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Estimation of Potato Farming Efficiency Using Data Envelopment Analysis

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Abstract: Nowadays to satisfy demands for growing population in developing country increasing production efficiency of agricultural output become a growing concern. In Bangladesh, Government encourages farmers to increase potato production to reduce pressure on rice and export to earn foreign currency. Increasing potato production requires more efficient use of farmers' resources with current technology. This Study uses DEA to examine economic, technical, and allocative efficiencies and applies Tobit model to detect the affecting factors of potato farming efficiency from purposively selected four districts. DEA reveals substantial inefficiencies in Potato production. Very few farms are found highly efficient. Variability of potato production are jointly determined by socio-economic and infrastructure factors. Comparison among three efficiencies shows that farms are more technically efficient. Therefore, Government needs to pay attention to improving allocative and economic efficiency.

Keywords: Potato Farming, Data Envelopment Analysis, Allocative Efficiency, Technical Efficiency, Economic Efficiency.

1. Introduction

Nowadays, to satisfy demands for a growing population in developing countries, increasing agricultural output production efficiency becomes an increasing concern. In Bangladesh, Government encourages farmers to increase potato production using efficient use of farmers' resources to reduce pressure on rice and export to earn foreign currency. It requires estimation of inefficiency, which benefits in raising overall productivity whether need to develop new technology or improve efficiency.

In 1957, Farrell pioneered the development of different approaches to efficiency measurement; Data Envelopment Analysis (after that DEA) method is one of them to estimate efficiency. DEA is a methodology that focuses on frontiers and estimates inefficiency as the difference from the frontier. It does not have any parametric structure on data and no distributional assumptions on the residuals (Chowdhury, 2007). (William W. Cooper; Lawrence M.; Seiford Joe Zhu, 2004) state frontiers as a piecewise linear surface floated on the data. From multiple inputs-outputs, DEA identifies the 'best' decision-making units (DMUs). The best DMU has efficiency score one and its position is on the production frontier. DMUs with a score less than one are inefficient and lie below the frontier (William W. Cooper et al., 2000).

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Different researchers applied DEA technique to measure the efficiency of different crops in other countries in the world, such as in Kamataka (Murthy et al., 2009) for tomato-producing farms, (Adeyonu et al., 2019) for Sweet Potato production efficiency in Nigeria, (Dedy Andriatmoko et al., 2018) for potato farming in Indonesia, (Karimov, 2013)for potato and melon production in Uzbekistan, (Shawky El-Khalifa & Zahran, 2020) for Maize crop in Egypt, and (Mezgebo et al., 2021) for sesame producer farmers in Ethiopia, (Balcombe et al., 2008) for rice farming, (Bagchi et al., 2019) for agricultural total factor productivity, (Jalilov et al., 2019) for rice production. (Mardani & Salarpour, 2015) applied the DEA method to analyze potato production's technical and scale efficiency in Iran. They used rent of human labor, land, machinery, diesel cost, fertilizer cost, irrigation cost, pesticide cost as input, and gross return from potato farming as output. They found 97% scale efficiency and 90% technical efficiency.

In Bangladesh, (Begum & Alam, 2010; Esmatara Begum et al., 2014; Khuda & Hassan, 2006; Shahriar et al., 2013; Sujan et al., 2018; Tanvir Ahmed et al., 2015) have done research on technical efficiency of potato farming using stochastic frontier analysis.

From the above literature reviews, it can conclude that there is no research has been done yet on potato farming efficiency (technical, allocative, and economic efficiencies) using DEA in Bangladesh. This is the first attempt to use DEA to know the potato farming efficiency and simultaneous estimation of technical allocative, economic efficiencies in Bangladesh. Therefore, the objective of present study is concerned with the efficient utilization of resource allocation in potato farming to develop policy parameters to improve the existing situation. This study examines the efficiency of potato farming using DEA and applies Tobit model to detect the affecting factors of potato farming efficiency.

