Rice Farmers' Production Efficiency under Abiotic Stresses: The Case of Bangladesh

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Abstract: More than half of the total extremely poor people in the world live in the major rice producing areas of Asia and Africa; rice is their staple. Enhancement of technical efficiency in producing rice in major rice producing countries of Asia and Africa can have tremendous positive impact on income of farm household, alleviate poverty and improve the livelihoods of millions in these countries. Using Household Income and Expenditure Survey (HIES) data from Bangladesh and stochastic frontier production function estimation approach, we examine the technical efficiency of the rice farmers in Bangladesh. Further, we determine the factors that affect the level of efficiency at the farm level. Results indicate that while drought leads to a significant loss in rice production, floods is a major source of technical inefficiency in rice farming in Bangladesh. We also found that the extent of basic infrastructure can also affect rice production efficiency. Policies are suggested based on the empirical findings.

Keywords: rice, efficiency, stochastic production function, farm household, drought, submergence

JEL: Q12, D24

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Rice is the staple food of half of the world population; it is a primary source of income and employment of millions of households in Asia and Africa. Importantly, rice consumption in the world has been increasing over the years, both due to increasing income and population. For example, the global rice consumption increased from 350 million tons in 1991 to 439 million tons in 2010, and is predicted to increase to 555 million tons by 2035 (GRiSP, 2010). This means that, to meet the global demand in 2035, farmers need to produce an additional 116 million tons of rice. Importantly, there is no or little scope to extend the land frontier to produce more rice, particularly in Asia, where 90 percent of the total rice is produced and consumed (Miah and Sarma, 2000). Also, the productivity gains derived from the Green Revolution in the 1970s that started with the development of short-duration fertilizer-responsive semi-dwarf modern high-yielding rice varieties are near exhaustion (Pingali et al., 1997). Therefore, a question arises as to how to produce more rice to ensure food security of billions of rice consumers?

Considering the fact that there is a limited scope to expand new land frontier to increase rice production enhancing the existing farm level rice production efficiency can be a possible solution. Rice production efficiency can be achieved by increasing rice production level per unit under a given set of input and technology, or by minimizing production costs under a given production target. Further, production efficiency can be increased by closing the yield gap, developing and disseminating biotic and abiotic stress tolerant rice varieties, and by releasing varieties with higher yield potential. Note that an enhancement of production efficiency can have direct positive impacts on farm income, poverty alleviation program, as the major rice-producing areas in the world are also riddled with the highest incidence of extreme income poverty. According to the World Bank (2013), more than 1 billion people in the world are extremely poor, who live on less than $1.25 per day, of which 560 million live only in the major rice-producing areas (GRiSP, 2010).

Given this backdrop, attempts have been made in this study to analyze production efficiency of the rice farmers and to identify factors that determine efficiency variation at the farm level using rice farmers of Bangladesh. We use Bangladesh as a case study for two distinct reasons. Firstly, more than 75 percent of the cropland in Bangladesh is dedicated solely to rice cultivation (Ganesh-Kumar et al., 2012), which means that the majority of the agricultural households are rice producing farm households. Similar to many other rice-dominated agrarian economies, more than 30 percent of the nearly 150 million people in Bangladesh are extremely poor (GOB, 2012).

Secondly, while it is well known that drought and submergence stresses are two of the major limiting factors that substantially reduce rice yield and production in the rainfed ecosystem (Bernier et al., 2008; Widawsky and O'Toole, 1996; Khush and Toenniessen, 1991; Devereux, 2007; Dey and Upadhyaya, 1996; Pandey et al., 2007; Pandey and Bhandari, 2007; Gauchan and Pandey, 2012; Evenson et al., 1996; Grover and Minhas, 2000). However, very few studies have investigated the impact of these stresses on production efficiency of rice farmers. Importantly, 45% of the total rice farmland in Bangladesh is rainfed in nature. Similar to other Asian and African countries, the frequent occurrences of submergence and drought are the major causes of crop failure, income volatility, and the persistent poverty among the small and marginal rice farmers in the rainfed ecosystem of the country. While a number of studies have tried to examine rice farmers' technical efficiency (e.g., Wadud and White, 2000; Sharif and Dar, 1996; Coelli et al., 2002; Rahman et al., 1999), however, to our knowledge not a single study has examined the impact of drought and submergence on the production efficiency of rice farmers. Therefore, the objective of this study is to investigate the impact of abiotic stresses on production efficiency of the rice farmers. Additionally, investigate the factors affecting technical efficiency of rice producers in Bangladesh. Findings from this study help policymakers in designing appropriate policies to ensure increased production, profitability and food security and of poor rice farmers in the rainfed rice ecosystem. To explain the farm level variation of production efficiency, this article includes farm and household characteristics as well as the extent of drought and submergence.

