Journal of Dry Zone Agriculture, 2021, 7(1):50-65

Technical efficiency and its determinants: Paddy farming in Mahakanumulla cascade system

K.L.P.A. Perera* and D. Hemachandra

Department of Agricultural Economics and Business Management, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.

Received 14th February 2021, Accepted 10th November 2021

Abstract

Paddy farming is predominantly practiced in the dry zone of Sri Lanka. Most paddy lands in the dry zone belong to traditional hydrological cascade systems known as Village Tank Cascade Systems (VTCS) and paddy lands receive irrigation water from the tanks in VTCS. Land is a scarce resource for agriculture in Sri Lanka. Therefore, it is important to achieve high efficiency in paddy farming to increase paddy production in the country. A paddy farm is technically efficient if it is producing the maximum output using the minimum quantities of inputs, such as labour, capital, and technology. This study examines technical efficiency of paddy farmers in Mahakanumulla VTCS and its determinants. The technical efficiency of the farmers is estimated using parametric frontier technique; the Stochastic Frontier Analysis (SFA). In the first stage of the analysis a production function is estimated using the Maximum Likelihood Estimator. In the second stage, an inefficacy model is estimated with plot size, age,

* Corresponding author
Postal address: Department of Agricultural Economics and Business Management, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.
Email: lakshanpriyabashana@gmail.com
ORCID ID: https://orcid.org/0000-0001-6666-7164

experience, household size, full time farming, and land ownership status as determinants of technical inefficiency. According to the results, the average technical efficiency of paddy farmers in Mahakanumulla VTCS is 92.3%. Only the plot size, experience, and household size are positively related to technical inefficiency and significant at 10%. According to the study findings, the technical efficiency of paddy farmers in Mahakanumulla VTCS does not vary significantly from the most efficient farmer in the area. This could be due to the fact that in the VTCS, farmers are operating under more homogenous conditions. However, it does not indicate that paddy farmers in Mahakanumulla VTCS are highly productive as results only reveal the technical efficiency level of paddy farmers in comparison to the most efficient paddy farmer in the area. Therefore, it is important that productivity improvements are continuously carried out.

Keywords: inefficiency model, land tenure, paddy, stochastic frontier analysis, technical efficiency

INTRODUCTION

Rice is the staple food of Sri Lankans. There are approximately 1.8 million farm families engaged in paddy cultivation in Sri Lanka. Paddy is grown on nearly about 957,596 ha of land and production is about 4,592,056 MT with an average yield of 4,795 kg/ha (Department of Census and Statistics, 2019).

Today, one of the main issues faced by Sri Lanka as well as the world is food scarcity due to rapid population growth. In order to face the challenge of food scarcity, it is vital to have an efficient agricultural sector. Efficiency can be defined as the ability to produce a given level of output at the lowest cost (Abdulai and Huffman, 1998). Efficient paddy farming systems will not help only to reduce the food shortage; but also, to generate new employment opportunities and to earn more foreign exchange.

To increase the production efficiency, it is essential to find out the individual efficiency level of farmers who produce paddy using inputs significantly affecting paddy production such as seeds, fertilizers, weedicides, pesticides, labor, and machines. Further, there could be other factors that affect the efficiency level of farms such as the socio-demographic characteristics of the farmer, institutional characteristics, and policy changes. Historically one of the important institutional arrangements in paddy farming is land tenure arrangements. Even though traditional tenure arrangements are not present today in their original form, we can observe different land ownership statuses which was the base for tenure arrangements. While some cultivate their own land, some others cultivate land obtained on lease, rent, and or permits. Depending on land ownership status, farmer's efforts could be different. Therefore, it is important to identify the effect of land ownership status on the technical efficiency of farms. Further, paddy land is subjected to fragmentation. While plot size gets smaller, they are dispersed geographically making managing them difficult by one farmer. Therefore, it is important to find out the effect of land ownership and plot size on the farm efficiency as this knowledge is important to the policymakers in suggesting changes to agricultural land policies in Sri Lanka to increase productivity. The dry zone of Sri Lanka does not receive enough rainfall for paddy cultivation in the *Yala* season. To facilitate paddy cultivation two seasons per year, the Village Tank Cascade Systems (VTCS) were introduced to the dry zone of Sri Lanka by ancient rulers. The VTCS ensured optimum water management and continuous paddy cultivation in both rainy as well as drought seasons (Geekiyanage and Pushpakumara, 2013). In this context, this research is carried out with the objectives of examining the average level of technical efficiencies of paddy farmers in Mahakanumulla VTCS, examining different determinants affecting the technical efficiency of farmers in Mahakanumulla VTCS and identifying the effect of land ownership status and plot size for the efficiency of paddy farmers in Mahakanumulla VTCS.