2. Methodology

Sampling and Data

Potato is being grown in almost all the districts of Bangladesh in winter from October to March when optimum growth temperature $15^0 - 21^0$ C prevails. A semi-structured questionnaire used to collect data from randomly selected 300 individual farmers from purposively selected four districts among the highest potato-grown areas: Munshigonj (Tongibari, Sirajdikhan), Rangpur (Pirgonj), Dinajpur (Hakimpur), and Joypurhat (Panch Bibi, Kalai). Two villages randomly selected from each upazila. Since potato farming is more or less homogeneous, 25 samples of each village.

The study collected the followings variables from the survey: Output (kg) Land (Decimal), Seed (kg), Cost of Labor (Tk.), Tilling (Tk.) Fertilizer (Tk.) Irrigation (Tk.), Pesticides (Tk.), and Vitamin (Tk.) in thousand. Factors associated with inefficiency are Age (year), Education (year), Training (dummy), experience (year), Land fragmentation (average plot size), Access to credit (dummy), Cold storage facility (dummy), Household size (number of family member) Weed uprooting cost (Tk.).

Method of Estimation

Data Envelopment Analysis Model

DEA is a linear programming method to formulate a piece-wise linear surface over the input and output data points. The solution of linear programming problems (one for each farm in the sample) constructs the frontier surface and produces the degree of inefficiency (the difference of frontier and observed data point). Production technology doesn't require to assume any functional form. It is deterministic and allows for multiple outputs and inputs. The DEA frontier gives either use of minimum input for a given output level (input-orientation) or maximum output for a given input level (Output-orientation).

Charnes, Cooper and Rhodes (1978) invented the term DEA and anticipated an input orientation model with constant returns to scale (CRS) assumption. After that Banker, Charnes, and Cooper (1984) suggested a variable return to scale (VRS) assumption.

If all outputs increase by α% for an increase in all inputs by α%, then it is called constant Returns to Scale (CRS) in production. If the frontier exhibits more than one of Constant Returns to Scale (CRS), Decreasing Returns to Scale (DRS), or Increasing Returns to Scale (IRS) then it is called Variable Returns to Scale (VRS) in production.

Therefore, this efficiency analysis can have an input-saving or an output-augmenting interpretation. This study has selected an input orientation model because it has one output potato and more inputs to produce it. This model addresses the issue by how much input can proportionally be changed to produce a fixed amount of output.

Technical efficiency (TE) measure under CRS:

$\min_{\theta,\lambda} \quad \theta_i^{CRS}$, subject to: $-y_i + Y\lambda \geq 0$; $\theta x_i - X\lambda \geq 0$, $\lambda \geq 0$ (1)

Where, θ = a scalar , Y = M×N output matrix, λ = an $N \times 1$ vector of constant, x_i = input matrix of ith farm, y_i = output matrix of i^{th} farm, and X = K×N input matrix.

The parameter θ represents i-th farm's technical efficiency score, and the vector λ represents peers (efficient farms) of inefficient i-th farm's. Technically efficient farm has value of θ=1and its position is on the frontier. On the other hand, technically inefficient farm has value of θ<1 and its place is below the frontier (Farrell, 1957). N times solved the linear program to estimate θ and λ for each individual farm in the sample.

Technical Efficiency (TE) measure under VRS:

All DMUs have constant return to scale indicates that they operate at an optimal level.

The convexity constant $N1'\lambda = 1$ add in equation 5.5 to estimate the VRS .

$\min_{\theta,\lambda} \quad \theta$, subject to $-y_i + Y\lambda \geq 0$, $\theta x_i - X\lambda \geq 0$, $N1'\lambda = 1$, $\lambda \geq 0$ (2)

N1 is an Nx1 vector of ones.

If in both CRS & VRS approaches, Technical Efficiency (TE) = 1 means that farms can gain the optimal output based on given inputs of the production.

Scale Efficiency

An individual farm has scale inefficiency when there is difference between CRS TE and VRS TE scores. An additional constraint (non-increasing returns to scale (NIRS: $N1'\lambda \leq 1$)) is imposed to determine the farm's increasing or decreasing returns to scale area.

