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Efficiency of Potato Farming in Bangladesh: Cobb-Douglas Stochastic Frontier Approach

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Abstract

This study examines efficiency of potato farming at farm-level in Bangladesh by estimating technical (TE), allocative (AE) and economic efficiencies (EE) using farm-level cross-sectional survey data from purposively selected six districts: Brahmanbaria, Dinajpur, Joypurhat, Munshigonj, Narsingdi and Rangpur. This study uses Cobb-Douglas Stochastic Frontier Analysis for measuring TE and after that AE and EE are obtained by applying the Kopp and Diewert stochastic cost decomposition method. Stochastic Frontier Analysis is more applicable to agriculture sector since it considers an error term that had two components: one to account for random effects (luck, weather, fires, measurement error in the output variable, etc.) which are not under the owner's control and another to account for technical inefficiency. An evaluation of factors associated with TE, AE and EE from stochastic frontier analysis reveals that except family size other factors are the significant factors affecting TE, AE and EE. Findings reveal that there is a considerable amount of technical, allocative and economic inefficiencies in potato farming and there is potential for boosting output levels through efficiency improvements, hence improving farm revenue and farm household welfare. This study expose that socioeconomic and infrastructure factors jointly determine the variability of potato output. The importance of education and training in improving farm households' ability to receive and understand information about modern technologies is highlighted in this study. Furthermore, land tenure as well as management policies could be designed to reduce land fragmentation in order to better utilization of fertilizer, irrigation, and land preparation using tractors in particular, because fragmentation creates barriers to operating existing technology efficiently and creates difficulties allocating inputs in a cost-effective manner.

Keywords: Potato farming, Stochastic Frontier Analysis, Technical Efficiency, Allocative Efficiency, Economic Efficiency

1. Introduction

The relative efficiency of agricultural farms in developing countries has attracted a lot of attention in the development literature, and economists have been interested in estimating it. Efficiency is a performance measure and success indicator. Studies of efficiency indicate whether it is possible to increase productivity by improving efficiency through utilizing available resources more efficiently without increasing the resource base or developing and adopting new technologies. If agricultural output needs to

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grow at a sufficiently quick rate to fulfill the requirements for food and raw materials emerging from population growth, agricultural farming efficiency is a critical aspect. Estimation of inefficiency can also assist to decide whether to enhance efficiency or to develop new technology to raise overall productivity.

Potatoes are attracting the attention of policymakers and planners in developing countries due to their shown ability to increase farm incomes, rural employment, and food consumption. It is considered as food as well as cash crop. Consumption is particularly important where large segment of the population who lived in rural areas are low-income consumers. Potato production is labor intensive and thus generate employment at farm level (Abedullah et al., 2002). Rice is staple food in Bangladesh but fluctuation in rice production causes significant effects on food security. To keep overall food and nutrition security of the country potato meets both productive and nutritionally balanced requirements (Azimuddin, et.al., 2009) and play vital role in poverty reduction (Zamil, et.al., 2010). The importance of the potato as a winter (October to March) cash crop in Bangladesh is fast increasing for its potential contribution to food security, nutrition, employment and improvement in the socio-economic status of the rural communities (Alam, et.al., 2012).

As producers refocus on home and international markets, the developed world's potato production for the first time surpassed by the developing countries in 2005 (Hossain & Miah, 2009). Using balanced fertilizer, modern seed varieties, integrated pest management and a sound weather during the growing stage helps to get a record crop. As a result, the level of efficiency of potato farming has important consequences for development strategy. The government of Bangladesh has been also trying to diversify food habits, encourages potato consumption to lessen pressure on rice and export of potato to earn foreign currency. The new inputs as well as technology are crucial elements to increase the efficiency of the potato production. If there are substantial opportunities to increase farming efficiency through more efficiently using the resources of farmers with current technology, more emphasis needs to be given on institutional investments in infrastructure, delivery, extension of systems, farm management services and skills of farmers at the farm level.

There is a "Quiet Revolution" of potato production in Bangladesh (Reardon, *et al.*, 2012). It is ranked just after rice and wheat considering the harvested area, production and consumption. Bangladesh ranked 4th position for production area (ha), 3rd position for production volume (MT), 4th position for production yield (tones/ha) and 3rd position for consumption (kg/capita/year) in Asia. It was ranked 9th position in 2005, which became 8th position in 2012 and 7th position in 2014 (FAO, 2014). Bangladesh has relatively favorable soil and climate condition for potato production. The yield potential of potato is about six to seven times more compared to that of rice and wheat from a unit area (Zamil et al., 2010). In terms of both cultivated area and overall production, it ranked first among all vegetables in Bangladesh (Begum, et al., 2010). It is also the 2nd best food energy source (FAO, 2014). Local and high yielding varieties of potato are being cultivated in Bangladesh. Farmers were interested in growing potatoes since they yielded more and made more money than other crops, and they chose Diamant as the most profitable variety (Hossain et al., 2014). However, to attain the target output level, efficiency necessitates sensible input allocation, which is critical for producers attempting to optimize their production decisions. It also improves the farms' ability to adapt to changing market conditions, rising input costs, economic downturns, and quick technology advancement. Moreover, it is useful for policymakers who want to improve farms' economic performance and competitiveness, as well as promote economic development and sustainable economic practices (Guesmi, 2014).

Several previous studies applied Cobb-Douglas Stochastic Frontier Production Model to various agricultural crops (Baten, et al., 2010; Ferdushi, et al., 2013; Ndubueze-Ogaraku & Ekine, 2015; Hossain, et al., 2015; Hossain, 2016; Sujan, et al., 2017; Shavgulidze, et al., 2017; Dube, et al., 2018; Njiku & Nyamsogoro, 2018; Radhakrishnan & Das, 2019; Mwanguhya & Ekere, 2021). However, a few studies on potato production efficiency (Huda, et al., 2019; Tiruneh, et al., 2017; Sapkota & Bajracharya, 2018; Hamjah, 2014; Shahriar, et al., 2013; Begum, et al., 2010; Hossain, et al., 2008) have been undertaken. Majority of the study have focused on estimating technical efficiency using Stochastic Frontier Analysis. Maganga (2012) shows empirically the technical efficiency of potato producer in Irish. Nyagaka, et al. (2010) assesses the technical efficiency in resource use and identifies the underlying determinants of variation in production efficiency among smallholder potato producers in Kenya.

