Impact of environmental production conditions on productivity and efficiency: a case study of wheat farmers in Bangladesh

IMPACT OF ENVIRONMENTAL PRODUCTION CONDITIONS ON PRODUCTIVITY AND EFFICIENCY: A CASE STUDY OF WHEAT FARMERS IN BANGLADESH

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ABSTRACT

Environmental conditions significantly affect production, but are often ignored in studies analysing productivity and efficiency leading to biased results. In this study, we examine the influence of selected environmental factors on productivity and efficiency in wheat farming in Bangladesh. Results reveal that environmental production conditions significantly affect the parameters of the production function and technical efficiency, as well as correlates of inefficiency. Controlling for environmental production conditions improves technical efficiency by 4 points (p<0.01) from 86% to 90%. Large farms are more efficient relative to small and medium sized farms (p<0.01 and 0.05), with no variation among regions. Policy implications include, soil fertility improvement through soil conservation and crop rotation, improvement in managerial practices through extension services and adoption of modern technologies, promotion of education, strengthening the research-extension link, and development of new varieties that have higher yield potential and are also suitable for marginal areas.

Keywords: Stochastic production frontier, environmental conditions, wheat, Bangladesh

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1. Introduction

Agriculture is characterized by its environmental, behavioural, and policy dimensions (Clapham, 1980). Agricultural intensification, particularly the adoption of modern agricultural technology (e.g., chemical fertilizers, pesticides, etc.), is often blamed for contamination of water, loss of genetic diversity and deterioration of soil quality (Pretty, 1995). However, some of the most significant environmental problems in resource poor areas, such as, soil degradation, biocide resistance in pests, adverse weather, can in turn affect agricultural production systems directly as well (Clapham, 1980). Farmers' production performance does not only depend on the physical resources and technology available to them, but also on existing environmental production conditions. On the one hand, Schultz's (1964) hypothesis claims that small farmers are rational and economically efficient given their level of resources and technologies. On the other hand, studies examining farming efficiency in developing countries refute the validity of Schultz's thesis and place production efficiency levels within a range of 60 – 82% irrespective of crop types and regions (e.g., Rahman, 2003; Coelli et al., 2002; Wang et al., 1996; Battese and Coelli, 1995; Ali and Flinn, 1989). Sherlund et al., (2002) claim that the prevalence of inefficiency among small farmers may partly be due to the consistent omission of variables representing environmental production conditions in the myriad of efficiency studies conducted over the past three decades. They demonstrate three consequences arising from omission of potentially relevant environmental variables. The first consequence is the omitted variable bias, because the environmental variables are arbitrarily omitted. The second consequence is that the omitted variable bias is absorbed in the composite error (v – u) and hence carried on to the efficiency score which is computed from the non-negative u term. The third and final consequence is that the determinants of inefficiency are regressed on an already biased estimate of technical efficiency score providing biased results (for details, see Sherlund et al., 2002).

In this study, we adopt the framework of Sherlund et al., (2002) to examine the impact of environmental production conditions on the performance of wheat production in Bangladesh. There are two reasons for adopting this framework. The first reason is that wheat production is gaining momentum in Bangladesh and the crop is relatively more sensitive to variations in environmental conditions as well as managerial factors as compared to rice production. The second reason is that, production environment differ largely between Cote d'Ivoire and Bangladesh in terms of topography, climate, land and soil conditions. Therefore, adoption of this framework provides an opportunity to evaluate performance of wheat production using a broader framework, as well as corroborate or contrast the findings of Sherlund et al., (2002), as it is applied to a different crop produced in a different production environment. Furthermore, in order to explain efficiency differentials among farmers, we utilize an elaborate set of managerial variables that are unique and critical in wheat production, but have not been reported in the existing literature on efficiency studies.

Wheat in Bangladesh

Bangladesh, traditionally a food deficit country dominated by rice production, also depended on wheat imports immediately after becoming an independent nation in 1971 which continued well into the late 1980s. This injection of wheat through imports gradually resulted in a change in dietary habits. As a result, wheat consumption now became an important supplement of rice. Also, wheat acreage now ranks second after rice area. The wheat area increased from 126,000 ha in 1971 to 832,000 ha in 2000 resulting in an increase in production from 103,000 tons to 1.84 million tons during the same period. Yield level also grew at an estimated 2.6% per annum increasing from 860 kg/ha in 1971 to 2.2 t/ha in 2000. According to the Bangladesh Soil Survey report, an estimated 3.1 million hectares are suitable for wheat (Hossain, 1985). During the early 1990s, a comprehensive review of food policy in Bangladesh dismissed wheat as a competitive crop in terms of economic and social profitability (Mahmud et al., 1994). However, it was later realised that wheat provides highest returns in non-irrigated zones and in areas that are unsuitable for *Boro* rice (dry winter irrigated rice) and represents the most efficient use of domestic resources when inputs and outputs are assigned economic prices (Morris et al., 1996). One unique feature of wheat in Bangladesh is 100% adoption of modern varieties as opposed to rice. Despite four decades of policy designed to increase the diffusion of modern rice technology, only 61% of the rice area is currently planted with modern varieties. Also, the use rate of modern inputs in wheat production is very high. For example, all our sample farmers used chemical fertilizers and supplementary irrigation. Nevertheless, OFRD (2001) reports that there is still a yield gap of 41 – 61% between farmers' practice and recommended package of the research station. Wheat yield with recommended package is 3.2 t/ha whereas actual production at farm level varies between 1.3 to1.9 t/ha. Nevertheless, best practice farmers can produce 2.8 t/ha when compared with 1.9 t/ha by the average farmer, thereby, revealing a 29% yield gap (Hasan, 2005). Such a yield gap between best practice farmers and average farmers amounts to a loss of 25% of gross margin (Tk. 9875/ha or US$169/ha). Therefore, considerable scope exists to improve the productivity performance of the average farmers. One way to assess the extent of such scope is to empirically estimate technical efficiency in wheat production and its determinants. Studies on wheat efficiency in Bangladesh are highly limited (e.g., Karim et al., 2003), when compared with other developing countries, such as Pakistan (Battese et al., 1996), India (Singh, et al, 2004) and Iran (Bakhsoodeh and Thomson, 2001).

