Technical Efficiency in Bangladesh Rice Production
Are There Threshold Effects in Farm Size?

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Introduction

The inverse relationship between farm size and productivity, been found in the many empirical studies on agricultural productivity, especially in developing countries, has been a basis of distributive land reform policies in many countries. The legitimacy of this classical premise of inverse relationship has been questioned due to possible flaws in constructing productivity measures and the assumption of linearity in the farm size-productivity relationship.

This study investigates the farm size-productivity relationship in Bangladesh rice production using a comprehensive efficiency measure within the framework of threshold regression. The study entertains the hypothesis that the relationship may vary across farm categories, depending on the level of farm size. It is of particular interest for policy makers to 1) ascertain how farm size affecting total factor productivity (TFP) of Bangladeshi rice farmers, 2) test the existence of farm size thresholds and estimate the threshold values, if any, and 3) assess how and what factors influence farmers' productivities across farm size categories.

Methods

Output-oriented technical efficiency scores (as a measure of TFP) are estimated using Data Envelopment Analysis (DEA), which uses linear programming techniques to construct a piecewise linear frontier that envelopes the observed input and output data. To correct for an upward bias in the traditional DEA estimate, Simar and Wilson's (1998, 2000) bootstrapping method is employed. The bias-corrected technical efficiency scores are then regressed on a set of farm-specific variables to gain insight into how efficiency scores vary among Bangladeshi rice farmers. The equation is estimated using Hansen's (1996, 1999) threshold regression procedure, allowing for possible threshold effects in farm size (measured as area planted). With the farm size being the threshold variable, the coefficients of the farm-specific explanatory variables vary across regimes, as defined by the unknown thresholds.

Data

Data are collected from 960 farmers in 64 villages through surveys conducted in 2008 by Bangladesh Institute of Development Studies with the support from the World Bank. In the sample, 93.2% of farm households grew rice in the Boro season while 48.4% in the Aman season.

The output variable is "rice harvested" and it is measured in kilograms. Common inputs for both seasons are land planted (measured in hectares), own and hired labor (in days), fertilizer (in kilograms), and own and hired draft power (in days), while rice in boro season requires irrigation (Aman is rain fed). The draft power input includes both bullock and power tiller working days because, unlike previous studies, most farmers in the survey regions use power tillers for plowing. The farm-specific variables used for explaining the imputed technical efficiency scores includes: the area planted, the degree of land fragmentation in the household farm, the education level of the household head, the number of people in the household, the age of the household head, a rice variety index, and a land level index. Summary statistics of the variables are presented in table 1.

Table 1. Summary Statistics

Variable (Unit)	Aman Mean	Aman SD[a]	Aman Min.	Aman Max.	Boro Mean	Boro SD[a]	Boro Min.	Boro Max.
(a) Output and Inputs								
Rice Output (kg)	1459	3023	12	54760	2534	2710	40	26020
Land (ha)	0.42	0.50	0.006	5.44	0.45	0.47	0.006	4.71
Labor (day)	44.36	46.18	3.00	296	57.65	59.49	2.00	525
Fertilizer (kg)	108	145	0.00	1344	190	242	0	3546
Draft power (day)	12.45	11.44	1.00	105	11.49	9.17	0.00	86.00
Irrigation (taka)	n.a.	n.a.	n.a.	n.a.	5284	6104	0	51300
(b) Farm-specific variables								
Farm size (ha)	0.42	0.50	0.006	5.44	0.45	0.47	0.006	4.71
Fragment (number)	3.26	2.55	1.00	19.00	3.34	2.40	1.00	16.00
Education (number)	3.38	4.17	0.00	16.00	3.07	4.11	0.00	16.00
Family size (persons)	4.68	1.75	1.00	11.00	4.83	1.93	1.00	18.00
Age (years)	44.59	12.29	17.00	80.00	45.15	13.32	17.00	95.00
Crop variety (number)	0.82	0.37	0.00	1.00	0.77	0.40	0.00	1.00
Land level (number)	2.92	0.55	1.00	4.48	2.85	0.59	1.00	4.64
Observation		465				890		

[a] SD stands for standard deviation.