2. Measuring efficiency using frontier production function

It is generally known that the farm level efficiency can be achieved in two ways: by maximizing the level of production under a given set of input, or by minimizing cost under a prescribed level of production. The popular approach to measure the level of efficiency at the farm level is the measure of technical efficiency by using frontier production function (Tzouvelekas, et al., 2001; Wadud and White, 2000; Sharma et al., 1999; Battesse and Coelli, 1995). Particularly, in this study, following Ail and Flinn (1989), Kumbhakar and Bhattacharya (1992) and Ali et al., (1994), we apply stochastic production function model of the rice farmers in Bangladesh in which technical efficiency is assumed as the ability of a farm to achieve highest possible production given the level of inputs, climate variables and abiotic stresses and the existing level of technology.

Also, a number of studies dealt with efficiency measurement, regressed the predicted efficiency score against a number of household level demographic variables, with an aim to identify the sources of technical efficiency at the farm level using a two stage procedure (e.g., Sharif and Dar, 1996, Wang et al., 1996). In this paper, an attempt has also been made to identify the sources of efficiency, particularly to quantify the impacts of drought and submergence and other climate variables (e.g., rainfall) on rice farmers' technical efficiency.

Note that characteristically, farm households in Bangladesh are predominantly small and subsistence farmers with an average farm size of 0.53 hectare (Hossain et al., 2007). Understanding the impact of abiotic stresses on technical efficiency of rice farming of the small and subsistence rice farmers may contribute significantly to formulate effective policy to ensure viable income of the poor rice farmers in Bangladesh. Interestingly, similar to Bangladesh, 85 percent of the total population in Laos, who live in rural areas, is mostly engaged in rice cultivation (Ly et al., 2012), and 50 percent of the cropland in Nepal and 33 percent of the cropland in India is used in rice cultivation, where drought and submergence are also the major limiting factors in rice production (Gumma et al., 2011; Pandey and Bhandari, 2007). The striking similarities in the importance of rice on the livelihoods, and the extent of abiotic stresses on rice production in many developing countries provide a strong indication of the general applicability of policies that this article intends to suggest based on the case of Bangladesh.

2.1 Data

In order to assess the impacts of abiotic stresses on rice production and technical efficiency of the rice farmers in major rice producing countries, this study primarily relies on Household Income and Expenditure Survey (HIES) data sets 2000, 2005, 2010, which were made available by the BBS (Bangladesh Bureau of Statistics), government of Bangladesh. In the HIES 2000 survey, a total of 7440 households were randomly selected from six divisions, 64 districts, 303 sub-districts and 360 mauzas (consisting of a few or parts of villages with a separate land jurisdiction). In the HIES 2005, a total of 10,080 households were randomly selected from six divisions, 64 districts, 364 sub-districts and 389 mauzas. Finally, in the HIES 2010, a total of 12,240 households were randomly selected from six divisions, 64 districts, 384 sub-districts and 454 mauzas. In this article, however, as we are particularly interested in estimating the production efficiency of rice farmers in Bangladesh, we considered only households with strictly positive income from rice during the sampled years. Therefore, we considered only 6,060 sampled rice farm households, of which 1,656 were from HIES 2000, 1,888 were from HIES 2005 and the rest 2,516, were from HIES 2010.

The second set of data is weather-related data on monthly average maximum temperature (°C) and yearly total rainfall in 2000 and 2005 made available by BARC (Bangladesh Agricultural Research Council) and the same information for year 2010 from Bangladesh Bureau of Statistics (BBS, 2011). Note that station-level information on temperature and rainfall[1] from BARC and BBS was converted into sub-district-level information by applying an inverse distance weighting algorithm, which was used to create climate surfaces of each weather variable providing estimates on a 25-km resolution grid. These estimates were then averaged to provide climate values for each sub-district and were then assigned to each household in its respective sub-district. All spatial data processing and analysis were done using the ArcGIS v 10.0 computer program.

Finally, the information on the extent of abiotic stresses at the sub-district level was extracted from Community Survey data from 2000 and 2005, which were also made available by the Bangladesh Bureau of Statistics (BBS), government of Bangladesh. The Community Survey data are the corollary data of HIES data sets, which were collected through the focus group discussion method. The groups consisted of the respondents who were interviewed for the HIES survey. The Community Survey 2000 covered all the sampled sub-districts (303) that were included in the HIES 2000 survey, and the Community Survey 2005 covered all the sampled

[1] In Bangladesh, there are 35 weather stations collect rainfall data and of which 23 weather stations collect temperature data and 18 weather stations collect humidity data (e.g., BBS, 2011).

sub-districts (355) that were included in the HIES 2005 survey. In the case of drought and submergence information in 2010 at the sub-district we used HIES2010 data, in which that information were available.