The paper proceeds as follows. The next section describes the analytical framework, study areas and the data. Section 3 presents the results. The final section concludes and draws policy implications.

2. Research Methodology

Analytical framework

The stochastic production frontier approach, developed by Aigner et al., (1977), is utilized in this study. We extend the framework and include variables representing environmental production conditions in addition to physical inputs to explain productivity performance as described by Sherlund et al, (2002). The stochastic production frontier for the *i*th farmer is written as:

$$Y_i = f(X_i, W_i) - u_i + v_i, \quad (1)$$

where Y_i is the output, X_i is the vector of physical inputs, W_i is the vector of relevant environmental variables that control production conditions, v_i is assumed to be independently and identically distributed $N(0,\sigma^2_v)$ two sided random error, independent of the u_i; and the u_i is a non-negative random variable $(u_i \geq 0)$, associated with inefficiency in production which is assumed to be independently distributed as truncation at zero of the normal distribution with mean $-Z_i\delta$, and variance σ_u^2 $(|N(-Z_i\delta, \sigma^2_u|)$, where Z_i are the correlates of inefficiencies on farm *i*. In this formulation, output is assumed to be strictly monotonically increasing in both physical inputs as well as environmental conditions. Most studies in the literature typically estimate:

$$Y_i = g(X_i, W_i^*) - u_i^* + v_i^*, \quad (2)$$

where $W_i^* \subseteq W_i$, which omits some or all of the elements of W_i, and, therefore, results in biased estimates of the parameters of the production function, overstatement of technical inefficiency, as well as biased correlates of inefficiency (Sherlund et al., 2002).

In determining the predictors of production efficiency, we use the single stage approach proposed by Battese and Coelli (1995) wherein the technical inefficiency parameter is related to a vector of farm-specific managerial and household characteristics subject to statistical error, such that:

$u_i = Z_i\delta + \zeta_i \geq 0$, (3)

where, Z_i are the farm-specific managerial and household characteristics and the error ζ_i is distributed as $\zeta_i \sim N(0, \sigma_\zeta^2)$. Since $u_i \geq 0, \zeta_i \geq -Z_i\delta$, so that the distribution of ζ_i is truncated from below at the variable truncation point, $-Z_i\delta$.

The production efficiency of farm *i* in the context of the stochastic frontier production function is defined as:

$$EFF_i = E[\exp(-u_i) \mid \xi_i] = E[\exp(-\delta_0 - \sum Z_i\delta \mid \xi_i) \quad (4)$$

where *E* is the expectation operator. This is achieved by obtaining the expressions for the conditional expectation u_i upon the observed value of ξ_i, where $\xi_i = v_i - u_i$. The method of maximum likelihood is used to estimate the unknown parameters, with the stochastic frontier and the inefficiency effects functions estimated simultaneously. The likelihood function is expressed in term of the variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$ (Battese and Coelli, 1995).

Selection of the study area and sample farmers

Wheat is cultivated almost all over the country, though the intensity of planted area and land suitability are not equal in all regions. Therefore, we computed a wheat area index for each greater district[2]. The wheat area index for the *j*th district is expressed as:

$WI_j = (Area_j / GCA_j) * 100$, (5)

where *WI* is the wheat area index, *Area* is the wheat area and *GCA* is the gross cropped area. Based on this index, wheat growing regions were classified into three levels of intensity: high intensity (WI>8.0), medium intensity (4.01<WI<8.0), and low intensity areas (WI<4.0).

[2] Although there are 64 districts in Bangladesh, most secondary data are still reported at the level of these 21 former greater districts.

A multistage sampling procedure was adopted to select the sample farmers. First, three wheat growing regions (two from high intensity areas – Dinajpur and Rajshahi, and one from medium intensity areas – Jamalpur) were selected purposively[3]. The selected three districts/regions[4] together cover 31% of the total wheat area of the country (Table 1). Also, each selected district belonged to different agro-ecological zones (AEZ) of Bangladesh, namely, AEZ-3, AEZ 11 and AEZ-9, respectively[5]. Dinajpur is located in the north-west, Rajshahi in the mid-west and Jamalpur in the mid-north of Bangladesh. In the second stage, one *upazila* (sub-district) from each district and one union from each *upazila* were selected at random. Next, three *mouzas* (one from each union) were selected at random for primary data collection from farm households. However, due to an insufficient number of households in one *mouza*, a fourth *mouza* was also selected at random to fulfil the required sample size. In the third stage, a number of steps were followed to select the households to ensure a high level of representation. At first, a sampling frame of wheat growing holdings was constructed with the assistance of village leaders, record book at the union council office and other key informants. The list included the names of household heads and their land holdings in the selected *mouzas*. These farm holdings were then stratified into three standard farm-size categories commonly adopted in Bangladesh (e.g., Hossain, 1989). Then, a total of 293 wheat producing households were selected following a stratified random sampling procedure. Two sets of structured questionnaires were administered. These questionnaires were pre-tested prior to finalization. The survey covered wheat growing period from November 2003 to April

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[3] The low intensity area is excluded because it is assumed that wheat production has limited potential in these districts.