MATERIALS AND METHODS

Technical Efficiency can be explained as a ratio between observed output and the frontier output of the corresponding farmer. The simple meaning of technical efficiency is getting the maximum amount of output from a minimum amount of input utilization. Technical inefficiency can be explained as the amount or level of output that falls below the frontier output (Danso-Abbeam, 2015; Mabe *et al.*, 2018). In this study, SFA was employed to estimate the production function. The SFA is based on a production frontier in an econometric specification. In SFA, a nonnegative random component is included in the error term which is used as the measure of technical inefficiency (Meeusen and van Den Broeck, 1977).

The stochastic frontier output varies around the deterministic frontier because of the noise effect. In the case of farm A (Figure 1), the noise effect is positive. In consequence, the stochastic frontier output (q_A*) lies above the deterministic frontier. However, since the inefficiency effect is greater than the noise effect, the observed output (q_A) lies under the deterministic frontier (Figure 1). In the case of farm B, both the noise and the inefficiency effect are negative. Thus, the stochastic frontier output (q_B*) and the observed output (q_B) both lie under the deterministic frontier. Empirically, the noise effect is equally distributed around the deterministic frontier while the inefficiency effect tends to lie below. The features of the model generalize to the multi-input, multi-output case (Coelli *et al.*, 2005).

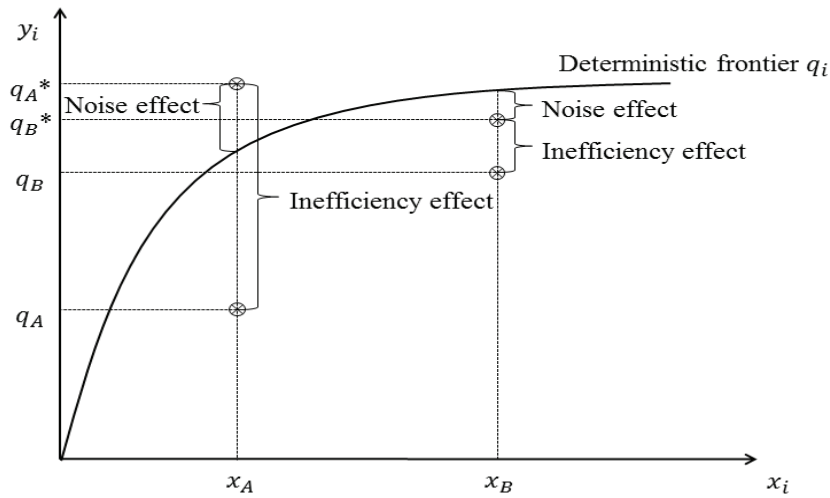

Figure 1: The Stochastic Frontier Model (Source: Coelli *et al.*, 2005)

The stochastic frontier production function is;

$$Y_i = f(x_i; \beta) + e_i$$
Where i = 1,2,3,4 … .N
and $e_i = (v_i - u_i)$

Here, Y_i is the output level of the i^{th} farmer, $f\ (x_i;\ \beta)$ is the production function, x_i is the vector of inputs for the i^{th} farmer and a vector β is the parameters to be estimated. e_i is the error term which is consisted of two components as v_i and u_i. The error term v_i is for the random error as a result of measurement errors and other factors that are not under the control of farmers in production. u_i is a non-negative error term associated with farmer-specific factors, making farmers unable to obtain maximum efficiency in production. The u_i measures the technical inefficiency effects

that fall within the control of the decision-making unit.
According to the above description, the model in the log-linear form of the stochastic production frontier using the Cobb-Douglas functional specification introduced by Battese and Coelli (1995) which was used to determine the technical efficiency of the rice farmers is expressed below.