There is a little information on efficiency, especially technical, allocative and economic efficiency of potato sector in Bangladesh. Therefore, it is necessary to undertake research efforts to estimate the efficiency of potato farming that will ensure better ways and enable to improve potato productivity in a sustainable manner. Efficiency improvement will be an important factor in order to get financial success for farmers and profit gain. Resources have to be optimally utilized in order to get maximum production and income. Estimation of the extent of inefficiency can help in deciding how to raise farming efficiency. Identifying sources of inefficiency plays an important role in designing policies to improve the performance of potato farming. However, efficiency of farmers depends on their experience, level of education, land size and fragmentation, use of modern technology, use of seeds, fertilizer and other inputs. Thus, this study attempts to estimate the farm-level TE, AE and EE of potato sector and to identify sources of inefficiency where improvements can be made and tries to find out how these factors affect the efficiency level of the potato farming at the study area. The rest of the paper outlines as Section 2, describes methodology, Section 3 examines the findings of the study and finally, Section 4 makes the conclusion.

2. Methods and Materials

2.1 Data Collection

For the study area, we select six potato growing districts purposively considering the volume of production. An empirical study of farming efficiency requires availability of farm level data, however, due to the lack of data in the selected study areas, a survey was conducted to gather the required data. A pilot survey was carried out prior to design the main survey. The survey documented two types of information, farm characteristics and farm production data. The target population of the study are the potato growers of the selected study areas. The selected districts are Munshigonj, Narsingdi, Brahmanbaria, Rangpur, Dinajpur and Joypurhat. One upazila from each of the districts and two villages from each upazila were selected. However, Munshigonj is in the top position of the potato production and Joypurhat also produces considerable amount of potato that's why two upazilas were selected from these two districts that is 8 villages were included from 6 districts. In each stage of selection, we chose purposive and convenience sampling because of unavailability of the list of farmers and some farmers were not willing to provide the required information. Since potato farming is more or less homogeneous sample size was disproportionately determined as 25 potato growers of each village totaling 400 potato growers. Data were collected using a structured questionnaire which designed in line with the objectives of the study. Output, land, and labor are measured initially by their original unit (output in kg., land in decimal, and labor in hour) and before going to analysis these variables are converted into BDT (Bangladeshi currency).

2.2 Study Area

The selected districts i.e., Munshigonj, Narsingdi, Brahmanbaria, Rangpur, Dinajpur and Joypurhat are shown in the following Bangladesh geographical map (Figure 1).

2.3 Methods

The technical efficiency is estimated using self-dual Cobb-Douglas Stochastic Frontier Model where the maximum likelihood method is used as a default estimation process. First technical efficiency is calculated in a single stage method in which the technical inefficiency effects are modeled as a function of socio-economic characteristics and infrastructure factors. After that allocative and economic efficiency measures are obtained by applying the Kopp and Diewert (1982) stochastic cost decomposition method. We estimate the Cobb-Douglas stochastic frontier model along with a technical inefficiency effects model considering the truncated and half-normal distribution. This study applies a Cobb-Douglas stochastic frontier Analysis Method. It is self-dual and its dual cost frontier model forms the basis for computing technical, allocative and economic efficiencies. The Cobb-Douglas stochastic frontier specified for this study is as follows:

$$\ln y_i = \beta_0 + \sum_{k=1}^{8} \beta_{ik} \ln x_{ik} + v_i - u_i \qquad (i = 1, 2, \ldots, 400) \qquad (1)$$

Figure 1. Study area

Now, subtracting v_i from both sides of equation (1) yields

$$\ln \tilde{y}_i = \ln y_i - v_i = \beta_0 + \sum_{k=1}^{8} \beta_{ik} \ln x_{ik} - u_i \quad (2)$$

where, ln: the natural logarithm; y: current year total potato production in ('000) Tk.; x_1: land in ('000) Tk.; x_2: labor in ('000) Tk.; x_3: tilling in ('000) Tk.; x_4: seed in ('000) kg.; x_5: fertilizer in ('000) Tk.; x_6: irrigation in ('000) Tk.; x_7: pesticide in ('000) Tk.; x_8: vitamin in ('000) Tk.; β_0: technical efficiency level; $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8$: coefficients of inputs with respect to output level; v_i: the random component accounts for random variations in output because of factors not under the control of the farmers; u_i: the non-negative random error measures the technical inefficiency relative to the stochastic frontier; $u_i = 0$ indicates the farm lies on the Stochastic Production Function; $u_i > 0$ implies that the farm is inefficient; v_i and u_i are assumed to be independent of each other and also independent of the input vector x and $\tilde{y}_i$: the farms observed output adjusted for the stochastic random noise captured by v_i.

The variance parameters of the model are expressed as:

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \,; \gamma = \sigma_u^2 / \sigma^2 \,; \text{and } 0 \leq \gamma \leq 1. \quad (3)$$

Here, γ = 0 indicates absence of stochastic technical inefficiency turning the stochastic frontier model to the average frontier model and γ = 1 represents absence of the stochastic random error term making the stochastic frontier model a full frontier model and it is considered by Aigner and Chu (1968). The parameter $\lambda = \sigma_u/\sigma_v$ is considered as a measure of the relative variability of two sources of inefficiency. when $\lambda^2 \rightarrow 0$, it implies that $\sigma_v^2 \rightarrow +\infty$ and /or $\sigma_u^2 \rightarrow 0$, which means that the random shocks dominate in the explanation of the inefficiency. When $\sigma_v^2 \rightarrow 0$ then the gaps to the frontier are essentially due to the technical inefficiency.