[4] In this study the term district and region are used interchangeably to emphasize the large spatial variation between our study areas.

[5] There are a total of 29 agro-ecological zones which cut across many of the 21 greater districts/regions.

2004.

[INSERT TABLE 1 HERE]

The empirical model

The general form of the Cobb-Douglas stochastic production frontier function is used[6]. In order to determine the consequences of omitting environmental production conditions, we estimated the production frontier 'with' and 'without' the environmental variables. Hence, the conventional specification which omits the W_i variables (as in equation 2) is written as:

$$\ln Y_i = \alpha_0 + \sum_{j=1}^{8} \alpha_j^* \ln X_{ij} + \sum_{j=1}^{2} \beta_j D_{ij} + \sum_{m=1}^{2} \tau_m R_{im} + v_i^* - u_i^* \qquad (6a)$$

and

$$u_i^* = \delta_0^* + \sum_{d=1}^{13} \delta_d^* Z_{id} + \zeta_i^* \qquad (6b)$$

where Y_i is the wheat output (including grain equivalent of straw output); X_{ij} is jth input for the ith farmer; D_{ij} are the dummy variables used to account for the zero values of input use and have the value of 1 if the jth input used is positive and zero otherwise[7]; R_{im} is the dummy variable for districts, v_i is the two sided random error, u_i is the one sided half-normal error, *ln* natural logarithm, Z_{id} variables representing managerial and socio-economic characteristics of the farm to explain inefficiency, ζ_i is the truncated random variable; α_0, α_j, β_j, τ_m, δ_0, and δ_d are the parameters to be estimated.

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[6] We did not use the translog model because of the limited sample size and the large number of explanatory indicators. Moreover, Kopp and Smith (1980) suggest that the choice of functional form has a limited effect on technical efficiency. Consequently, the Cobb-Douglas specification is widely used in studies (e.g., Rezitis et al., 2002; Xu and Jeffrey, 1998).

[7] In this study, inputs that contain zero values for some observations are specified as $\ln \{\max (X_j, 1 - D_j)\}$ following Battese and Coelli (1995).

Similarly, the full specification including variables representing environmental production conditions (i.e., Equation 1) is written as:

$$\ln Y_i = \alpha_0 + \sum_{j=1}^{8} \alpha_j \ln X_{ij} + \sum_{j=1}^{2} \beta_j D_{ij} + \sum_{k=1}^{7} \varphi_k E_{ik} + \sum_{m=1}^{2} \tau_m R_{im} + v_i - u_i \qquad (7a)$$

and

$$u_i = \delta_0 + \sum_{d=1}^{13} \delta_d Z_{id} + \zeta_i \qquad (7b)$$

where, E_{ik} are the environmental production condition variables, and φ_k is the parameter to be estimated. All other variables as defined earlier.

A total of eight production inputs (X), seven environmental production condition variables (E), and two regional dummies (R) are used in the full specification, and 13 variables representing managerial and socio-economic characteristics of the farmer (Z) are included in the inefficiency effects model as predictors of technical inefficiency in both short and full specifications. Table 2 presents the definitions, units of measurement, and summary statistics for all the variables.

[INSERT TABLE 2 HERE]

3. Results

From the information provided in Table 2, we can see that average farm size is very small (0.13 ha). Land type is in the suitable range whereas soil type is of average quality. Variables representing environmental production conditions are non-zero ($p<0.01$). The average age of the farmers is 47 years with 16 years of experience in growing wheat, education is less than five years, 61% used mechanical power services, extension link is relatively high (13.4 times in a year), farmers are exposed to at least two sources of agricultural information, and only 14% received training on wheat production in the past 5 years.

Environmental production conditions and production inputs

The assumption underlying the inclusion of environmental production conditions in estimating the parameters of the production frontier is that they are exogenously determined. Furthermore, if these variables are asymmetrically distributed, then their omission will lead to upward bias in the estimates of firm specific technical inefficiency. The assumption of exogeneity of these variables can be challenged, as weed and pesticide infestations or poor soil fertility could be improved in the long run by adding more labour or by adopting soil conservation measures. However, the production scenario in Bangladesh is dominated by usufruct tenurial arrangement wherein tenants have little or no incentive to invest in conservation measures since benefits accruing from such activities are simply unrealizable and uncertain due to high insecurity of tenure. On the other hand, weather (e.g., storm, flood, drought, rainfall, etc.) is truly exogenous, and the variables 'soil types' and 'land types' are quasi-fixed in nature. So, the suite of variables chosen to control for environmental production conditions includes the truly exogenous (e.g., weather), quasi-fixed characteristics (e.g., soil types and land types) as well as combinations of exogenous shocks and managerial response (e.g., pest and weed infestation). Table 3 presents the results of the correlation between production inputs and the environmental variables. The strength of correlation is relatively weak but half of the relationships are non-zero ($p<0.01$ to $p<0.10$). Sherlund et al., (2002) also reported similar strong correlation, thereby making a valid case for the need to control for environmental production conditions while examining farmers' production performances.