$\min_{\theta,\lambda} \quad \theta$, subject to: $-y_i + Y\lambda \geq 0$, $\theta x_i - X\lambda \geq 0$, $N1'\lambda \leq 1$, $\lambda \geq 0$ (3)

Allocative and Economic Efficiencies

To estimate economic efficiency, the following DEA model need to solve(Färe et al., 1994)

$\min_{\lambda, x_i*} w_i' x_i^*$, subject to $-y_i + Y\lambda \geq 0, \theta x_i - X\lambda \geq 0, N1'\lambda = 1, \lambda \geq 0$ (4)

Where, w_i: input prices matrix (vector) for an individual farm, x_i^* :cost minimizing input quantities matrix obtain from given output levels (y_i) and input prices (w_i) for an individual farm.

The economic or cost efficiency for an individual farm is

$EE = CE = w_i' x_i^* / w_i' x_i$ where $w_i' x_i^*$=the minimum cost, and $w_i' x_i$= observed cost

Allocative Efficiency: AE = EE/TE

Inefficiency Factors

DEA method cannot directly incorporate farm-specific inefficiency effects on efficient frontier because it is a nonparametric linear programming. Therefore, firstly estimate efficiencies using DEA model and secondly, regression model applies to analyze and quantify the impact of the farm-specific inefficiency factors.

Hypothesize the regression equation as follows:

$$IE_i = \delta' z_i + w_i, \qquad w_i \sim N(0, \sigma^2_w) \quad (5)$$

Where, δ_i: Unknown parameter (k×1), z_i: Variables (k×1) and w_i: residuals (k×1).

The Tobit (1958) regression model used to estimate the inefficiency effects since the estimation of δ and σ^2_w using ordinary least square (OLS) method produces biased and inconsistent result for inefficiencies' parameters.

Tobit regression model is as follows:

$$IE_i = \delta' z_i + w_i \text{ if } (\delta' z_i + w_i) \geq 0, \quad (6)$$

i.e., inefficiency for an individual farm is not negative.

The following Tobit regression model is used to estimate inefficiency effects for an individual farm:

$$U_i = \delta_0 + \delta_1 Z_{i1} + \delta_2 Z_{i2} + \delta_3 Z_{i3} + \delta_4 Z_{i4} + \delta_5 Z_{i5} + \delta_6 Z_{i6} + \delta_7 Z_{i7} + \delta_8 Z_{i8} + \delta_9 Z_{i9} + w_i \quad (7)$$

Where, U_i: Inefficiency, Z_1:Age (year), Z_2: Education (years of schooling), Z_3: Training (dummy), Z_4: Experience (year), Z_5: Number of plot, Z_6: Access to credit (dummy), Z_7: Cold storage facilities (dummy), Z_8: Household size, Z_9: Deweeding.

3. Empirical Result and Discussion

Empirical results and implications of DEA are presented below. The DEA method constructs scale and technical efficiencies of the input-oriented DEA frontier to classify the existing potato farm based on CRS, VRS, and scale efficiency (Table 1).

In Table 1, CRS and VRS DEA results show that 39 farms (13%) and 63 (21%) farms respectively are over 70 percent technically efficient. Most of the farms are belongs to less than 50% technically efficient for both CRS and VRS DEA. Summary statistics point out that mean technical Efficiency for CRS DEA model is 43.76. and for VRS DEA model is 52.71. The range of technical efficiency are from 7.4 to 100 per cent with standard deviation of 21.49 for CRS DEA and from 15.9 to 100 percent with a standard deviation of 23.12 for VRS DEA. Scale efficiency estimate for input-oriented DEA model ranges from 7.4 to 100 percent. Standard deviations for input-oriented DEA models are 18.32. So, DEA shows considerable inefficiencies in Potato farming in Bangladesh. Most of the farms are 40 percent technically efficient. There are very few highly efficient farms. Mean efficiency scores CRS TE < VRS TE represents a scope for comprehensive improvement in production. The farms are 22% for constant, 54% for increasing, 24% for decreasing return to scale. It is clear from the DEA frontier analysis that farmer can reduce the production cost and hence can get more output gain through improving efficiency without introducing new or more improved technologies in production processes.