A summary table on selected variable related to rice production, inputs, and household specific socio-demographic information are presented in Table 1. It shows that on average a farm household in Bangladesh is equipped with only 2.41 acres of land and annual average rice production is 2.95 tons. Table 1 demonstrates that out of 378 sampled sub-districts, 22 percent of them were affected by drought during the period sampled and 34 percent of them were affected by submergence. It would be interesting to see how these factors affected the efficiency of the rice farmers in Bangladesh. The table further demonstrates that on average 34 percent of the household in a sub-district were connected to electricity and 25 percent of them had telephone (either land or mobile). We included these two variables in the estimated equation explaining efficiency of the rice farmers to examine how the pace of development affects farm efficiency in a developing country. Table 1 shows that on average a sampled household is consist of 5.27 family members, and 94 percent of them are headed by a male who is on average 47 years old with 2.29 year of formal schooling.

3. Theoretical framework

Stochastic production frontier model is widely used framework to assess the factors contributing production efficiency. A general specification of frontier model is given by:

$$Y_i = f(X_i, \beta) e^{v_i - u_i}, \qquad (1)$$

Where Y_i is output of firm i, X_i is the vector of inputs for firm i and β is the vector of unknown parameters to be estimated. Specifically, production frontier includes two-component error terms $V_i - u_i$, where V_i is identical and independently distributed random error term that is assumed to be independently distributed of u_i. The term u_i is a one sided error term assumed to be non-negative and represents technical inefficiency effects. Let's denote $\varepsilon_i = V_i - u_i$. Once frontier is estimated, the second estimation step is necessary to estimate the technical efficiency. The most well-known estimation of technical efficiency is proposed by Jondrow et al. (1982) and Battese and Coelli (1988) exploit the conditional distribution of u_i given ε_i. The point estimates of inefficiencies can be obtained by using mean $E(u|\hat{\varepsilon})$ of this conditional distribution. Once point estimates are obtained, technical efficiency are derived as: $Eff_i = \exp(-\widehat{u_\iota})$ where $\hat{u}$ is $E(u|\hat{\varepsilon})$.

Several factors are hypothesized to influence technical efficiency in rice production in Bangladesh, including unusual situations of drought and flooding. To analyze the determinants of technical efficiency, Eff_i is assumed to be a function of explanatory variables (Coelli et al., 1998) as follows:

$$Eff_i = \delta_0 + z_i\delta + \vartheta_i \qquad (2)$$

Where z_i is a vector of explanatory variables determining the technical efficiency of production that includes factors related to flood and drought; δ is vector of unknown coefficients to be estimated and ϑ_i is defined by the truncation of the normal distribution N(0, σ_ϑ^2).

3.1 Empirical model

In order to estimate the level of technical efficiency in a way consistent with the theory of production function, we firstly specified a Cobb-Douglas type stochastic frontier production function, as Cobb-Douglas production function is widely used in agricultural economics for its simplicity and a few of the well-known properties of it (Handerson and Quandt, 1971). The explicit Cobb-Douglas stochastic frontier production function that we have used in this article is in the following form:

$$lnY_i = a_0 + \sum_{k=1}^{8} \beta_i lnX_i + \alpha_1 ln(asset)_i + \alpha_2 \ln(T\_max)_i + \alpha_2 \ln(Rainfall)_i + \alpha_3(Droughtdummy)_i + \alpha_2(Submergence\ dummy)_i + \sum_{j=1}^{2} a_i(Year\ dummies) + \sum_{z=1}^{6} \omega_i(Division\ dummies) + V_i - U_i \quad (3)$$

where Y=log of rice produced in kilogram, X_1= log of see used, X_2= log chemical fertilizer used; X_3= log of compost used; X_4= log of total rice land (in acres); X_5= log of total man-days applied; X_6= log of costs of insecticides; X_7= log of monthly average maximum temperature (^{0}C) at the sub-district level; X_8= log of yearly total rainfall (mm) at the sub-district level; a dummy for drought affected sub-district that assumes value 1 if a sub-district was affected by drought during the sampled period, or 0 otherwise; a dummy for submerged sub-district that assumes value 1 if a sub-district was affected by floods during the sampled period, or 0 otherwise; two year dummies for year 2005 and 2010 where the base year was 2000, and six division dummies for seven divisions where Barisal division is the base, V is the random error term assumed to be independently and identically distributed, having $N(0, \sigma_v^2)$ distribution pattern and U is the non-negative one sided random variable presents inefficiency index; B_0 is a scaler and B_i, α_i, a_i and ω_i are the parameters to be estimated. It is assumed that the inefficiency effects are independently distributed with a half normal distribution (U ~| $N(0, \sigma_{vu}^2)$). In our econometric approach we also have reported an estimated production function explaining rice production by farm households in Bangladesh using stochastic translog production function using the same set of variables what we used in estimating Cobb-Douglas production function.