The farm specific technical efficiency of i-th farm is defined as the ratio of the observed output (y_i) to the corresponding frontier output (y*), given the levels of the inputs as:

$$TE_i = \frac{y_i}{y_i^*} = \frac{f(x_{i,}\beta)e^{v_i - u_i}}{f(x_{i,}\beta)e^{v_i}} = e^{-u_i}, (0 \le TE_i \le 1) \tag{4}$$

Here, u_i are non-negative truncation of the $N\left(\mu, \sigma_u^2\right)$ distribution and $\mu = z_i\delta_i$, where, z_i is a (k×1) vector of variables which may influence efficiency and $\delta_i$is an (1×k) vector of parameters to be estimated.

The equation (2) constitutes the basis for obtaining the technically efficient input vector x_{ik}^T. The dual stochastic frontier cost function model is analytically derived from the stochastic production model. Algebraically deriving the dual stochastic frontier cost function is the basis for calculating the economically efficient input vector x_{ik}^E. The dual stochastic frontier cost function model is

$$C(p_{ik}, \tilde{y}_i) = \alpha_0 \prod_{k=1}^{8} p_{ik}^{\beta_{ik}\alpha_{ik}} \tilde{y}_i^{\alpha_{ik}} , \tag{5}$$

where, $C(p_{ik}, \tilde{y}_i)$ is cost function, $\alpha_0 = \left(\frac{1}{\beta_0^{\alpha_{ik}}}\right)\left(\sum_{k=1}^{8} \beta_{ik} / \prod_{k=1}^{8} \beta_{ik}^{\beta_{ik}\alpha_{ik}}\right)$ and $\alpha_{ik} = \frac{1}{\sum_{k=1}^{8} \beta_{ik}}$.

$$\text{Also, } x_{ik}^E = \frac{\partial C(p_{ik}, y)}{\partial p_{ik}} = x_{ik}^E\ (p_{ik}, \tilde{y}_i) = \alpha_0(\beta_{ik}\alpha_{ik}) \prod_{k=1}^{8} \frac{1}{p_{ik}} p_{ik}^{\beta_{ik}\alpha_{ik}} \tilde{y}_i^{\alpha_{ik}} . \tag{6}$$

From the result of stochastic frontier production function (1) we can get technically efficient input vector x_{ik}^T. Multiplying the observed input vector x_{ik}, technically efficient input vector x_{ik}^T and economically efficient input vector x_{ik}^E by the input price vector provides the observed, technically efficient and economically efficient costs of production of the i-th farm equal to $p_{ik}x_{ik}$, $p_{ik}x_{ik}^T$ and $p_{ik}x_{ik}^E$ respectively which compute the TE, AE and EE indices for the ith farm as:

$$\text{TE} = p_{ik}x_{ik}^T / p_{ik}x_{ik},\ \text{AE} = p_{ik}x_{ik}^E / p_{ik}x_{ik}^T \text{ and EE} = p_{ik}x_{ik}^E / p_{ik}x_{ik} . \tag{7}$$

The linear form of the dual cost function can be written as (Ouattara, 2010),

$$\ln\left(C\left(p_{ik},\tilde{y}_i\right)\right)=\alpha_0+\phi_1\ln\left(p_{i1}\right)+\phi_2\ln\left(p_{i2}\right)+\ldots+\phi_8\ln\left(p_{i8}\right)+\varphi\ln\left(\tilde{y}_i\right) \quad (8)$$

where, p_1: price of land; p_2: price of labor; p_3: price of tilling; p_4: price of seed; p_5: price of fertilizer; p_6: price of irrigation; p_7: price of pesticide; p_8: price of vitamin and $\tilde{y}_i$: the farms observed output.

The inefficiency effects model is presented by the following equation

$$U_i = \delta_0 + \delta_1 Z_{i1} + \delta_2 Z_{i2} + \delta_3 Z_{i3} + \delta_4 Z_{i4} + \delta_5 Z_{i5} + \delta_6 Z_{i6} + \delta_7 Z_{i7} + \delta_8 Z_{i8} + \delta_9 Z_{i9} + w_i \quad (9)$$

where, U_i : inefficiency ; Z_1: age of farmers in years; Z_2: education of farmers in years; Z_3: training (dummy); Z_4: experience of potato cultivation in years; Z_5: number of plot; Z_6: access to credit (dummy); Z_7: cold storage facilities (dummy); Z_8: household size (number of family member); Z_9: deweeding or weed uprooting cost in Tk.

3. Results and Discussion

Empirical results of stochastic frontier analysis model i.e. the maximum likelihood estimates of the parameters along with other results are presented in Table 1.

Table 1. Results of the Cobb-Douglas Frontier Model of the Selected Districts

Variables	Parameters	Coefficients					
		BB	N	M	J	D	R
Constant	β_0	3.353 (42.397)	9.860 (4.152)	5.262 (5.235)	10.176 (2.475)	12.894 (3.857)	6.445 (6.422)
Ln of Land	β_1	0.760 (15.684)	0.678 (3.818)	0.533 (2.782)	0.512 (5.571)	0.758 (4.269)	0.662 (3.650)
Ln of Labor cost	β_2	0.515 (3.543)	0.591 (6.679)	0.648 (3.379)	0.448 (2.645)	0.445 (2.982)	0.429 (11.372)
Ln of Tilling cost	β_3	0.187 (2.585)	0.380 (3.036)	0.449 (2.614)	0.299 (1.208)	0.267 (3.862)	0.365 (2.451)
Ln of Seed	β_4	0.201 (7.131)	0.591 (5.123)	0.342 (2.663)	0.482 (2.051)	0.381 (8.692)	0.439 (2.893)
Ln of Fertilizer cost	β_5	0.608 (5.155)	0.163 (5.910)	0.457 (5.902)	0.315 (3.664)	0.356 (2.245)	0.330 (2.917)
Ln of Irrigation cost	β_6	0.361 (4.526)	-	0.240 (2.130)	0.108 (8.033)	0.067 (4.003)	0.263 (3.338)
Ln of Pesticide cost	β_7	0.081 (2.566)	0.149 (2.158)	0.155 (2.613)	0.007 (3.228)	0.074 (2.253)	0.215 (4.508)
Ln of Vitamin cost	β_8	0.056 (2.563)	0.029 (2.506)	0.183 (2.311)	0.009 (3.032)	0.052 (2.621)	0.193 (3.587)
Inefficiency Variables							
Constant	δ_0	1.099 (3.098)	1.109 (2.105)	2.315 (7.196)	2.420 (0.246)	18.263 (3.308)	8.013 (5.013)
Age	δ_1	-0.798 (-3.778)	-0.378 (-4.796)	-0.274 (-8.003)	-0.311 (-2.696)	-0.416 (-2.069)	-0.229 (-7.822)