Estimation Results

Technical Efficiency Estimates

The kernel density estimates of the bias-corrected technical efficiency distributions for the Aman and Boro seasons and their summary statistics are reported in figure 1 and table 2, respectively. Note from figure 1 that the Aman season has fatter and longer tails than the Boro season. Further, the average bias-corrected technical efficiency score in the Aman season is a few percentage points smaller than that in the Boro season, reflecting the relative difficulties of farming due to monsoon rains and floods in the Aman season. The 95% confidence intervals for the average point estimates are rather tight, with the widths being ranging from 0.04 to 0.05. Note that the widths are slightly wider for more efficient famers and narrower for less efficient farmers as illustrated by the confidence intervals for the maximum and minimum point estimates.

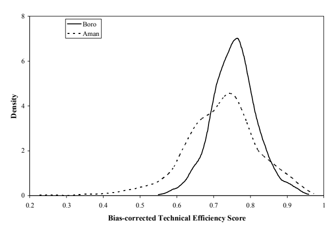

Figure 1. Kernel density estimates for bias-corrected technical efficiency distributions

Table 2. Estimated Technical Efficiency Score

	Aman Tech. Eff.	Aman Bias-corrected	Aman Lower bound[a]	Aman Upper bound[a]	Boro Tech. Eff.	Boro Bias-corrected	Boro Lower bound[a]	Boro Upper bound[a]
Average	0.760	0.721	0.702	0.753	0.785	0.756	0.742	0.781
Median	0.755	0.728	0.710	0.749	0.776	0.756	0.744	0.771
Std. Dev.	0.115	0.100	0.097	0.113	0.078	0.062	0.060	0.077
Min	0.265	0.250	0.243	0.261	0.580	0.563	0.548	0.578
Max	1.000	0.949	0.928	0.988	1.000	0.946	0.933	0.994

[a] The lower and upper bounds for the estimated 95% confidence intervals are reported.

Farm size-Productivity Threshold Estimation: Boro Season

Test results of threshold effects, threshold estimates, and regression coefficients for the Boro season are reported in table 3. Based on Hansen's (1999) sequential tests, one detects the presence of two thresholds, 0.332 and 0.959, with the associated 95% confidence intervals non-overlapping each other. The results indicate that sample farms can be divided into three categories based on farm size (i.e., area planted): small farms (below 0.33 ha), medium farms (between 0.33 ha and 0.96 ha), and large farms (above 0.96 ha). Note that the lower threshold of 0.33 ha is slightly above the sample median of 0.32 ha, while the upper threshold of 0.96 ha is close to the 90 percentile of the sample. All told, 52% of farm households fall in the class of 'small farms,' 38% in the 'medium farms' and 10% in the 'large farms.'

The regression coefficients in table 3 clearly indicate that the marginal effects of factors affecting rice productivity vary across farm size categories, demonstrating the importance of allowing for threshold effects of farm size (which is also an explanatory variable). The coefficient for the *Farm size* variable is statistically significant in each of the three size categories. Farm size has a very large positive impact on technical efficiency among the small size farms, with the effect being substantially lower for the medium size farms, and becomes negative for the large size farms. Rice farmers in the Boro season could improve their productivity holding up to nearly one ha, which is considered as a level for sustaining farmers' livelihood by Niroula and Thapa (2005).

Table 3. Threshold Technical Efficiency Model for Boro Rice

Null	Alternative	LR Statistic	Bootstrapped Critical Values 1%	5%	10%
No Threshold	One Threshold	140.15	27.55	24.02	21.82
One Threshold	Two Thresholds	30.83	28.60	23.68	21.22
Two Thresholds	Three Thresholds	10.55	28.83	23.15	21.00

Threshold parameters	Estimate	95% Confidence Intervals Lower Bound	Upper Bound
First threshold	0.332	0.247	0.384
Second threshold	0.959	0.656	1.093