$$lnYi = b_0 + b_1 lnX_{1_i} + b_2 lnX_{2_i} + b_3 lnX_{3_i} + b_4 lnX_{4_i} + b_5 lnX_{5_i} + (V_i - U_i) \quad (2)$$

Here i= i^{th} farmer.
Y=Income from paddy (Rs./Year/Acre)
X_1=Land preparation cost (Rs./Year/Acre)
X_2=Seed cost (Rs./Year/Acre)
X_3=Fertilizer cost (Rs./Year/Acre)
X_4=Labour cost (Rs./Year/Acre)
X_5=Total Harvest cost (Rs./Year/Acre)

TE of the i^{th} farmer can be specified as:

$$TE_i = \frac{Observed\ output\ of\ ith\ farm\ household}{Frontier\ output\ of\ all\ farm\ household} = \frac{Y_i}{Y_i^*} = \frac{f(x_i;\beta).e^{v_i - u_i}}{f(x_i;\beta).e^{v_i}} = e(-u) \quad (3)$$

Technical inefficiency=1 - TE_i (4)

(Konja *et al.*, 2019)

The error component v_i is assumed to be identically, independently and normally distributed with zero mean and constant variance, N(0,. The error component u_i is also assumed to be distributed as truncation of a normal distribution with mean and variance N(0, such that the inefficiency error term can be explained by exogenous variables (Battese and Coelli,1995).

The inefficiency distribution parameter can be specified as;

$$u_i = \delta_0 + Z_i\delta + \omega_i \quad (5)$$

Here Z_i is a vector of farmer characteristics and, δ is a vector of parameters to be estimated, and ω_i is unobservable random variables.

Determinants of technical inefficiency

Many studies have identified a positive relationship between technical efficiency and socio-demographic variable of the farmers, institutional characteristics and policy changes. The factors such as the age of farmer, farming experiences, plot size, and land ownership status were considered as determinants of technical efficiency in paddy farming in Mahakanumulla VTCS. Among different land ownership types, sole ownership, shared ownership, rented in, permits were considered in the inefficiency model (Ureta and Evenson, 2007).

The inefficiency model specified for Battese and Coelli (1995) specification was,

$$Ui = \alpha_0 + \alpha_1 lnZ_1 + \alpha_2 lnZ_2 + \alpha_3 lnZ_3 + \alpha_4 Z_4 + \alpha_5 Z_5 + \alpha_6 Z_6 + \propto_7 lnZ_7 + \propto_8 Z_8 + \in \quad (6)$$

Z_1 = Plot size (acres)
Z_2 = Age of farmers (years)
Z_3 = Paddy farming experiences (years)
Z_4 = Sole ownership (sole ownership=1 if the land is solely owned and rented in=0)
Z_5 =Shared ownership (shared=1, rented in=0)
Z_6 = Permits (permits=1, rented in=0)
Z_7 =Household size
Z_8= full-time farming (fulltime=1, parttime=0)

(Shantha *et al.,* 2012)

Data and sample

Individual paddy farmer belonging to the Mahakanumulla VTCS in the Thirappane Divisional Secretariat (DS) in Anuradhapura District was the unit of analysis. A cascade system is a hydrological system comprising of a network of tanks that harvest rainwater and a canal system that distributes water to the paddy lands. A cascade system was selected as the study site because it is a paddy-based production system and at present, the cascade system has undergone a lot of changes which may have affected paddy farming. For the sample, all farm households in the thirteen villages from the Thirappane DS division which belong to the Mahakanumula VTCS were considered. Face to face questionnaire surveys was carried out during a ten-day period from the twenty-first of February to the first of

March in 2020. At the initial screening of data, incomplete questionnaires and outliers were removed. Data from a sample of 199 farmers were used for the analysis.

RESULTS AND DISCUSSION

Descriptive statistics

Summary statistics of the variables used in the stochastic production function estimation and the inefficiency model are given in Table 1. According to Table 1 data, the average size of paddy land per farm in the Mahakanumulla VTCS is 1.59 acres (6434.5 m^2). This implies that the paddy farmers in the study area are mainly smallholder farmers operating on less than a hectare of paddyland.

