR | SYR | RANGR |
|-----------|-----|-----|------|-----|-----|-----|-------|
| Area      | 0.007 | -0.010 | 0.048 | 0.128 | 0.023 | -0.022 | -0.014 |
| Labor     | -0.410 | 0.123 | -0.0008 | 0.050 | 0.001 | -0.121 | 0.370 |
| Seed      | 0.342 | -0.171 | -0.0879 | 0.097 | -0.055 | 0.096 | -0.034 |
| Fertilizer | -0.050 | -0.586 | -0.109 | 0.297 | 3.079 | -0.304 | -0.307 |
| Pesticide | -0.083 | -0.286 | 0.195 | 0.0002 | -3.069 | -0.159 | -1.031 |
| STS       | 0.010 | 0.015 | -0.005 | -0.064 | -0.015 | 0.008 | 0.025 |
| MEM       | 0.008 | -0.049 | -0.114 | -0.121 | -0.108 | -0.305 | 0.215 |
| SCH       | 0.068 | -0.069 | 0.047 | 0.032 | 0.047 | 0.090 | 0.053 |
| EXP       | 0.037 | -0.013 | 0.045 | -0.037 | 0.015 | -0.116 | -0.074 |
| TR        | 0.029 | 0.073 | -0.019 | 0.054 | 0.049 | 0.082 | 0.004 |
| CEO       | -0.007 | -0.014 | 0.018 | -0.010 | 0.009 | 0.008 | -0.011 |
| PS        | -0.0003 | -0.056 | -0.051 | 0.002 | -0.016 | -0.113 | 0.547 |
| ST        | -0.0698 | -0.120 | 0.019 | -0.290 | -0.0009 | -0.124 | -0.158 |
| IS        | 0.015 | -0.231 | 0.154 | 0.006 | 0.092 | 0.411 | -0.249 |
| CL        | -0.294 | 0.067 | -0.073 | 0.022 | -0.080 | -0.075 | 0.086 |
| Disease   | 0.0005 | 0.160 | 0.082 | -0.015 | -0.090 | -0.284 | -0.084 |
| NCL       | 0.078 | 0.057 | 0.030 | -0.036 | -0.041 | -0.326 | -0.269 |
| TVE       | -0.319 | -1.11 | 0.178 | 0.115 | -0.159 | -1.254 | -0.931 |

Note. *, **, *** are Significance level at 1%, 5%, 10% consecutively; Values in parentheses are standard deviations.
## Appendixes

**Table A1.** Districts Covered Under AEZ

| AEZ                                      | Division Covered under AEZ | District Covered under AEZ                  |
|------------------------------------------|----------------------------|---------------------------------------------|
| Brahmaputra-Jamuna Floodplain            | Dhaka Division (DHR)       | Jamalpur, Kishoreganj                       |
| Middle Meghna River Floodplain and Lower Meghna River and Estuarine Floodplain | Chittagong Division (CHR)  | Brahmanbaria, Feni                          |
| Karatoya Floodplain and Atrai Basin      | Rajshahi Division (RAJR)   | Naogaon, Jhalokhathi                        |
| High Gaunges River Floodplain            | Khulna Division (KHR)       | Jhenaidah, Kustia                           |
| Ganges Tidal Floodplain                  | Barisal Division (BAR)     | Barguna, Patuakhali                         |
| Sylhet Basin and Surma-Kusiyara Floodplain | Sylhet Division (SYR)     | Sunamgonj, Gopalgonj                        |
| Old Himalayan Piedmont Plain and Tista Floodplain | Rangpur Division (RANGR) | Gaibandah, Lalmonirhat                      |
### Table A2. Description of the variables

| Name of Variables | Symbol | Description of Variables |
|-------------------|--------|--------------------------|
| **Input Variables** |        |                          |
| Production        | (y)    | Production was the output variable and represented by standard unit as kilogram. Total production of T. AMAN during monsoon season year 2011. |
| Area              | (x₁)   | The quantity of appropriate land used for T. AMAN rice farm was considered as Area. As a single crop, the area coverage of AMAN rice is highest. Area was measured by standard unit as hectare. |
| Labor             | (x₂)   | The amount of day labor worked for T. AMAN rice farm, included the farmer, family member (unpaid) and hired man power. |
| Seed              | (x₃)   | The quantities of seed were produced by the farmer themselves or from the government or from other organizations are considered for the variable seed. |
| Fertilizer        | (x₄)   | Fertilizers that were consumed by T. AMAN rice farmers were also considered as a variable. Chemical and non-chemical fertilizers were considered for this study. Fertilizers were measured by kilogram. The chemical fertilizers were UREA, MP and GIPSAM. We considered a combination of all fertilizers. Mostly used non-chemical fertilizer was cow dung in Bangladesh. |
| Pesticide         | (x₅)   | The total cost of pesticide during monsoon season of T. AMAN rice farms year 2011 were considered as variable pesticide. |
| **Socioeconomic Variables** |        |                          |
| Status            | (z₁)   | Status is defined by the farmers’ size of the farm. Size of the farm was categorized into three types: large farm (>2 hectares), medium farm (>1 hectare and ≤2 hectares), and small farm/marginal farm (≤1 hectare). |
| Member            | (z₂)   | The spouse and the number of children were considered as family members. |
| Education         | (z₃)   | The numbers of schooling years of the farmers were considered for education. |
| Experience (EXP)  | (z₄)   | The number of years the farmers had been working in the T. AMAN rice farm until 2015 was considered as variable Experience. |
| Contact with extension Officer | (z₅) | CWE=1, if farmers had contact with the agricultural officer; otherwise, zero. |
| Training          | (z₆)   | Skilled worker=1, if farmers had training within 5 years; otherwise, zero. |
| **Farm-specific Variables** |        |                          |
| Plough System     | (z₇)   | Bangladesh has many types of plough systems. If used machine, bullock=1 and Not used machine/ bullock=0. |
| Seed Type         | (z₈)   | Different types of seed were used by farmers. ST=1, if improved seed (High Yielding Variety) supplied by Govt., own self or other organization were used by farmers; ST=0, supplied by other’s company were used by farmers. |
| Irrigation System | (z₉)   | There are many traditional irrigation systems available in Bangladesh. Categorical variable had been defined for irrigation systems. If farmer’s irrigation systems were traditional; then traditional irrigation=1, Had not received any irrigation=0 |
| Variable          | Condition                          |
|-------------------|------------------------------------|
| **Condition of Land** | Condition of land was a dummy variable. Before cultivation, if farm land was degraded by any unusual circumstances. If degraded CL=1, not degraded CL=0. |
| **Natural Calamity** | Categorical variable that farmers’ rice farm was affected by drought, flood, insects, or others. NCL=1, if farm had been faced flood during production; NCL=0, if farm had not been faced flood during production |
| **Disease**       | Disease was a dummy variable. DSE=1, if rice farm had been affected by the disease; DSE=0, if rice farm had not been affected. |
Table A3. Descriptive Statistics of Output, Input and Socioeconomic Variables