Variables	Parameters	Coefficients					
		BB	N	M	J	D	R
Education	δ_2	-0.536 (-3.582)	-0.438 (-3.227)	-0.127 (-6.625)	-0.863 (-2.559)	-0.427 (-5.713)	-0.214 (-17.239)
Experience	δ_3	-0.548 (-4.235)	-0.558 (-3.588)	-0.421 (-4.193)	-0.153 (-2.953)	-0.365 (-4.509)	-0.261 (-14.426)
Land Frag-mentation	δ_4	0.231 (15.048)	0.166 (4.445)	0.387 (4.065)	0.297 (6.118)	0.584 (2.866)	0.140 (2.846)
Family size	δ_5	0.056 (0.056)	0.102 (3.894)	0.139 (0.108)	0.125 (0.808)	0.183 (0.837)	0.054 (1.057)
Deweeding	δ_6	-0.103 (-2.914)	-0.606 (-5.037)	-0.222 (-4.744)	-0.415 (-3.850)	-0.049 (-2.227)	-0.820 (-6.758)
Access to Credit (dummy)	δ_7	-	-	-0.121 (-3.929)	-0.534 (-4.451)	-	-0.106 (-2.436)
Cold Storage (dummy)	δ_8	-	-	-0.010 (-3.004)	-0.357 (-2.565)	-	-0.276 (-.2604)
Training (dummy)	δ_9	-	-	-0.104 (-2.758)	-0.741 (-2.244)	-0.670 (-3.775)	-0.217 (-15.313)
Variance Parameters							
$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.042 (2.729)	0.636 (7.472)	0.345 (3.074)	0.282 (2.589)	0.280 (4.325)	0.081 (6.405)
$\gamma = \left(\sigma_u^2 / \sigma_v^2 \right)$		0.523 (5.463)	0.518 (4.264)	0.569 (5.601)	0.473 (4.960)	0.685 (15.694)	0.675 (9.317)
σ_v^2		0.011	0.221	0.123	0.075	0.118	0.025
σ_u^2		0.031	0.415	0.222	0.207	0.162	0.056
Log-likelihood		460.92	334.45	786.29	555.40	437.17	482.65

Note: values in the parenthesis indicate the value of t-statistic, BB: Brahmanbaria; N: Narsingdi; M: Munshigonj; J: Joypurhat; D: Dinajpur; R: Rangpur.

The results of t-statistic reveal that the estimated coefficients of eight positive parameters are statistically significant at 5% significance level for all study areas. In Munshigonj, the elasticity of labor is comparatively higher than other districts. This is quite obvious for Munshigonj district as most of the young people are living abroad which can cause labor scarcity. A lot of seasonal workers migrate to Munshigonj from rest of the country. We found irrigation; pesticide and vitamin have a relatively small effect. According to the calculated δ-coefficients of the explanatory variables, the farm specific variables included in the inefficiency model impact significantly to the explanation of the technical inefficiency effects in potato farming as a group. The signs of estimated coefficients indicate that these variables cause variation in farm technical efficiency, which has an impact on farms' ability to use existing infrastructure and technology effectively. All coefficients are statistically significant which indicating that there are inefficiency effects in the potato farming in the sample farms and also prevails the random component of the inefficiency effects which makes significant contribution in the analysis of efficiency in potato farming. That is the technical inefficiency effects are a significant component in determining the level and variability of output of potato farming in each district.

The coefficient of education is negative suggesting that the farmers with higher years of schooling having higher technical efficiency (Begum, et.al 2012, Maganga, 2012). The higher educational qualification of a farmer tends to adopt new technology. Farmers with basic literacy may utilize contemporary fertilizers and insecticides, as well as select input combinations. With education and extension services, farmers can be introduced to new technology and techniques. The efficiency of allocative allocation is connected to the level of improved education (Ram, 1980). Similarly, coefficients of age and experience have negative impacts on the inefficiency of the yield of potato production which implies that the older and experienced farmers are more technically efficient. As they grow older, they are more technically sound because of experience (Haider, et.al. 2011; Belete, 2020). If the farmers have cold storage facilities, they do not need to sell their product soon after they harvest. In our study areas, only three districts have cold storage facilities. Study shows that storage facilities negatively affects the efficiency level of the potato production, other three districts such as Brahmanbaria, Narsingdi and Dinajpur have not any cold storage facilities, they need to sell their product soon after they harvest (Hoque, 2011; Mukul, et.al. 2013). During harvest time products are usually fetches lower price. If they can keep the potato at the cold storage, then they will get a good margin.

The credit facilities and training also have similar pattern of impacts on inefficiency level of the potato production because the access to credit and training will be substantially reduce the inefficiency of production and this findings is consistent with previous research (Hossain, et.al., 2008; Haider, et.al., 2011, Abate, et al., 2019; Belete, 2020), the production would be more efficient if the farmer do de-weeding their land when they grow potato because weed hampers the potato production substantially (Khan, et.al., 2008; Shahriar, et.al. 2013). As far as land fragmentation is concerned, technical inefficiency effects are greater for farmers with smaller plot size and this findings is supported by other studies (Balogun, & Akinyemi, 2017; Danquah, et al., 2019; Abate, et al., 2019; Belete, 2020). The higher the smaller plots to be managed it would be difficult to manage the land and especially irrigation and tillage would be difficult with tractor and water pump with electricity. In Narsingdi, Rangpur, Dinajpur and Brahmanbaria districts the lands are smaller and the farmers do have smaller pieces of land and they don’t use very much technologically advanced method of cultivation. Since, the coefficient of the family size is not statistically significant, family size has not any significant impact on inefficiency performance of the potato production which is supported by other study (Pandit, et al., 2009).