Table 1: Frequency Distribution (%) of Farms according to Scale and Technical Efficiencies

Efficiency index (%)	**Technical Efficiency (TE)**		**Scale Efficiency**
	CRS(Overall TE)	**VRS(Pure TE)**	
1-40	52	35	4
40-50	17	21	3
50-60	12	17	4
60-70	6	6	6
70-80	4	5	9
80-90	3	3	20
90-100	6	13	54
Summary Statistics			
Mean	43.76	52.71	84.5
Minimum	7.4	15.9	7.4
Maximum	100	100	100
Standard Deviation	21.49	23.12	18.32
Total Farms	300	300	300

Sources: Authors' calculation

Technical, Economic, and Allocative Efficiencies of DEA Frontier

The frequency distribution (%) of technical, economic, and allocative efficiencies measures under CRS and VRS DEA are presented in Table 2.

Table 2: Frequency Distribution (%) of efficiency

Efficiency index (%)	**Constant Returns to Scale**			**Variable Returns to Scale**		
	Technical Efficiency	Allocative Efficiency	Economic Efficiency	Technical Efficiency	Allocative Efficiency	Economic Efficiency
01-40	24	8	43	20	11	44
40-50	8	8	2	6	7	4
50-60	5	17	5	7	15	5
60-70	3	19	23	5	16	14
70-80	6	32	17	6	26	14
80-90	12	14	7	8	13	10
90-100	42	2	3	48	12	9
Summary Statistics						
Mean	71.04	65.56	48.08	74.52	67.92	51.77
Minimum	14.9	4.3	3.3	15.9	4.1	3.5
Maximum	100	98.5	98.5	100	100	100
Standard Deviation	29.73	16.91	26.50	28.76	18.89	28.02
Total Farms	300	300	300	300	300	300

Sources: Authors' calculation

For the CRS DEA frontier, the estimated mean of technical, economic, and allocative efficiencies are 71.04, 48.08, and 65.56 respectively. For the VRS DEA frontier, those efficiencies are 74.52, 51.77, and 67.92 respectively. The results imply that farmers can reduce costs and increase production volume by efficiency improvement without changing and improving new technology. The DEA model shows room for improving potato farming efficiency to increase potato production. If farms' TE = 1 in both CRS and VRS DEA implies that farms can gain the optimal output based on given inputs.

Results of Factors Affecting Inefficiency from DEA Model

The factors affecting the technical, economic, and allocative efficiencies of CRS and VRS DEA are shown in Table 3.

Table 3: Factors Affecting Inefficiency in Farming

Factors	**Technical Inefficiency**		**Allocative Inefficiency**		**Economic Inefficiency**	
CRS	**Coefficients**	**t – ratios**	**Coefficients**	**t – ratios**	**Coefficients**	**t – ratios**
Constant	0.583	6.970	0.729	14.774	0.479	6.524
Age	-0.028	-16.018	-0.014	-12.949	-0.015	-9.971
Education	-0.016	-4.247	-0.064	-29.407	-0.040	-12.431
Experience	-0.059	-4.874	-0.034	-25.691	-0.073	-3.705
Land fragmentation	0.017	4.092	0.005	2.137	0.014	4.165