The model of the technical efficiency effects in the stochastic frontier of equation (1) is defined as:

$Eff_i = a_0 + \alpha_1$(dummy for drought affected sub-district) $+\alpha_2$(dummy for submergence prone sub-district)+ β_1 (labor to land ratio)$_i$+ β_2(seed to land ratio)$_i$ + β_3(chemical fertilizer in kilogram)$_i$+ β_4(yearly total crop income)$_i$

$+ \beta_5$(distance from the district head quarter to the capital city, Dhaka)$_i$

$+\beta_6$(% households with electricity at sub-district level)$_i$

$+\beta_7$(% households with telephone at sub-district level)$_i$

$+\beta_8$(% households with electricity at sub-district level)$_i$ $+ Z_i\gamma_i$

$+ \sum \Omega_j$ (Two year dummied for three sampled year (base=2000))

$+ \sum \mu_j$ (Six division dummies for seven division (base= Barisal division)) $+\vartheta_i$ (4)

where Eff_i is the efficiency index calculated from equation (2); Z_i is a vector of variables that include age and years of schooling of the household head and spouse, size of the household measured by the number of family members; a male dummy for a household head is a male (=1). The variable labor to land ratio is measured as man-days employed by the household per hundred acres of rice land, and the variable seed to land ratio is measured as total seed applied per hundred acres of rice land.

4. Results and Discussion

Table 2 presents the estimated function explaining production of rice by rice farmers in Bangladesh using Cobb-Douglas and translog production function. The table demonstrates that chemical fertilizer, compost, labor, insecticides and the size of the rice land significantly and positively determine rice production, while seed and rainfall negatively and significantly affect rice production. Importantly, Table 1 shows that while maximum temperature at the sub-district level positively affects the production of rice, the extent of drought at the sub-district level significantly and negatively affects rice production. Unfortunately, the extent of flood at the sub-district level does not show any significant impact on rice production both in Cobb-Douglas and translog specification of the production function. We conjecture that Bangladesh rice production is now dominated by dry season Boro rice which is highly modernized and almost completely irrigated. The incidence of floods in the rainy season actually increases the water availability in the dry season for Boro rice cultivation. Thus, floods in rainy season actually generate positive impacts on dry season Boro rice.

Among the division dummies, where Barisal division is the base, except Khulna division, rice production are higher in all other division compared to Barisla division. Barisal division is consists of coastal districts, where salinity is a major problem in the dry season, and in many areas the only crop farmers can produce is the rainfed Aman rice. By contrast, modern Boro rice cultivation, applying irrigation and modern rice seeds and technology has been spreading rapidly in less stress prone areas, such as Rajshahi and Rangpur divisions. Khulna division, similar to Barisal, is a coastal division where salinity is a major abiotic stress resulting poor rice yield. The division dummies therefore reflecting the real picture of Bangladesh, in which Rajshahi, Rangpur, Sylhet and Chittagong divisions are emerging as rice bowls of Bangladesh compared to stress prone coastal areas.

Importantly, based on the estimated production function, we have calculated technical efficiency score of the rice farmers in Bangladesh. Table 3 and Figure 1 present the technical efficiency score of the rice farmers in Bangladesh. Interestingly, Table 3 reports that out of 6,060 sampled farm households, efficiency score of the 394 farms were less than 25 percent, and efficiency score of 1895 rice farmers were lies within 25 percent to 50 percent; and efficiency score of 2,847 farmers' lies within 50 to 75 percent range, the rest, 924 farmers efficiency ranged above 75 percent. Our estimation indicated that on average rice production efficiency in Bangladesh is nearly 60 percent, which means there is enormous scope to increase rice production efficiency of the rice farmers in Bangladesh.

Table 4 presents the estimated function explaining the factors that affect the rice production efficiency. The table shows that while the extent of drought and flood reduce the efficiency of the rice farmers in rice production, the effect of flood is statistically significant. Recall that in Table 3, flood did not show any significant impacts on rice production. Combining these two results indicate that water management in Bangladesh, a low lying delta, is crucial for rice production and overall agriculture of the country, while water availability enhances the scope of irrigation particularly in the dry season, uncontrolled water in the form of flood can reduce the efficiency of the rice farmers. Therefore, a comprehensive flood control for better use of water is essential for ensuring rice production efficiency and to rice food security.

Among other variables, distance from the capital city (Dhaka), age and education of the head of household had a negative and significant impact on rice production efficiency. Dhaka the capital city of Bangladesh is also the largest market, where information on new technology, seeds and innovations on agro machinery are more frequently and readily available than any other place in Bangladesh. The greater the distance, the higher is the transaction and transportation costs of moving goods and information to and from the countryside. Thus, remotely located rice farmers tend to be less efficient compared the famers who are located in the proximity to Dhaka. Since rice farming is highly labor intensive, relatively old farmers might have less physical strength and ability to work hard compared to young farmers, and it can affect the level of efficiency negatively. Relatively highly educated farmers might employ relatively less amount of their time for rice farming compared their counterpart, as highly educated persons might have greater opportunities to earn higher income in nonfarm sector.

Interestingly, while the connectivity of electricity significantly affects the efficiency level of rice farmers, the extent of telephone connection significantly decreases the efficiency of level of rice farmers. It is difficult to explain why this might be the case, but in Bangladesh electricity is a cheap source of energy for irrigation particularly in the case of dry season Boro rice which may enhance technical efficiency of the rice farmers.