[INSERT TABLE 3 HERE]

Productivity effects of environmental production conditions

Parameter estimates for both short and full specification are reported in Table 4 using the Maximum Likelihood Estimation (MLE) procedure in STATA Version 8 (STATA Corp, 2003). First we checked the sign of the third moment and the skewness of the Ordinary Least Squares (OLS) residuals of the data in order to justify the use of the stochastic frontier framework (and hence the MLE procedure)[8]. The computed value of Coelli's (1995) standard normal skewness statistic (M3T) based on the third moment of the OLS residuals are -2.997 ($p<0.001$) and -2.100 ($p<0.013$) tested against H_0: M3T = 0 in both the short and the full model, respectively. In other words, the null hypothesis of no inefficiency component is strongly rejected for both models and, therefore, the use of the stochastic frontier framework is justified. The result of the Likelihood Ratio (LR) test of γ reported in Table 5 also strongly suggests presence of technical inefficiency.

The statistical superiority of the full specification is apparent from the LR test statistic of 60.04 ($p<0.000$) tested against the $\chi^2(7)$ distribution based on Log Likelihood values reported in Table 4. Two of the production input variables, herbicides and cow-dung, recorded large numbers of zero observations, and therefore, corrected with dummy variables as mentioned in Footnote 7. As expected, land is the most dominant input followed by fertilizers, labour, irrigation, and animal/mechanical power services in both specifications. The test of hypotheses that environmental variables are jointly zero in the full specification is rejected indicating environmental production conditions significantly affect productivity as expected[9] (Table 5). Poor land types, delay in sowing and poor soil quality significantly reduce productivity. The omission of variables representing environmental production conditions also affects estimates of the production function itself. For example, the output elasticity of wheat increases by 4.9% than it is under conventional specification[10]. On the other hand the elasticity of fertilizers declines by 27.7%. Once one controls for the

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[8] In the stochastic frontier framework, the third moment is also the third sample moment of the u_i. Therefore, if it is negative, it implies that the OLS residuals are negatively skewed and technical inefficiency is present.

[9] The LR test reported earlier also effectively tested the same hypothesis.

[10] Since the Cobb-Douglas model is used, the parameter estimates of the production inputs can be directly read as production elasticities.

environmental production conditions, the role of fertilizer input becomes less responsive to productivity increases. Sherlund et al., (2002) also reported a high positive response of rice output by 20% and drastic fall in inputs of labour by almost 70% when they controlled for environmental production conditions for Cote d'Ivoire rice farmers. However, the hypothesis of constant returns to scale in wheat production cannot be rejected in both specifications (Table 5) implying that wheat output can be increased proportionately at the same rate with increases in input quantities. It also implies that the wheat farmers are operating at an optimal scale. This finding is encouraging because in contrast, decreasing returns to scale is often reported for rice production in Bangladesh (e.g., Wadud and White, 2000; Asadullah and Rahman, forthcoming), implying that the rice farmers are not operating at an optimal scale.

[INSERT TABLES 4 and 5 HERE]

Production efficiency

Controlling for environmental production conditions improves technical efficiency by 4 points ($p<0.01$), thereby validating the claim that inefficiency is overstated when these variables are omitted (Table 6). The main improvement is at the lower end of the distribution (Figure 1). For example, the minimum technical efficiency score under the short specification is 55.2% while under the full specification it is 64.9%, a 17.5% improvement (Table 6). In the short specification, 22.5% of farmers are operating below the 70% efficiency level, whereas under the full specification the figure falls to only 8.2%. Sherlund et al, (2002) reported much larger improvements in mean technical efficiency for rice farmers from 36% to 77% when they controlled for environmental production conditions. The mean technical efficiency level in wheat production is estimated at 90% which implies that production can be increased by 10.6% [{(0.902–1.00)/0.902}*100] with efficiency improvements. The mean estimate exactly matches with that of Karim et al., (2003) and is also comparable to estimates in other developing countries. For example, technical efficiency in wheat production varies between

57.0% – 78.9% in Pakistan (Battese et al., 1996), 81.0 – 93.4% in India (Singh, et al, 2004) and 91.0 – 93.0% in Iran (Bakhsoodeh and Thomson, 2001), respectively.

[INSERT TABLE 6 and FIGURE 1 HERE]

Efficiency effects of environmental production conditions

The omission of the environmental production conditions also significantly affects the correlates of inefficiency (see lower panel of Table 4). Although, the parameter estimates are broadly similar across both regressions, the effects are intuitively more precise under the full specification. The hypotheses that the managerial variables are jointly zero are rejected for both specifications (Table 5). Technical efficiency in wheat farming is highly sensitive to managerial factors. For example, failure to sow on time, delay in the first application of fertilizer and selection of poor quality seeds significantly decrease efficiency. On the other hand, education and agricultural information sources significantly increase efficiency. The expected effect of training in increasing efficiency is also consistent with theory but the coefficient is not significantly different from zero. Use of modern technology, i.e., mechanical power services instead of animal power, significantly improves efficiency.