The returns to scale $\left(\sum_{i=1}^{8}\beta_i\right)$ for Brahmanbaria, Narsingdi, Munshigonj, Joypurhat, Dinajpur and Rangpur are 2.77, 2.58, 3.00, 2.18, 2.40 and 2.90 respectively. This signifies that there is increasing returns to scale in potato production for each district. The estimated value of γ parameter for Brahmanbaria, Narsingdi, Munshigonj, Joypurhat, Dinajpur and Rangpur are 0.52, 0.52, 0.57, 0.47, 0.69

and 0.68 respectively. The variance parameters of the selected districts are 0.04, 0.63, 0.35, 0.28, 0.28 and 0.08 respectively.

In Brahmanbaria we can see that most of the farms (80%) are technologically efficient and falls 1-70% efficiency class while 90% farms fall 60-100% efficiency class as far as AE is concerned but 80% farms falls 1-60% efficiency class in case of EE. In Narsingdi, we can see that most of the farms (95%) are technologically, allocatively and economically efficient and fall 60-100% efficiency class. We can see the same picture in case of Joypurhat, Dinajpur and Rangpur in case of Munshigonj we can see that 80% farms falls 1-60% efficiency class as far as EE is concerned. The results demonstrate that there are considerable variations of efficiency among farms. Summary statistics shows that estimated mean TE, AE and EE are better if we compare with Munshigonj and Brahmanbaria where all three efficiencies i.e., TE, AE and EE are lower which implies that potato farming is technically, allocatively and economically more inefficient than any other districts though Munshigonj is famous for potato production in entire Bangladesh. The results also indicate that there is considerable inefficiency in potato farming and rooms for production gain through efficiency improvement in all the districts especially in Munshigonj and Brahmanbaria [Appendix 1]. The dual cost frontier analytically resulting from the stochastic production frontier for the inefficiency components. The stochastic production function and other related functions are represented in Appendix 2.

Moreover, the factors affecting technical, allocative and economic efficiencies of stochastic frontier analysis model are presented in Appendix 3. The coefficient of farming experience is negative implying that households who are into farming for more number of years tended to more technically efficient which indicates that the majority of farmers improve production performance from skills gained through years of experience in potato cultivation. The coefficient for land fragmentation variable is positive in all the districts and groups as well implying that inefficiency tended to increase with the increase in land fragmentation. Less land fragmented farms are more technically efficient compared to more land fragmented farms because farmers can easily apply modern technologies and which is more economic. The coefficient of family size is also positive in all the districts and groups but not significant implies large or small family size has not significantly effect on farming efficiency. The coefficient of de-weeding, access to credit and cold storage facility also have statistically significant effects on farming efficiency and in some districts it is a very important factor of production and inefficiency depends on this factor. The coefficient of Training through contact with extension workers is estimated negative and an important factor for production and efficiencies for Munshigonj, Rangpur, Dinajpur, Joypurhat group which indicates that farmers who have more contact with extension workers tend to be more technically efficient and operate their farms more efficiently and produce closer to the frontier output. The negative sign of the education variable implies farmers with more schooling tended to be technically more efficient. The education coefficient is considerable. It means that farmers with a greater level of education are less inefficient (or more efficient) than farmers with a lower level of education or none at all [Appendix 3].

4. Conclusion

The empirical results of Cobb-Douglas stochastic frontier show that the sign of the estimated coefficients are all positive which implies that all inputs are important in determining production of potato. The returns to scale for Brahmanbaria, Narsingdi, Munshigonj, Joypurhat, Dinajpur and Rangpur are 2.77, 2.58, 3.00, 2.18, 2.40 and 2.90 respectively indicating that the selected farm households have increasing returns to scale in potato production. The estimates of the variance parameter σ^2 and the parameter γ are statistically significant indicating that there are inefficiency effects in the potato farming of sample farms and the random component of the inefficiency effects make significant contribution in the analysis of efficiency of potato farming. Technical inefficiency effect is a significant component in determining the level and variability of output of potato farming in Bangladesh. The results of the technical inefficiency effects model demonstrate that the combined error term is dominated by technical inefficiency effects. The estimated δ-coefficients of the explanatory variables such as age, education, experience, plot size, etc. imply that the farm-specific factors in the inefficiency model contribute significantly to the explanation of technical inefficiency effects in potato farming as a whole.

This study emphasizes the need of education and training to enhance the ability of farm households to receive as well as understand information regarding advanced technology. Formal education particularly agriculture related education can help the farmers to increase their knowledge about cultivation and cost minimizing input use which can improve allocative efficiency. Extension programs could be utilized to reorient the usage of methods, as well as the time and amount of inputs and production processes. Soil tenure and management regulations could be developed to lessen fragmentation in order to effectively utilize irrigation, fertilizer, and land preparation methods employing tractors in particular. It poses issues in distributing inputs in a cost-effective manner because it creates barriers to employing existing technology efficiently. Credit facility is directly related to efficiency and it need to improve and make easy access to farmers.

This study has taken a sample size of 400 farms. It would be preferable if the data and information collected were based on a larger sample size. Other samples may have different findings. To increase efficiency in potato production, more study and inquiry is required. Many other factors, like management style, experience, input quality, and so on, may be included in further study to identify the efficiency of a farm's.