Finally, the division dummies indicate that compared to rice farmers in Barisal, production efficiency of rice farmers in Rajshahi, Rangpur, and other division are high. Note that until now, Barisal division is the least adopter of modern high yielding rice variety mainly because of less expansion of irrigation facility in the dry season for intensive soil salinity.

4. Conclusion and policy implications

Using rice farmers in Bangladesh as a case and estimating stochastic frontier production function, present paper explores the production efficiency of rice farmers in a developing country, Bangladesh. Enhancement of rice production efficiency in the major rice producing regions can improve the livelihoods of the millions of households as more than half of the total extremely poor people live in South Asia and Sub-Saharan Africa where rice is the most important crop. By enhancing production efficiency, it is possible to make the rice farming more profitable, and, thus it is possible to enhance income and livelihood of millions of poor rice farmers.

This paper predicted the efficiency score of the rice farmers in Bangladesh after estimating a standard stochastic production function and indicated that there is substantial scope for further improvement of the technical efficiency of the rice farming in Bangladesh. It is demonstrates that floods is one of the major abiotic stresses that substantially reduces rice farmers production efficiency. Also, transportation and transaction costs presented by distance from the capital city, significantly and negatively affects rice production efficiency in Bangladesh. This indicates the adoption of combined micro as well as macro level intervention to enhance rice farming efficiency in developing countries. At the micro level, the development and dissemination of flood tolerant rice and short- duration high yielding rice to the farmers in the flood prone areas can sufficiently enhance technical efficiency of the rice farmers. At the macro level, comprehensive water management and flood control in the flood prone areas, and investment on basic infrastructure, such as on roads and electricity can substantially contribute to the improvement of technical efficiency of rice farmers.

Based on the findings, this paper suggests to invest on disseminating flood and other abiotic stress tolerant rice to the stress prone areas, particularly in Barisal and Khulna divisions where flood and salinity problems significantly reduce rice productivity and thus technical efficiency of the poor rice farmers.. Importantly, this type of technology would not only mitigate current losses in rainfed rice production and enhance technical efficiency, but would also allow poor rice farmers in the abiotic stress prone areas to adapt to worsening global climate and allow them to mitigate the adverse effects of climate change in the future. Consequently, in the long run, the returns to investment in developing abiotic stress tolerant rice variety would be very high. Thus, we strongly encourage policymakers and donors to fund research, development and dissemination of new rice varieties that are more tolerant of flood and other abiotic stresses.

5. References

Ali, F., Parikh, A., and Shah, M.K. 1994. "Measurement of Profit Efficiency Using Behavioural and Stochastic Frontier Approaches." *Applied Economics,* 26:181-188.

Ali, M. and Flinn, J.C., 1989. "Profit Efficiency among Basmati Rice Producers in Pakistan Punjab." *American Journal of Agricultural Economics*, 71: 185-208.

Battese, G. and Coelli, T.1995. "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data." *Empirical Economics,* 20: 325-332.

BBS (Bangladesh Bureau of Statistics). 2011. *Statistical Yearbook of Bangladesh 2010.* Dhaka: Statistics Division, Ministry of Planning.

Bernier, Jerome, Gray N. Atlin, Rachid Serraj, Arvind Kumar and Dean Spaner. 2008. "Review: Breeding Upland Rice for Drought Resistance." *Journal of the Science of Food and Agriculture,* Vol. 88, No. 6: 927-939.

Coelli, T., Rahman, S., and Thirtle, C. 2002. "Technical, Allocative, Cost and Scale Efficiencies in Bangladesh Rice Cultivation: A Non-parametric Approach." *Journal of Agricultural Economics,* 53: 607-627.

Devereux, Stephen. 2007. "The Impact of Drought and Floods on Food Security and Policy Options to Alleviate Negative Effects." *Agricultural Economics,* Vol. 37, No. S1: 47-58.

Dey M.M. and Upadhyaya, H.K. 1996. "Yield Loss Due to Drought, Cold and Submergence in Asia". In Evenson, R.E., Herdt, R.W., and Hossain, M. (eds.). *Rice Research in Asia: Progress and Priorities.* Los Baños: International Rice Research Institute in association with CAB International

Evenson, R.E., Herdt, R.W., and Hossain, M. (eds.). 1996. *Rice Research in Asia: Progress and Priorities.* Wallingford (UK): CAB International in association with the International Rice Research Institute, Philippines.

Ganesh-Kumar, A., Prasad, Sanjay.K., & Pullabhotla, Hemant. 2012. *Supply and demand for cereals in Bangladesh, 2010-2030*. IFPRI Discussion Paper 01186. Washington, DC: International Food Policy Research Institute.

Gauchan, D. and Pandey, S. 2012. "Synthesis of Key Results and Implications." in Pandey, S., Gauchan, D., Malabayabas, M., Bool-Emerick, M. and Hardy, B. *Patterns of Adoption of Improved Rice Varieties and Farm-Level Impacts in Stress-Prone Rainfed Areas in South Asia.* Los Baños (Philippines): International Rice Research Institute.