Efficiency increases with size of operation. The middle panel of Table 6 provides information on the mean technical efficiency scores by farm-size categories. It is obvious from Table 6 that large farms operate at the highest level of efficiency when compared with medium and small farms. The reason that large farmers are more efficient in wheat farming is due to better education, higher level of modern technology adoption, better managerial practices, and extension facilities (Table 7). Table 7 clearly shows that the use of mechanical power services, mechanical ploughing and irrigation are higher for large farmers. The timing of fertilizer application is nearly optimal, although first weeding is relatively late. Also, 22% of large farmers received training on wheat production over the past 5 years. The mean education level is well above primary level (7.5 years of schooling) with 18.1 years of experience in wheat production. All these factors have contributed to a significantly higher level of technical efficiency of large farmers when compared with medium and small farmers. The computed F-test statistics prove the results (Table 7).

[INSERT TABLE 7 HERE]

4. Conclusions and policy implications

The present study examined the impact of environmental production conditions on the production performance of wheat producers in Bangladesh. The environmental production conditions, within which the farmer operates, are considered vital but are often arbitrarily omitted in productivity and efficiency studies, resulting in biased estimates of the production parameters, efficiency scores and correlates of inefficiency. Our results demonstrate the validity of this claim for Bangladeshi wheat farmers. Poor land type, poor soil fertility and delay in sowing results in significant production loss. Controlling for environmental production conditions improves technical efficiency by 4 points ($p<0.01$) from 86% to 90%. Farmers' managerial practices, particularly, timely sowing and fertilizer application, use of mechanical power, higher education and diverse sources of agricultural information, all significantly improve efficiency. Nevertheless, scope to raise wheat production remains limited with the existing set of varieties and technologies because farmers have already adopted 100% percent of popular modern varieties and are also producing at a high level of efficiency (90%).

The results of our study has significant policy implications as it demonstrates the need to evaluate farmers' production performance using an extended framework of analysis, that takes into account the environmental production conditions within which farmers have to operate. Otherwise, the upward bias of inefficiency measures, widely reported in the literature, would lead to a redirection of scarce resources to less than optimal uses. Also, in modelling predictors of inefficiency, it is important to use an elaborate set of variables, particularly managerial variables unique to each crop studied, so that management factors that directly affect production performance can be addressed through policy redressing.

Furthermore, based on the results of our study, a number of specific policy implications can be drawn. First, soil fertility improvement seems essential to raise productivity. This may be addressed through adopting soil conservation practices and/or improving crop rotation practices (e.g., including soil health enhancing crops, such as pulses and oilseeds, in the system). Of the nine total cropping patterns observed among the sample farmers, most followed rice-based cropping. Only two patterns included jute in the system and none included any pulse or oilseed crops, which is potentially highly detrimental to soil health in the long run. Second, is the improvement in managerial practices (e.g., timely sowing and fertilizer application) and the use of modern technology (e.g., mechanical power services and irrigation). These can be addressed through strengthening agricultural extension services and improvements in rural infrastructure. Third, promotion of education above primary level for the farming population seems crucial. Our results show that the large farmers who are educated above primary level and have relatively higher access to modern resources, services and skills are performing significantly better. Asadullah and Rahman (forthcoming) also noted that farmers who complete secondary schooling enjoy significant efficiency gains. Fourth, is to improve existing research-extension link. Currently, new varieties that are developed remain confined at the research stations. Dominance of only one variety at the farm-level which was released 21 years ago[11], clearly points towards the need to develop the research-extension link. Finally, our study shows that poor land type significantly reduces productivity. Therefore, research effort should be geared towards developing varieties that are suitable for marginal areas. Evidence suggests that wheat production in marginal

[11] Although 24 modern varieties of wheat have been released since 1974 (including three in 2005), 'Kanchan' released in 1983, remains the most popular choice. In fact, 94% of our sample farmers used only 'Kanchan'.

lands accounts for 25% of global production and that research innovation has led to significant improvement in yield growth in these areas, particularly in drought and high temperature environments (Lantican et al, 2003). The challenges to realize all of these policy options are formidable. However, a boost in wheat production could significantly curb dependence on rice as the main staple in Bangladeshi diet, which is a goal worth pursuing.

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Table 1. Selection of the study area and sample size

Study area	Area selection criteria			Farm size categories			
	Wheat area index (WI)	Intensity Rank (Out of 21 greater districts)	% of total wheat area	Large farms (2.0 ha and above)	Medium farms (1.01 to <2.0 ha)	Small farms (up to 1.0 ha)	All categories
Dinajpur	16.94	2	16	33 (92)	29 (86)	39 (122)	101 (300)
Rajshahi	9.12	4	11	19 (32)	32 (49)	52 (228)	103 (309)
Jamalpur	7.55	6	4	8 (11)	25 (46)	56 (178)	89 (235)
All area	-	-	31	60 (135)	86 (181)	147 (528)	293 (844)

Notes: Figures in parentheses indicate sampling frame.
Source: BBS (2000), and field survey, 2004.