| Variable                      | Dhaka Region | Chittagong Region | Rajshahi Region | Khulna Region | Barisal Region |
|-------------------------------|--------------|------------------|-----------------|--------------|---------------|
| Production (Kg)               | 1288         | 1330.600         | 2876.125        | 1287.000     | 1733.385      |
| Area (Ha)                     | .470         | .366             | 1.1567          | .432         | .472          |
| Labor (Person)                | 22           | 18               | 40              | 19           | 21            |
| Seed (Kg)                     | 18.99        | 12.695           | 63.645          | 20.152       | 37.255        |
| Fertilizer (Kg)               | 79.315       | 16.105           | 176.630         | 63.645       | 173.605       |
| Pesticide (Taka)              | 324.225      | 176.630          | 338.655         | 357.145      | 173.385       |
| Family Member (Person)        | 5            | 6                | 5               | 5            | 5             |
| Education (Years)             | 3.97         | 5                | 5               | 5            | 5             |
| Experience (Years)            | 14           | 14               | 20              | 14           | 20            |

| Variable                      | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum |
|-------------------------------|---------|---------|---------|---------|---------|---------|
| Dhaka Region                  | 4800    | 80.00   | 13000   | 320     | 28000   | 40      |
| Chittagong Region             | 3.34    | .07     | 4600    | .00     | 8000    | 25      |
| Rajshahi Region               | 28000   | 25      | 13000   | 320     | 6400    | 40      |
| Khulna Region                 | 21600   | 25      | 6400    | 40      | 21600   | 25      |
| Barisal Region                | 4800.00 | 0       | 240.00  | 1       | 4800.00 | 0       |


|                | Family Member (Person) | Education (Years) | Experience (Years) |
|----------------|------------------------|-------------------|-------------------|
|                | 5                      | 4                 | 18                |
|                | 2                      | 4                 | 15                |
|                | 2                      | 0                 | 63                |

**Sylhet Region**

|                | Production (Kg) | Area (Ha) | Labor (Person) | Seed (Kg) | Fertilizer (Kg) | Pesticide (Taka) | Family Member (Person) | Education (Years) | Experience (Years) |
|----------------|----------------|-----------|----------------|-----------|----------------|-------------------|-----------------------|-------------------|-------------------|
|                | 1358.000       | .862      | 14             | 20.266    | 33.351         | 150.226           | 5                     | 3                 | 14                |
|                | 5676.849       | .962      | 7              | 15.294    | 31.028         | 66.958            | 2                     | 4                 | 7                 |
|                | 120            | .13       | 2              | 5         | 7              | 60                | 2                     | 0                 | 2                 |
|                | 80000          | 10.70     | 51             | 80        | 200            | 350               | 12                    | 12                | 12                |

**Rangpur Region**

|                | Production (Kg) | Area (Ha) | Labor (Person) | Seed (Kg) | Fertilizer (Kg) | Pesticide (Taka) | Family Member (Person) | Education (Years) | Experience (Years) |
|----------------|----------------|-----------|----------------|-----------|----------------|-------------------|-----------------------|-------------------|-------------------|
|                | 1084.300       | .334      | 37             | 13.525    | 221.615        | 554.275           | 5                     | 5                 | 11                |
|                | 824.235        | .208      | 38.475         | 8.622     | 248.283        | 446.077           | 2                     | 5                 | 5                 |
|                | 200            | .00       | 2              | 2         | 6              | 20                | 2                     | 0                 | 0                 |
|                | 6800           | 1.34      | 250            | 70        | 1400           | 3200              | 9                     | 9                 | 9                 |

Family Member (Person) = 5, 2, 2, 12
Education (Years) = 3, 4, 0, 20
Experience (Years) = 14, 7, 2, 50