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Appendix 1. Frequency distribution (%) of farms specific efficiencies for the selected districts

Efficiency Index (%)	Brahmanbaria			Narsingdi			Munshigonj			Joypurhat			Dinajpur			Rangpur		
	TE	AE	**EE**	**TE**	AE	**EE**	**TE**	AE	**EE**	**TE**	AE	**EE**	**TE**	AE	**EE**	**TE**	AE	**EE**
1-40	15	1	34	0	1	2	18	15	55	1	2	2	0	0	0	1	3	7
40-50	18	1	22	0	1	1	10	19	18	2	3	5	0	0	0	1	3	9
50-60	22	3	20	0	3	7	7	5	10	3	8	7	0	2	5	2	5	12
60-70	20	9	2	0	20	30	15	20	5	10	12	10	2	9	27	5	18	30
70-80	5	22	4	5	45	35	12	12	7	12	25	32	6	55	45	17	38	15
80-90	2	40	6	10	20	13	18	14	3	22	30	24	24	20	12	15	17	8
90-100	18	24	12	85	10	12	20	15	2	50	20	20	68	14	11	59	16	19
Total Farms	50	50	50	50	50	50	100	100	100	100	100	100	50	50	50	50	50	50
Summary Statistics																		
Mean	65.76	83.25	50.32	97.82	78.25	75.67	68.75	60.32	38.91	99.07	80.29	79.75	96.78	82.52	79.12	90.95	78.32	70.82
Minimum	25.15	55.5	28.2	90.5	32.6	30.3	21.5	20.3	12.7	90.3	9.5	9.5	78.3	53.1	53.5	45.7	5.3	7.5
Maximum	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Standard Deviation	20.28	12.32	17.18	5.7	10.25	11.15	25.23	18.15	20.12	1.55	15.35	15.27	5.45	7.47	10.38	12.21	15.17	17.75

Appendix 2. Estimated stochastic production functions

Brahmanbaria

I. Stochastic Production Function:

$Ln\ y_i = 3.353 + 0.760 \ln x_{i1} + 0.515 \ln x_{i2} + 0.187 \ln x_{i3} + 0.\ 201 \ln x_{i4} + 0.608 \ln x_{i5} + 0.361 \ln x_{i6} + 0.081 \ln x_{i7} + 0.056 \ln x_{i8}$

or, $y_i = 3.353\ x_{i1}^{0.760}\ x_{i2}^{0.515}\ x_{i3}^{0.187} x_{i4}^{0.201}\ x_{i5}^{0.608}\ x_{i6}^{0.361} x_{i7}^{\ 0.081}\ x_{i8}^{0.056}$

II. Dual stochastic frontier cost function:

$C\ (P_{ik}, \tilde{y}_i) = 3.990 P_{i1}^{0.274}\ P_{i2}^{0.186}\ P_{i3}^{0.068}\ P_{i4}^{0.073}\ P_{i5}^{0.220}\ P_{i6}^{0.130}\ P_{i7}^{0.029}\ P_{i8}^{0.020}\ \tilde{y}_i^{0.361}$

III. Input demand function:

$x_{i1} = \frac{\partial C}{\partial P_{i1}} = 3.990(0.274)\ P_{i1}^{(0.274\text{-}1)}\ P_{i2}^{0.186}\ P_{i3}^{0.068}\ P_{i4}^{0.073}\ P_{i5}^{0.220}\ P_{i6}^{0.130}\ P_{i7}^{0.029}\ P_{i8}^{0.020}\ \tilde{y}_i^{0.361}$

or, $x_{i1} = \frac{1.093\ P_{i2}^{0.186}\ P_{i3}^{0.068}\ P_{i4}^{0.073}\ P_{i5}^{0.220}\ P_{i6}^{0.130}\ P_{i7}^{0.029}\ P_{i8}^{0.020}\ \tilde{y}^{0.361}}{P_{i1}^{0.726}}$

where, i = 1, 2, 3, …, 50, number of farms

Narsingdi

I. Stochastic Production Function:

$Ln\ y_i = 9.860 + 0.678 \ln x_{i1} + 0.591 \ln x_{i2} + 0.380 \ln x_{i3} + 0.591 \ln x_{i4} + 0.163 \ln x_{i5} + 0.149 \ln x_{i6} + 0.029 \ln x_{i7}$

or, $y_i = 9.860\ x_{i1}^{0.678}\ x_{i2}^{0.591}\ x_{i3}^{0.380} x_{i4}^{0.591}\ x_{i5}^{0.163}\ x_{i6}^{0.149} x_{i7}^{\ 0.029}$

where, i = 1, 2, 3, …, 50, number of farms.

II. Dual stochastic frontier cost function:

$C(P_{ik}, \tilde{y}_i) = 2.251 P_{i1}^{0.263}\ P_{i2}^{0.229}\ P_{i3}^{0.147}\ P_{i4}^{0.229}\ P_{i5}^{0.063}\ P_{i6}^{0.058}\ P_{i7}^{0.011}\ \tilde{y}_i^{0.387}$

where, i = 1, 2, 3, …, 50, number of farms.

III. Input demand function:

$x_{i1} = \frac{\partial C}{\partial P_{i1}} = 2.251(0.263) P_{i1}^{(0.263\text{-}1)}\ P_{i2}^{0.229}\ P_{i3}^{0.147}\ P_{i4}^{0.229}\ P_{i5}^{0.063}\ P_{i6}^{0.058}\ P_{i7}^{0.011}\ \tilde{y}_i^{0.387}$

or, $x_{i1} = \frac{0.592\ P_{i2}^{0.229}\ P_{i3}^{0.147}\ P_{i4}^{0.229}\ P_{i5}^{0.063}\ P_{i6}^{0.058}\ P_{i7}^{0.011}\ \tilde{y}^{0.387}}{P_{i1}^{0.737}}$

where, i = 1, 2, 3, …, 50, number of farms.

Munshigonj

I. Stochastic Production Function:

$\ln y_i = 5.262 + 0.533 \ln x_{i1} + 0.648 \ln x_{i2} + 0.449 \ln x_{i3} + 0.342 \ln x_{i4} + 0.457 \ln x_{i5} + 0.240 \ln x_{i6} + 0.155 \ln x_{i7} + 0.183 \ln x_{i8}$

or, $y_i = 5.262 x_{i1}^{0.533} x_{i2}^{0.648} x_{i3}^{0.449} x_{i4}^{0.342} x_{i5}^{0.457} x_{i6}^{0.240} x_{i7}^{0.155} x_{i8}^{0.183}$

where, i = 1, 2, 3, …, 100, number of farms.

II. Dual stochastic frontier cost function:

$C(P_{ik}, \tilde{y}_i) = 4.169\, P_{i1}^{0.177} P_{i2}^{0.215} P_{i3}^{0.149} P_{i4}^{0.114} P_{i5}^{0.152} P_{i6}^{0.080} P_{i7}^{0.052} P_{i8}^{0.061} \tilde{y}_i^{0.333}$

where, i = 1, 2, 3, …, 100, number of farms.