GOB (Government of Bangladesh). 2012. Bangladesh Economic Review 2012 (Bengali version). Dhaka: Ministry of Finance. Online: www.mof.gov.bd/en/budget/12_13/ber/bn/Chapter-13%20_Bangla_%202012.pdf, accessed April 22, 2013.

GRiSP (Global Rice Science Partnership). 2010. Sustainable Crop Productivity Increase for Global Food Security: A CGIAR Program on Rice-Based Production Systems. Los Baños (Philippines): International Rice Research Institute (IRRI).

Grover, Anil and Deepika Minhas. 2000. “Towards Production of Abiotic Stress Tolerant Transgenic Rice Plants: Issues, Progress and Future Research Needs.” *Proceedings of the Indian National Science Academy*, Vol. B66, No. 1: 13-32.

Gumma, Murali Krishna, Devendra Gauchan, Andrew Nelson, Sushil Pandey, and Arnel Rala. 2011. “Temporal Changes in Rice-growing Area and Their Impact on Livelihood over a Decade: A Case Study of Nepal.” *“Agriculture, Ecosystems and Environment”* Vol. 142, No. 3, pp. 382–392.

Handerson, J.M. and Quandt, R. 1971. *Microeconomic Theory.* New York: McGraw hill. Page: 106-113

Hossain, Mahabub, David Lewis, Manik L. Bose, and Alamgir Chowdhury. 2007. “Rice Research, Technological Progress, and Poverty: The Bangladesh Case” in Michelle Adato and Ruth Meinzen-Dick (eds.) *Agricultural Research, Livelihoods and Poverty: Studies of Economics and Social Impacts in Six Countries.* Baltimore: Johns HopkinsUniversity Press in association with International Food Policy Research Institute (IFPRI).

Khush, Gurdev S. and Toenniessen, Gary H. (eds.). 1991. *Rice Biotechnology.* Wallingford: CAB International in association with the International Rice Research Institute, Philippines.

Kumbakhar, S.C., Bhattacharyya, A. 1992. “Price Directions and Resource Use Efficiency in Indian Agriculture: A Restricted Profit Function Approach.” *Review of Economics and Statistics*, 74: 231-239.

Ly, Proyuth, Lars Stoumann Jensen, Thilde Bech Bruun, Dominik Rutz, and Andreas de Neergaard. 2012. “The System of Rice Intensification: Adapted Practices, Reported Outcomes and Their Relevance in Cambodia.” *Agricultural Systems* 113 (November): 16-27.

Miah, M.A. Hamid and Sarma, N.P. 2000. “Hybrid rice: progress, issues and outlook for Bangladesh”. *International Rice Commission Newsletter*, 49:65-72.

Pandey, S., and Bhandari, H. 2007. “Analytical Framework”. in Pandey, S., Bhandari, H. and Hardy, B. (eds.). *Economic Costs of Drought and Rice Farmers’ Coping Mechanisms*. Los Baños (Philippines): International Rice Research Institute.

Pandey, S., Bhandari, H. and Hardy, B., editors. 2007. *Economic Costs of Drought and Rice Farmers’Coping Mechanisms: A Cross-Country Comparative Analysis*. Los Baños (Philippines): International Rice Research Institute.

Pingali, P.L, M. Hossain and R.V. Gerpacio. 1997. *Asian Rice Bowls: The Returning Crisis?* Los Baños (Philippines): International Rice Research Institute (IRRI) and CAB International.

Rahman, K.M.M, Schmitz, P.M. and Wronka, T.C. 1999. “Impact of Farm Specific Factors on the Technical Efficiency of Producing Rice in Bangladesh.” *The Bangladesh Journal of Agricultural Economics*, 22(2): 19-42.

Sharif, N.R., and Dar, A. 1996. “An Empirical Study on the Patterns and Sources of Technical Efficiency in Traditional and HYV Rice Cultivation in Bangladesh.” *Journal of Development Studies,* 32:612-629.

Sharma, K.R., Leung, P. and Zaleski, H.M. 1999. "Technical, Allocative and Economic Efficiencies in Swine Production in Hawaii: A Comparison of Parametric and Non-parametric Approaches." *Agricultural Economics,* 20: 23-35.

Tzouvelekas, V. Pantzois, CJ, and Fotopoulos, C. 2001. "Technical Efficiency of Alternative Farming Systems: The Case of Greek Organic and Conventional Olive-Growing Farms." *Food Policy,* 26: 549-569

Wadud, A. and White, B. 2000. "Farm Household Efficiency in Bangladesh: A Comparison of Stochastic Frontier and DEA Methods." *Applied Economics,* 32: 1665-1673.

Wang, J., Cramer, G.L. and Wailes, E.J. 1996. "Production Efficiency of Chinese Agriculture: Evidence from Rural Household Survey Data." *Agricultural Economics,* 15: 17-28.