Regression parameters

Variable	Small Farms Estimate[a]	Small Farms *t*-stat	Medium Farms Estimate[a]	Medium Farms *t*-stat	Large Farms Estimate[a]	Large Farms *t*-stat
Constant	72.321 ***	39.547	78.540 ***	34.517	95.179 ***	19.485
Farm size	35.798 ***	9.795	5.047 ***	2.664	-2.268 **	-2.528
Education	0.004	0.055	0.120	1.620	0.021	0.165
Fragment	-1.870 ***	-7.746	-0.520 ***	-3.540	0.058	0.283
Family size	-0.201	-1.284	-0.031	-0.206	-0.658 **	-1.964
Age	0.014	0.699	-0.014	-0.615	-0.136 ***	-2.583
Crop variety	0.081	0.123	1.935 **	2.567	1.438	0.890
Land level	-0.099	-0.222	-1.176 **	-2.240	-1.575 *	-1.664
Adjusted R-squared			0.19			
Heteroskedasticity test: $\chi^2(24)$			21.81 (*p*-value: 0.59)			

[a] The coefficients are scaled up by 100 for ease of presentation.
Note: The superscripts *, **, and *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Farm size-Productivity Threshold Estimation: Aman Season

The estimation results pertaining to the Aman rice is reported in table 4. Only one threshold (0.354) is identified, which is very close to the first threshold estimate for the Boro rice. Note that the threshold value of 0.35 ha is slightly below the 60 percentile of 0.36 ha, casting 275 farm households into the class of 'small farms,' and the remaining 190 households into the 'medium/large farms.'

Similar to the results for the Boro season, *Farm size* and land fragmentation (*Fragment*) have significant positive and negative impacts, respectively. Unlike the case of Boro season, *Education* has significant and positive effect on productivity for the medium/large farmers. It is plausible that education contributes to a better understanding of how to cultivate and manage medium/large size farms during the punishing monsoon (Aman) season.

Table 4. Threshold Technical Efficiency Model for Aman Rice

Null	Alternative	LR Statistic	Bootstrapped Critical Values 1%	5%	10%
No Threshold	One Threshold	102.85	29.69	25.28	23.17
One Threshold	Two Thresholds	22.94	31.32	25.92	24.04

Threshold parameters	Estimate	95% Confidence Intervals Lower Bound	Upper Bound
First threshold	0.354	0.164	0.571

Regression parameters

Variable	Small Farms Estimate[a]	Small Farms *t*-stat	Medium Farms Estimate[a]	Medium Farms *t*-stat
Constant	64.387 ***	14.068	79.780 ***	18.446
Farm size	56.004 ***	8.686	2.271 *	1.790
Education	0.211	1.486	0.311 ***	3.111
Fragment	-3.608 ***	-8.063	-1.345 ***	-4.961
Family size	0.184	0.506	-0.136	-0.455
Age	-0.039	-0.752	-0.070	-1.581
Crop variety	2.621	1.555	2.632 *	1.889
Land level	0.609	0.557	0.138	0.136
Adjusted R-squared			0.24	
Heteroskedasticity test: $\chi^2(16)$			29.37 (*p*-value: 0.02)	

[a] The coefficients are scaled up by 100 for ease of presentation.
Note: The superscripts *, **, and *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Summary and Conclusions

Allowing for the threshold effect of farm size, this study estimates the productivity of rice farmers in Bangladesh and how the productivity is affected by farm-specific variables. Using rich survey data of 960 rice farm households spread over 64 villages collected in 2008, total factor productivity measures are estimated via Data Envelopment Analysis. The estimates of productivity scores are further regressed on a set of farm specific variables using Hansen's (1996, 1999) threshold estimation procedures to examine how the effects of such productivity determinants vary as one moves from one farm size category to another size category.

In terms of the technical efficiency scores, the distributions of the bias-corrected estimates for the Aman season has fatter and longer tails than the Boro season and the average technical efficiency scores are 0.721 for Aman season and 0.756 for Boro season. In terms of the threshold equations explaining the technical efficiency scores, the results confirm that 1) there are two farm-size thresholds for the Boro equation and one threshold for the Aman equation, 2) the effects on productivity of the underlying determinants vary across farm-size categories, suggesting the importance of allowing for threshold effects in the estimation, and 3) farm size and productivity are positively related, with the exception of the Boro farms holding more than 1 ha in size. Contrary to previous findings, result (3) suggests that land reform policies aiming at small farms could have the potential of increasing rice production in Bangladesh, but the implementation of such a policy could be challenging because of the reversal of the farm size-productivity relationship as the former increases beyond a certain threshold level.

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