III. Input demand function:

$$x_{i1} = \frac{\partial C}{\partial P_{i1}} = 4.169(0.177) P_{i1}^{(0.177-1)} P_{i2}^{0.215} P_{i3}^{0.149} P_{i4}^{0.114} P_{i5}^{0.152} P_{i6}^{0.080} P_{i7}^{0.052} P_{i8}^{0.061} \tilde{y}_i^{0.333}$$

or, $$x_{i1} = \frac{0.738\, P_{i2}^{0.215} P_{i3}^{0.149} P_{i4}^{0.114} P_{i5}^{0.152} P_{i6}^{0.080} P_{i7}^{0.052} P_{i8}^{0.061} \tilde{y}^{0.333}}{P_{i1}^{0.823}}$$

where, i = 1, 2, 3, …, 100, number of farms.

Joypurhat

I. Stochastic Production Function:

$\ln y_i = 10.176 + 0.512 \ln x_{i1} + 0.448 \ln x_{i2} + 0.299 \ln x_{i3} + 0.482 \ln x_{i4} + 0.315 \ln x_{i5} + 0.108 \ln x_{i6} + 0.007 \ln x_{i7} + 0.009 \ln x_{i8}$

or, $y_i = 10.176\, x_{i1}^{0.512} x_{i2}^{0.448} x_{i3}^{0.299} x_{i4}^{0.482} x_{i5}^{0.315} x_{i6}^{0.108} x_{i7}^{0.007} x_{i8}^{0.009}$

where, i = 1, 2, 3, …, 100, number of farms.

II. Dual stochastic frontier cost function:

$C(P_{ik}, \tilde{y}_i) = 1.968 P_{i1}^{0.235} P_{i2}^{0.206} P_{i3}^{0.137} P_{i4}^{0.221} P_{i5}^{0.144} P_{i6}^{0.050} P_{i7}^{0.003} P_{i8}^{0.004} \tilde{y}_i^{0.459}$

where, i = 1, 2, 3, …, 100, number of farms.

III. Input demand function:

$$x_{i1} = \frac{\partial C}{\partial P_{i1}} = 1.968(0.235) P_{i1}^{(0.235-1)} P_{i2}^{0.206} P_{i3}^{0.137} P_{i4}^{0.221} P_{i5}^{0.144} P_{i6}^{0.050} P_{i7}^{0.003} P_{i8}^{0.004} \tilde{y}_i^{0.459}$$

or, $$x_{i1} = \frac{0.462 P_{i2}^{0.206} P_{i3}^{0.137} P_{i4}^{0.221} P_{i5}^{0.144} P_{i6}^{0.050} P_{i7}^{0.003} P_{i8}^{0.004} \tilde{y}^{0.459}}{P_{i1}^{0.}}$$

where, i = 1, 2, 3, …, 100, number of farms.

Dinajpu

I. Stochastic Production Function:

Ln y_i = 12.894 + 0.758 ln x_{i1} + 0.445 ln x_{i2} + 0.267 ln x_{i3} + 0.381 ln x_{i4} + 0.356 ln x_{i5} + 0.067ln x_{i6} + 0.074 ln x_{i7}+ 0.052 ln x_{i8}

or, $y_i = 12.894\, x_{i1}^{0.758}\, x_{i2}^{0.445}\, x_{i3}^{0.267}\, x_{i4}^{0.381}\, x_{i5}^{0.356}\, x_{i6}^{0.067}\, x_{i7}^{0.074}\, x_{i8}^{0.052}$,

where, i = 1, 2, 3, …, 50, number of farms.

II. Dual stochastic frontier cost function:

$C(P_{ik}, \tilde{y}_i) = 2.056 P_{i1}^{0.316}\, P_{i2}^{0.185}\, P_{i3}^{0.111}\, P_{i4}^{0.159}\, P_{i5}^{0.148}\, P_{i6}^{0.028}\, P_{i7}^{0.031}\, P_{i8}^{0.022}\, \tilde{y}_i^{0.417}$

where, i = 1, 2, 3, …, 50, number of farms.

III. Input demand function:

$x_{i1} = \frac{\partial C}{\partial P_{i1}} = 2.056(0.316) P_{i1}^{(0.316-1)}\, P_{i2}^{0.185}\, P_{i3}^{0.111}\, P_{i4}^{0.159}\, P_{i5}^{0.148}\, P_{i6}^{0.028}\, P_{i7}^{0.031}\, P_{i8}^{0.022}\, \tilde{y}_i^{0.417}$

or, $x_{i1} = \frac{0.650\, P_{i2}^{0.185}\, P_{i3}^{0.111}\, P_{i4}^{0.159}\, P_{i5}^{0.148}\, P_{i6}^{0.028}\, P_{i7}^{0.031}\, P_{i8}^{0.022}\, \tilde{y}^{0.417}}{P_{i1}^{0.684}}$,

where, i = 1, 2, 3, …, 50, number of farms.

Rangpur

I. Stochastic Production Function:

Ln y_i = 6.445 + 0.662 ln x_{i1} + 0.429 ln x_{i2} + 0.365 ln x_{i3} + 0.439 ln x_{i4} + 0.330 ln x_{i5} + 0.263ln x_{i6} + 0.215 ln x_{i7}+ 0.193ln x_{i8}

or, $y_i = 6.445\, x_{i1}^{0.662}\, x_{i2}^{0.429}\, x_{i3}^{0.365}\, x_{i4}^{0.439}\, x_{i5}^{0.330}\, x_{i6}^{0.263}\, x_{i7}^{0.215}\, x_{i8}^{0.193}$

where, i = 1, 2, 3, …, 50, number of farms.