Widawsky, D.A. and O'Toole, J.C. 1996. "Prioritizing the Rice Research Agenda for Eastern India". In Evenson, R.E., Herdt, R.W., and Hossain, M. (eds.). *Rice Research in Asia: Progress and Priorities* Wallingford: CAB International in association with the International Rice Research Institute, Philippines.

World Bank. 2013. Ending Extreme Poverty and Promoting Shared Prosperity. Online: www.worldbank.org/en/news/feature/2013/04/17/ending_extreme_poverty_and_promoting_shared_prosperity, accessed May 05, 2013.

Figure 1: Technical efficiency scores for Rice growers in Bangladesh; based on Jondro, Lovell, Materov, and Schmidt, 1982 estimation (Left), based on Battese and Coelli, 1988 (right)

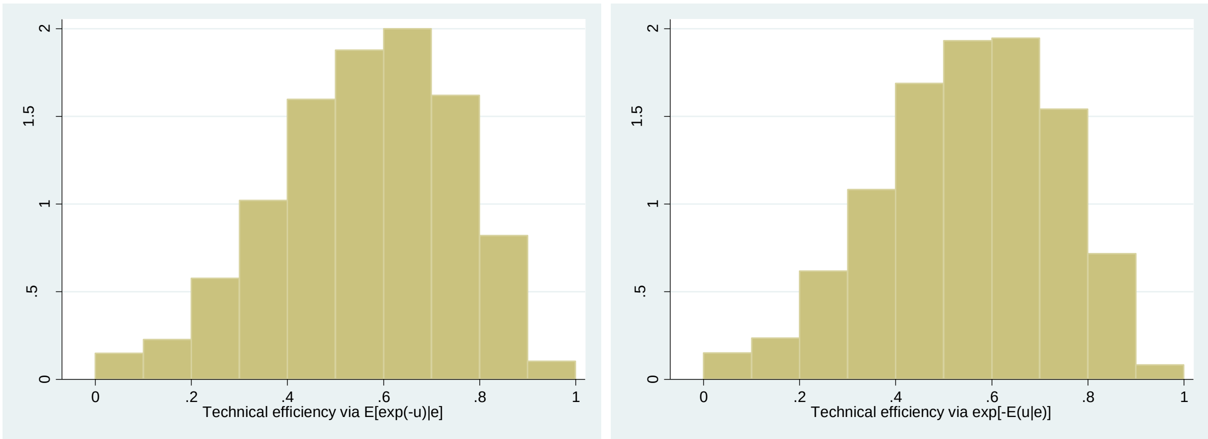

Table 1: Descriptive Statistics of the variables in the dataset, Rice growers in Bangladesh

Variable	Description	Mean	Standard Deviation
Production	Log of total rice produced in kilogram (Kg)	7.35	1.22
Seed	Log of total seed used (kg)	0.40	6.09
Fertilizer	Log of total chemical fertilizer used (kg)	2.17	5.85
Compost	Log of compost fertilizer used (kg)	7.37	7.03
Feed	Log of feed fertilizer used (Kg)	7.87	7.03
Riceland	Total area under rice cultivation (acres)	0.17	1.05
Labor days	Total man days used	3.15	1.23
Insecticide cost	Total cost for Insecticides	0.30	7.98
Temperature	Maximum annual temperature in the area	3.42	0.019
Rainfall	Total annual rainfall in the area	7.62	0.25
Assets	Total value of assets	8.72	3.82
Drought	Whether the area is drought prone, dummy variable	0.22	0.41
Flood	Whether the area is flood prone, dummy variable	0.34	0.02
Labor land ratio	Total man days per hundred acres of rice land	0.26	1.59
Seed land ratio	Total seed used per hundred acres of rice land	0.40	4.01
Total income	Household's total income from crops	39887.65	56284.71
Chemical fertilizer	Total chemical fertilizer used (kg)	155.72	289.93
Distance	Distance of the district headquarter from Capital city	196.81	91.97
Electricity	%age of households with electricity in the village	0.34	0.27
Telephone	%age of households with telephone in the village	0.25	0.29
Spouse's years of formal school	Year of formal school education of spouse	2.29	3.38
Spouse age	Age of Spouse	36.93	12.81
Head's years of school education	Year of formal school education of spouse	2.99	3.68
Sex of the Head	Whether Household head is male	0.94	0.22
Age of the Head	Age of household head (in years)	46.84	13.52
Family size	Number of family members in the household	5.27	2.16
Year 2000	Dummy (=1 if year is 2000)	0.29	0.45
Year 2005	Dummy (=1 if year is 2005)	0.31	0.46
Year 2010	Dummy (=1 if year is 2010)	0.40	0.49
Chittagong	Dummy (=1 if region is Chittagong, else 0)	0.16	0.36
Dhaka	Dummy (=1 if region is Dhaka, else 0)	0.26	0.44
Khulna	Dummy (=1 if region is Khulna, else 0)	0.14	0.35
Rajshahi	Dummy (=1 if region is Rajshahi, else 0)	0.15	0.36
Rangpur	Dummy (=1 if region is Rangpur, else 0)	0.16	0.36
Sylhet	Dummy(=1 if region is Sylhet, else 0)	0.06	0.24