Table 2. Definition, measurement and summary statistics of variables

Variables	Measure	Mean	Standard deviation	Minimum	Maximum
Inputs and output					
Wheat (includes grain equivalent of straw)	Kg per farm	655.5495	346.414	120.00	2265.00
Land cultivated	Hectare	0.13	0.06	0.03	0.41
Labour	Persons	13.35	6.23	3.95	44.25
Fertilizers	Kg of active nutrients (N, P, K, and S)	19.28	9.85	2.76	60.90
Draft/mechanical Power	Taka	289.12	158.32	58.58	870.09
Irrigation	Taka	22.25	8.15	5.00	60.00
Seed	Kg	21.67	11.28	5.50	77.00
Herbicides	Taka	10.38	26.24	0.00	160.00
Cow dung	Kg	175.49	298.84	0.00	2000.00
Environmental production conditions					
Land type	Indexed (1 = Medium high land – most suitable; 2 = High land – suitable; 3 = Low land – not suitable)	1.49	0.74	1.00	3.00
Soil type	Indexed (1 = loamy – good; 2 = sandy loam – average; 3 = clay loam – poor)	1.86	0.71	1.00	3.00
Weed infestation[a]	Indexed (1 = 1 – 10%, 2 = 11 – 20% of crop yield)	0.73	0.53	0.00	2.00
Pest infestation[a]	Indexed (1 = 1 – 10%, 2 = 11 – 20% crop yield)	0.80	0.49	0.00	2.00
Weather[a]	Indexed (1 = 1 – 10%, 2 = 11 – 20%, 3 = 21 – 30%, 4 = 31 – 40% of crop yield)	0.69	0.68	0.00	4.00
Late sowing[a]	Indexed (1 = 1 – 10%, 2 = 11 – 20% of crop yield)	0.68	0.80	0.00	2.00
Soil fertility[a]	Indexed (1 = 1 – 10%, 2 = 11 – 20%, 3 = 21 – 30% of crop yield)	0.50	0.81	0.00	3.00
Other variables					
Jamalpur region	Dummy (1 = Yes, 0 = No)	0.35	0.48	0.00	1.00
Rajshahi regions	Dummy (1 = Yes, 0 = No)	0.30	0.46	0.00	1.00
Cow dung users	Dummy (1 = Used cow dung, 0 = No)	0.41	0.49	0.00	1.00

Variables	Measure	Mean	Standard deviation	Minimum	Maximum
Weedicide users	Dummy (1 = Used weedicides, 0 = No)	0.17	0.38	0.00	1.00
Managerial variables					
Age of the farmer	Years	46.99	12.08	19.00	80.00
Education of the farmer	Completed years of schooling	4.88	4.12	0.00	14.00
Experience in wheat farming	Years of growing wheat	16.14	6.23	4.00	30.00
Sowing date[b]	Indexed (1 = if sown during optimum time, i.e., November 15 – 30th, 2 = slightly late, 1 – 7th December, 3 = moderately late, 8 – 14th December, 4 = extreme late, 15 – 30th December)	2.11	0.94	1.00	4.00
Timing of first top-dressing of urea fertilizer[c]	Indexed (1 = 10 – 21 DAS [days after sowing], 2 = 22 – 28 DAS, 3 = 29 till maximum DAS)	1.22	0.44	1.00	3.00
Timing of first weeding[c]	Indexed (1 = 16 – 21 DAS, 2 = 22 – 28 DAS, 3 = 29 – 35 DAS, 4 = no weeding at all)	3.26	1.17	1.00	4.00
Timing of first irrigation[c]	Indexed (1 = 15 – 21 DAS, 2 = 22 – 28 DAS, 3 = 29 – 35 DAS, 4 = 36 – 42 DAS, 5 = 43 – 60 DAS or no irrigation)	1.57	1.08	1.00	5.00
Mechanical power	Dummy (1 = Used, 0 = No)	0.61	0.49	0.00	1.00
Source of procuring seed	Indexed (1 = Research centre or BADC – good source, 2 = Own processed – average, 3 = Local market or neighbour – poor)	2.17	0.63	1.00	3.00
Link with extension services[d]	Frequency of contact in the past year (number)	13.84	16.50	0.00	42.00
Sources of agricultural information[e]	Number of sources	2.11	0.97	0.00	5.00
Training	Dummy (1 = received training on wheat production in the past 5 years, 0 = No)	0.14	0.35	0.00	1.00
Wheat area	Amount of land under wheat	0.13	0.06	0.03	0.41
Total number of observations		293			

Note:

[a] = figures are based on farmer's own account of his/her crop loss due to each specific factors.

[b] = wheat cultivation is very sensitive to sowing date. The optimum time of planting is November 15 – 30th. Failure to sow wheat by November 30th reduces crop yield by an estimated 1.3% per day.

[c] = to ensure optimum production of wheat, three operations need to be done simultaneously in the first spell. These are, applying first irrigation, first weeding and first top-dressing of urea fertilizer, all within 17 – 21 days after sowing.

[d] = information was collected on the nature of extension link: 0 = no link, 1 = weekly contact, 2 = fortnightly, 3 = monthly, 4 = quarterly. The information was then converted into frequencies in one year using: quarterly = 4 times, monthly = 12 times, fortnightly = 24 times (deducted two weeks to account for official holidays), and weekly = 42 times (deducted 10 weeks to account for official holidays and other missing days).

[e] = figures are number of sources that the farmers reported as his/her sources of information. A total of six sources were recorded. These are: electronic media (radio/television), block supervisor (lowest unit of extension service), NGO, neighbours, printed media (e.g., leaflets), and fertilizer/pesticide dealer.