II. Dual stochastic frontier cost function:

$C(P_{ik}, \tilde{y}_i) = 3.907\, P_{i1}^{(0.229)}\, P_{i2}^{0.148}\, P_{i3}^{0.126}\, P_{i4}^{0.152}\, P_{i5}^{0.114}\, P_{i6}^{0.091}\, P_{i7}^{0.074}\, P_{i8}^{0.067}\, \tilde{y}_i^{0.345}$

where, i = 1, 2, 3, …, 50, number of farms.

III. Input demand function:

$x_{i1} = \frac{\partial C}{\partial P_{i1}} = 3.907(0.229) P_{i1}^{(0.229-1)}\, P_{i2}^{0.148}\, P_{i3}^{0.126}\, P_{i4}^{0.152}\, P_{i5}^{0.114}\, P_{i6}^{0.091}\, P_{i7}^{0.074}\, P_{i8}^{0.067}\, \tilde{y}_i^{0.345}$

or, $x_{i1} = \frac{0.895\, P_{i2}^{0.148}\, P_{i3}^{0.126}\, P_{i4}^{0.152}\, P_{i5}^{0.114}\, P_{i6}^{0.091}\, P_{i7}^{0.074}\, P_{i8}^{0.067}\, \tilde{y}^{0.345}}{P_{i1}^{0.771}}$,

where, i = 1, 2, 3, …, 50, number of farms.

Appendix 3. Factors Affecting Inefficiency in Potato Farming

	Brahmanbaria			Narsingdi			Munshigonj			Joypurhat			Dinajpur			Rangpur		
Factors	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE
	Coefficients (t-ratios)			Coefficients (t-ratios)			Coefficients (t-ratios)			Coefficients (t-ratios)			Coefficients (t-ratios)			Coefficients (t-ratios)		
Constant	0.109 (10.012)	0.116 (4.229)	0.059 (3.012)	0.085 (8.158)	0.258 (2.309)	0.277 (2.263)	0.207 (7.625)	0.146 (9.88)	0.368 (2.490)	0.226 (15.108)	0.063 (3.302)	0.064 (5.275)	0.019 (3.001)	0.140 (8.889)	0.163 (3.605)	0.050 (4.767)	0.264 (2.353)	0.310 (2.236)
Age	-0.005 (-4.707)	-0.003 (-2.987)	-0.008 (-5.837)	-0.009 (-7.944)	-0.004 (-3.583)	-0.007 (-3.234)	-0.004 (-3766)	-0.002 (-2.259)	-0.004 (-3.514)	-0.002 (-2.141)	-0.009 (-4.673)	-0.009 (-4.696)	-0.003 (-2.701)	-0.008 (-4.803)	-0.003 (-2.838)	-0.004 (-3.608)	-0.005 (-2.219)	-0.005 (-2.579)
Education	-0.003 (-3.259)	-0.006 (-2.644)	-0.004 (-3.091)	-0.007 (-2.690)	-0.004 (-4.141)	-0.003 (-2.288)	-0.007 (-4.824)	-0.006 (-4.104)	-0.003 (-2.259)	-0.006 (-6.403)	-0.009 (-4.192)	-0.007 (-8.055)	-0.005 (-4.745)	-0.004 (-3.249)	-0.007 (-4.696)	-0.005 (-3.640)	-0.009 (-4.507)	-0.007 (-5.604)
Experience	-0.006 (-5.226)	-0.004 (-3.763)	-0.003 (-2.834)	-0.008 (-3.374)	-0.006 (-5.253)	-0.004 (-3.674)	-0.008 (-7.085)	-0.007 (-2.376)	-0.004 (-3.820)	-0.008 (-3.337)	-0.003 (-3.134)	-0.003 (-2.338)	-0.006 (-4.086)	-0.005 (-2.131)	-0.002 (-2.136)	-0.008 (-4.005)	-0.005 (-3.929)	-0.003 (-2.367)
Land Frag - mentation	0.054 (2.720)	0.041 (2.992)	0.065 (3.824)	0.018 (5.015)	0.011 (0.502)	0.017 (2.716)	0.001 (2.159)	0.003 (2.680)	0.006 (3.138)	0.003 (2.528)	0.017 (3.018)	0.017 (3.993)	2.937	0.004 (2.447)	0.007 (2.743)	0.015 (2.683)	0.031 (2.967)	0.023 (2.281)
Family size	0.002 (0.167)	0.009 (1.321)	0.010 (1.133)	0.002 (0.289)	0.008 (4.373)	0.002 (1.063)	0.008 (0.552)	0.017 (1.997)	0.009 (0.892)	0.005 (1.137)	0.011 (0.774)	0.126 (0.826)	0.015 (0.937)	0.002 (0.351)	0.010 (1.102)	0.005 (0.335)	0.004 (0.415)	0.006 (0.519)
Deweeding	-0.001 (-5.126)	-0.001 (-2.898)	-0.001 (3.466)	-0.002 (-2.011)	-0.001 (-2.166)	0.001 (-2.195)	-0.001 (-2.630)	-0.011 (-2.062)	-0.006 (-2.295)	-0.002 (-2.304)	0.002 (-2.876)	-0.001 (-2.815)	-0.002 (-6.213)	-0.002 (-2.160)	-0.001 (-2.217)	-0.015 (-5.976)	-0.001 (-2.702)	-0.011 (-2.145)
Access to Credit – Dummy							-0.153 (-8.116)	-0.008 (-5.428)	-0.076 (-5.340)	-0.015 (-11.320)	-0.014 (-3.089)	-0.009 (-4.207)				-0.189 (-3.624)	-0.105 (-9.624)	-0.038 (-3.782)
Cold Storage – dummy							-0.167 (-2.113)	-0.165 (-2.062)	-0.226 (-2.352)	-0.191 (-4.288)	-0.116 (-2.982)	-0.121 (-3.182)				-0.307 (-2.276)	-0.087 (-2.100)	-0.212 (-2.198)
Training – Dummy							-0.049 (-2.621)	-0.034 (-2.920)	-0.050 (-3.613)	-0.032 (-18.462)	-0.087 (-2.992)	-0.092 (-2.056)	-0.071 (-5.572)	-0.009 (-3.404)	-0.043 (-2.156)	-0.245 (-3.357)	-0.008 (-5.973)	-0.132 (-8.847)