Factors	Technical Inefficiency		Allocative Inefficiency		Economic Inefficiency	
CRS	**Coefficients**	**t – ratios**	**Coefficients**	**t – ratios**	**Coefficients**	**t – ratios**
Family size	0.012	0.691	0.002	0.611	0.009	1.462
Deweeding	-0.011	-4.491	-0.010	-3.173	-0.014	-3.106
Access to Credit (dummy)	-0.038	-4.527	-0.090	-4.259	-0.036	-2.072
Cold Storage (dummy)	-0.128	-8.557	-0.046	-3.521	-0.123	-2.805
Training (dummy)	-0.033	-8.340	-0.030	-2.409	-0.194	-5.516
VRS						
Constant	0.823	10.302	0.635	11.494	0.554	7.113
Age	-0.048	-2.856	-0.014	-12.102	-0.013	-7.802
Education	-0.032	-9.041	-0.094	-3.886	-0.026	-7.612
Experience	-0.083	-3.843	-0.042	-3.427	-0.095	-4.546
Land Fragmentation	0.063	7.546	0.059	2.232	0.020	5.349
Family size	0.027	0.376	0.002	-0549	0.022	0.320
Deweeding	-0.022	-4.297	-0.027	-7.711	-0.043	-8.494
Access to Credit (dummy)	-0.071	-3.007	-0.076	-3.188	-0.106	-3.163
Cold Storage (dummy)	-0.056	-3.816	-0.028	-8.792	-0.125	-2.704
Training (dummy)	-0.167	-4.341	-0.041	-6.220	-0.109	-2.918

Sources: Authors' calculation

The DEA results show that the estimated coefficients of nine variables are negative and positive for family size and land fragmentation, which implies that all inputs are important in determining potato production. The coefficient of farming experience is negative, implying that households who are into farming for more years tend to be more technically efficient, which indicates that most farmers improve production performance from skills gained through years of experience in potato cultivation.

The negative sing of education coefficient implies that the farmers are more technically efficient with more years of schooling. The coefficients of age, de-weeding, education, experience, access to credit, cold storage, and training of the farmers are negative. This can explain that as farmers grow older, they are more technically sound because of experience. The higher the educated they are, they tend to adopt new technology, etc. If the farmers have cold storage facilities, they do not need to sell their products soon after the harvest. During harvest time, products are usually fetched at lower prices. They can keep the potato at the cold storage; they will get a good margin. If the farmers had access to credit and training, inefficiency would reduce substantially. The production would be more efficient if the farmer de-weed their land when they grow potatoes because weed hampers the potato production substantially. The coefficients of the family size is positive but insignificant, which means that family size does not significantly affect farming efficiency at 5% level. As far as land fragmentation is concerned, the coefficient is positive for all inefficiency effects. Farmers with larger plots are more efficient because they can easily manage the land, especially irrigation and tillage with tractors and water pumps with electricity.

4. Implication and Conclusion

Technical, allocative, and economic efficiencies and inefficiencies in potato farming are estimated by using DEA approach. It is observed that in potato farming CRS and VRS DEA results show that 13% farms and 21% farms respectively are over 70 percent technically efficient. Scale efficiency estimate ranges from 7.4 to 100 percent Most of the farms are 40 percent technically efficient and very few farms are highly efficient. Results show considerable inefficiencies in Potato farming in Bangladesh. CRS TE < VRS TE implies that there are room for improving efficiency level without any change in potato production process.

Farm households are attributed by increasing returns to scale in potato farming. Determination of the level and variability of potato production, technical inefficiency effects found a significant component. The results imply that there are significant allocative, economic, and technical inefficiencies in potato farming. Household in potato farming may improve efficiency by increasing production level and thereby increase farm welfare and income. Socio-economic and infrastructure factors jointly determine the variability of potato farming.

This study emphasizes the requisite for agriculture-related education that can help the farmers to increase their knowledge about farming and cost-minimizing input as a result improve allocative efficiency. To improve the productivity farm households, require training of understanding and receiving modern technology. Extension program can help in applying appropriate production method, timing, amount of inputs and better utilization of fertilizer, irrigation, land tenure, tractor usage and management policy to reduce land fragmentation. The credit facility is directly related to efficiency, and it needs to improve and make easy access to farmers. The choice of appropriate technology, management method, quality of inputs should emphasis to achieve production efficiency.

Further research may examine how much the factors explain differences in efficiency and how the farmers can adjust to the new training and education-related programs. Before changing and implementing any policy, farms need encouragement and awareness to adapt the policy.

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