Table 3. Correlation among inputs and environmental production conditions

Environmental production conditions	Production inputs							
	Land	**Labour**	**Animal/mechanical power**	**Fertilizer**	**Seed**	**Irrigation**	**Herbicides**	**Cow dung**
Land type	0.004	-0.031	-0.176***	-0.073	-0.059	0.025	-0.160***	-0.103*
Soil type	0.018	-0.007	-0.067	-0.029	-0.157***	0.025	-0.169***	-0.064
Weed infestation	0.134**	0.084	0.114**	0.224***	0.048	0.163***	0.083	0.075
Pest infestation	0.116**	0.042	0.098*	0.149	0.036	0.137**	0.126**	0.170***
Weather	-0.208***	-0.193***	-0.202***	-0.115***	-0.076	-0.227***	0.006	-0.331***
Late sowing	0.026	0.006	-0.168***	-0.130**	-0.038	0.005	-0.126**	-0.075
Soil fertility	-0.031	-0.041	-0.254***	-0.236***	-0.053	-0.055	-0.218***	-0.151***
Number of observations	293	293	293	293	293	293	293	293

Note: *** significant at 1 percent level (p<0.01)
** significant at 5 percent level (p<0.05)
* significant at 10 percent level (p<0.10)

Table 4. Maximum likelihood estimates of production frontier

Variables	Parameters	Without environmental variables		With environmental variables	
		Coefficient	t-ratio	Coefficient	t-ratio
Production function					
Constant	α_0	6.545	19.27***	6.798	14.72***
ln Land	α_1	0.618	9.23***	0.648	7.17***
ln Labour	α_2	0.070	1.95**	0.088	1.87*
ln Fertilizer nutrients	α_3	0.166	6.64***	0.120	4.64***
ln Animal/mechanical power	α_4	0.043	2.49***	0.037	1.88*
ln Irrigation	α_5	0.088	7.81***	0.071	6.84***
ln Seed	α_6	0.008	0.19	0.022	0.52
ln Herbicides	α_7	0.015	0.64	0.014	0.60
ln Cow dung	α_8	-0.007	-0.53	-0.007	-0.54
Cow dung users	β_1	0.071	0.91	0.059	0.73
Weedicide users	β_2	-0.035	-0.38	-0.048	-0.52
Land type	φ_1	-	-	-0.023	-3.02***
Soil type	φ_2	-	-	0.002	0.26
Weed infestation[a]	φ_3	-	-	-0.012	-1.01
Pest infestation[a]	φ_4	-	-	0.009	0.89
Weather[a]	φ_5	-	-	-0.009	-1.20
Late sowing[a]	φ_6	-	-	-0.018	-2.01**
Soil fertility[a]	φ_7	-	-	-0.047	-5.70***
Jamalpur region	τ_1	-0.022	-1.11	-0.022	-1.08
Rajshahi region	τ_2	0.026	0.86	-0.004	-0.15
Variance parameters					
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	σ^2	0.007	7.50***	0.006	5.16***
$\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$	γ	0.762	7.13***	0.603	4.28***
Log likelihood		348.43		378.45	
Inefficiency effects function					
Constant	δ_0	-0.034	-0.47	0.013	0.16
Age of the farmer	δ_1	0.001	0.78	0.001	0.80

Variables	Parameters	Without environmental variables		With environmental variables	
		Coefficient	t-ratio	Coefficient	t-ratio
Education of the farmer	δ_2	-0.006	-3.74***	-0.006	-2.68***
Experience in wheat farming	δ_3	0.000	-0.03	-0.001	-0.53
Sowing date[b]	δ_4	0.089	7.36***	0.056	2.81***
Timing of first top-dressing of urea fertilizer[c]	δ_5	0.042	2.63***	0.038	2.20**
Timing of first weeding[c]	δ_6	0.000	-0.02	0.016	1.41
Timing of first irrigation[c]	δ_7	-0.011	-1.60	-0.016	-1.46
Mechanical power	δ_8	-0.027	-1.20	-0.052	-2.36**
Source of procuring seed	δ_9	0.027	2.62***	0.015	1.45
Link with extension services	δ_{10}	0.000	-0.47	0.000	-0.61
Sources of agricultural information	δ_{11}	-0.016	-1.82*	-0.017	-1.68*
Training	δ_{12}	-0.031	-1.42	-0.018	-0.80
Wheat area	δ_{13}	-0.344	-1.57	-0.496	-1.74*
Total number of observations		293		293	

Note: *** significant at 1 percent level ($p<0.01$)
** significant at 5 percent level ($p<0.05$)
* significant at 10 percent level ($p<0.10$)

Table 5. Tests of hypotheses

Hypothesis	Critical value of $\chi^2(v, 0.99)$	Without environmental variables		With environmental variables	
		LR statistic	Decision	LR statistic	Decision
No effect of environmental variables on productivity (H_0: $\varphi_1 = \varphi_2 = \ldots. = \varphi_7 = 0$)	18.48	—	_	69.10***	Reject H_0
Presence of inefficiency (H_0: $\gamma = 0$)	6.64	7.13***	Reject H_0	4.27**	Reject H_0
No effect of managerial variables on inefficiency (H_0: $\delta_1 = \delta_2 = \ldots. = \delta_{13} = 0$)	27.69	100.52***	Reject H_0	40.78***	Reject H_0
Constant returns to scale in production (H_0: $\alpha_1 + \alpha_2 + \ldots. + \alpha_8 = 1$)	20.09	0.01	Accept H_0	0.04	Accept H_0

Note: In testing (H_0: $\gamma = 0$) in the full model, the critical value of $\chi^2_{(1,0.95)}$ wa used which is 3.84.
*** significant at 1 percent level (p<0.01)
** significant at 5 percent level (p<0.05)

Table 6. Technical efficiency estimates with and without environmental production condition variables