Table 2: Parameter estimates generated by production function specifications for rice farming in Bangladesh (*Dependent variable= log of Rice produced, in kilograms*)

Variable	Cobb-Douglas function		Translog function	
	Estimates	t-ratio	Estimates	t-ratio
Constant	-0.390	(0.09)	0.29	(0.18)
Log of seed used (in kg)	-0.01**	(-4.10)	-0.01**	(-3.81)
Log of fertilizer used (in kg)	0.01**	(4.67)	0.01**	(4.94)
Log of compost used (in kg)	0.003**	(2.76)	0.003**	(2.82)
Log of feed used (in kg)	-0.001	(-1.18)	-0.001	(-1.00)
Log of total land under rice	0.76**	(82.68)	0.60**	(14.16)
Log of total labor days (man days)	0.10**	(12.83)	0.09**	(10.90)
Log of insecticide costs	0.01**	(9.33)	0.01**	(8.02)
Log of maximum temperature	2.51**	(2.87)	2.43**	(2.77)
Log of total rainfall in the region	-0.17**	(-3.52)	-0.17**	(-3.43)
Log of total assets	0.01**	(5.49)	0.01**	(5.29)
Drought	-0.04**	(-2.31)	-0.04**	(-2.22)
Flood	0.01	(0.30)	0.001	(0.04)
LogLand*LogLabor			0.02**	(3.81)
LogLand*LogSeed			-0.0001	(-0.07)
LogLand*LogFertilizer			-0.002	(-1.32)
LogLand*LogInsectcost			0.002**	(2.27)
Year dummies (base= 2000)				
Year2005	0.0124	(0.50)	0.01	(0.37)
Year2010	-0.190**	(-6.35)	-0.19**	(-6.24)
Regional Dummies (base=Barisal)				
Chittagong	0.177**	(4.70)	0.16**	(4.31)
Dhaka	0.0966**	(2.65)	0.09**	(2.41)
Khulna	-0.0898**	(-2.29)	-0.10**	(-2.44)
Rajshahi	0.106**	(2.71)	0.09**	(2.27)
Rangpur	0.0896*	(1.93)	0.07	(1.59)
Sylhet	0.170**	(3.71)	0.16**	(3.38)
Usigma				
	0.0864**	(3.95)	0.0779**	(3.55)
Vsigma				
	-3.025**	(-59.04)	-3.010**	(-58.91)
N	6060		6060	

t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$

Table 3: Summary of Technical Efficiency Scores

	Technical efficiency score							
Year	< 0.25		0.25-0.5		0.5-0.75		> 0.75	
	N	Mean	N	Mean	N	Mean	N	Mean
2000	118	0.138	537	0.402	749	0.622	252	0.895
2005	122	0.163	543	0.404	942	0.622	281	0.809
2010	154	0.170	815	0.394	1156	0.622	391	0.814

Table 4: Determinants of Technical efficiency in Rice farming areas in Bangladesh

Variable	Coefficient	t-ratio (based on bootstrapped SE)	t-ratio (based on asymptotic SE)
Constant	0.53**	(29.64)	(26.72)
Drought	-0.003	(-0.59)	(-0.55)
Flood	-0.01**	(-3.00)	(-2.64)
Labor to land ratio (Man days per hundred acres of riceland)	-0.01	(-0.66)	(-4.70)
Seed to land ratio (total seeds per hundred acres of Riceland)	0.001	(0.30)	(1.66)
Chemical fertilizers (in Kg)	-0.0001	(-1.05)	(-1.29)
Total Income from crops	0.0001**	(8.35)	(17.15)
Distance from capital city	-0.0001**	(-5.01)	(-4.83)
% of households with electricity in the village	0.09**	(8.16)	(8.16)
% of households with telephone in the village	-0.07**	(-2.76)	(-2.91)
Spouse years of school education	-0.0001	(-0.21)	(-0.23)
Age of Spouse	0.0001	(0.14)	(0.15)
Head's years of school education	-0.002**	(-2.24)	(-2.22)
Sex of HH head (=1 if male)	0.01	(1.14)	(0.95)
Age of Household head	-0.001**	(-2.10)	(-2.07)
Number of family members	0.002	(1.04)	(1.23)
Year dummies (base= 2000)			
Year 2005	0.0001	(0.05)	(0.04)
Year 2010	-0.003	(-0.29)	(-0.30)
Regional Dummies (base=Region1)			
Region 2	-0.002	(-0.16)	(-0.17)
Region 3	0.019	(1.44)	(1.67)
Region 4	0.034**	(2.47)	(2.85)
Region 5	0.034**	(2.46)	(2.84)
Region 6	0.086**	(6.10)	(6.43)
Region 7	0.047**	(2.98)	(3.29)
R-squared	0.086		
N	6060		