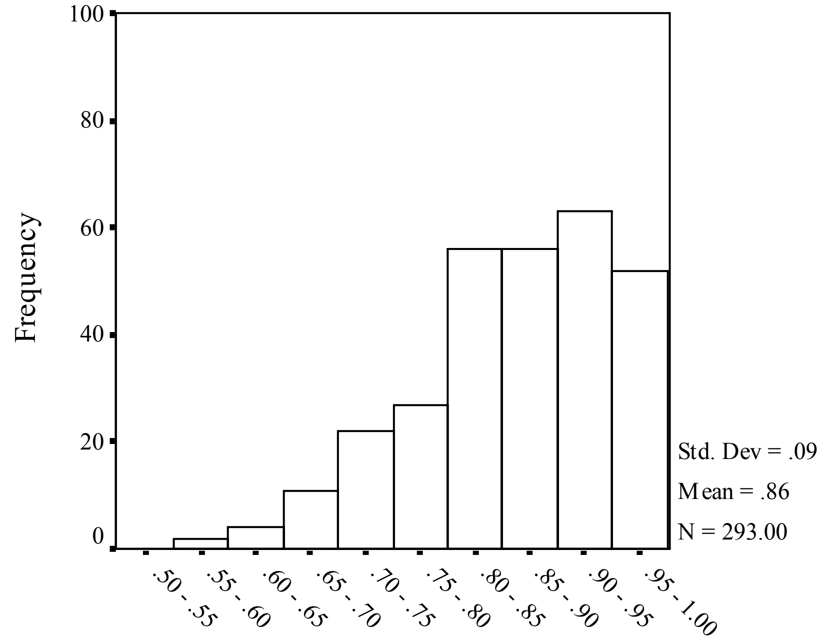
Items	Without environmental production condition variables	With environmental production condition variables
Efficiency levels		
up to 60%	0.68	-
61 – 70%	5.12	0.68
71 – 80%	16.72	7.51
81 – 90%	38.22	34.81
91% and above	39.26	57.00
Mean efficiency by farm size		
Large farms	0.898	0.935
Medium farms	0.856	0.902
Small farms	0.847	0.889
Overall		
Mean efficiency score	0.860	0.902
Standard deviation	0.09	0.07
Minimum	0.552	0.649
Maximum	0.989	0.990
t-test for difference in mean efficiency score between alternative models		0.042 (20.30)***

Note: Figure in parenthesis is the t-ratio.
*** significant at 1 percent level ($p<0.01$)

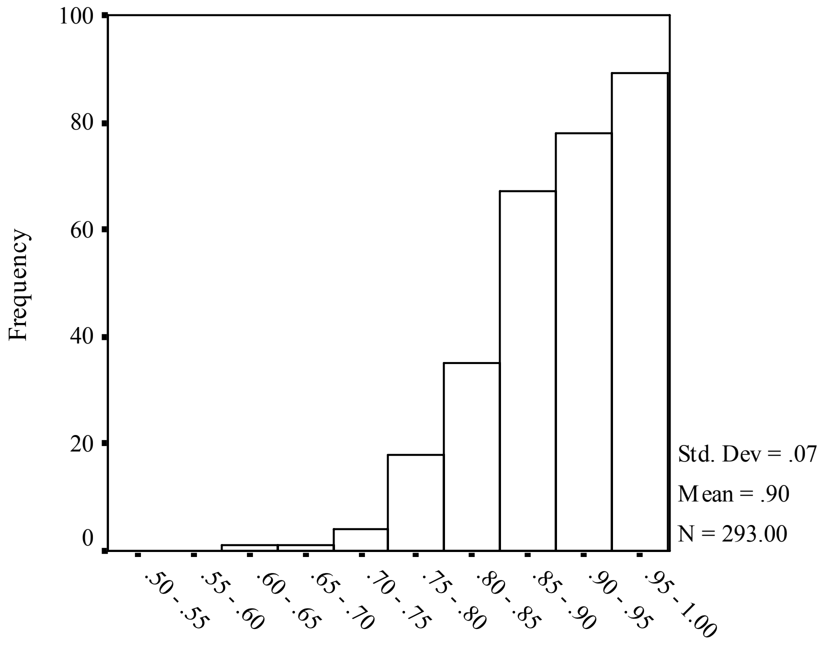
Table 7. Key managerial characteristics by farm-size categories

Managerial characteristics	Farm size categories			F-test[a] of differences across farm size categories
	Large farms (2.0 ha and above)	Medium farms (1.01 to <2.0 ha)	Small farms (up to 1.0 ha)	
Education (competed years of schooling)	7.45	4.35	4.14	16.27***
Wheat growing experience (years)	18.10	16.86	14.91	6.64***
Timing of first fertilization (index)	1.08	1.13	1.33	9.72***
Timing of first weeding (index)	3.62	3.21	3.15	3.61**
Number of irrigation (nos.)	1.83	1.49	1.40	9.17***
Mechanical power services (%)	0.78	0.62	0.54	5.28***
Number of mechanical ploughing (nos.)	3.47	2.84	2.47	6.92***
Sources of agricultural information (nos.)	2.23	2.08	2.07	0.66
Training in wheat production (%)	0.22	0.15	0.11	2.36*

Note: [a] = One-way ANOVA using the Generalised Linear Model (GLM).
*** significant at 1 percent level ($p<0.01$)
** significant at 5 percent level ($p<0.05$)
* significant at 10 percent level ($p<0.10$)



Technical efficiency (without environmental variables)



Technical efficiency (with environmental variables)

Figure 1. Technical efficiency scores under short and full specifications