Stochastic Frontier Production Efficiency Model

The maximum likelihood parameter estimates of the stochastic production function estimation are presented in Table 2. Coefficients, standard error, and *p*-value of each variable are shown.

The coefficients of all input costs are positive. Apart from labor cost and fertilizer cost, all the other inputs are significant at 5% significant level. This explains that output and hence income increases with the increased use of these variables. The cost of inorganic fertilizer is not significant due to less variability in the data. The government issues 50 kg of Urea, 16 kg of MOP, and 8 kg of TSP for one acre of paddy land free. Since most of the farmers in the Mahakanumulla VTCS are smallholders, paddy revenue may not be affected by the fertilizer cost.

Determinants of technical inefficiency of rice farmers

The inefficiency model was run with stochastic frontier inefficiency estimates. The inefficiency model estimates are provided in Table 3. None of the variables are significant at 95% confidence level. However, log of plot size is marginally significant (p=0.05) and positively related. This implies that inefficiency increases with plot size. That could be because when plot size is small it is easier to manage than managing a large plot. Since most farmers are relying on family labor, larger plots could be difficult to manage. Therefore, smaller paddy farms could be technically more efficient than larger farms. The coefficient estimate for farming experience is -1.8472 and it is marginally significant (p=0.056). This result

Table 1: Summary statistics

Variable	Mean	Maximum	Minimum	Standard deviation
Production Function				
Input variables				
Land preparation cost (Rs./Year/Acre)	14343	36500	0	7457.54
Seed cost (Rs./Year/Acre)	5229	30300	0	4601.79
Fertilizer cost (Rs./Year/Acre)	4049	22150	0	7117.22
Labour cost (Rs./Year/Acre)	1102	19200	0	2658.03
Harvesting cost (Rs./Year/Acre)	11557	30650	0	6127.80
Output				
Income (Rs./Year/Acre)	97656	680000	10750	66756.21
Inefficiency Model Determinants				
Plot size (Acres)	1.59	7	0.25	1.39
Age (Years)	50.75	80	22	12.12
Experience (Years)	24.58	60	1.5	13.65
Household size	6.81	18	2	2.78

(Source: Field Survey, 2020)

Table 2: Maximum-Likelihood Parameter Estimates for the Stochastic Production Frontier Model

Variable	Coefficient	Standard error	*P*-Value
*ln*land preparation cost	0.2007	0.0289	0.000
*ln*seed cost	0.0683	0.0213	0.001
*ln*fertilizer cost	0.0006	0.0142	0.961
*ln*labor cost	0.0016	0.0110	0.880
*ln*harvest cost	0.1606	0.0294	0.000

Table 3: Maximum Likelihood Estimates of the Determinants of Technical Inefficiency Model for paddy farms in Mahakanumulla VTCS

Variable	Coefficient	Standard error	p-Value
*ln*plot size	1.2171	0.2617	0.050
*ln*age	2.1327	1.3510	0.483
*ln*experience	-1.8472	0.4575	0.056
*ln*household size	2.9304	1.5328	0.056
Sole ownership(dummy)	-1.3173	1.0388	0.205
Shared ownership(dummy)	-3.1124	2.6734	0.244
Permits(dummy)	-4.4239	4.4921	0.206
Full time farming dummy	25.18	1249	0.984

implies that the higher the experience of the farmer, the lesser the level of inefficiency. Even though it was hypothesized that the land ownership status has a significant impact on technical inefficiency, the results show no significant effect of land ownership.

Technical efficiency distribution among farmers

The obtained technical efficiency estimates were categorized into efficiency ranges. Then the frequency of farms under each range and frequency percentages were calculated and are presented in the Table 4.

Table 4: Distribution of Technical Efficiency among Farmers

Range	Frequency	Percentage	Cumulative Percentage
0-0.19	1	0.5	0.5
0.2-0.299	0	0	0.5
0.3-0.399	0	0	0
0.4-0.499	1	0.5	1.5
0.5-0.599	0	0	1.5
0.6-0.699	2	1	2.5
0.7-0.799	9	4.5	7
0.8-0.899	42	21	28
0.9-1	144	72	100.00
Total Farms	199	100	
Mean	0.923		
Maximum	1		
Minimum	0.183		
Standard Deviation	0.1065		

(Source: Field survey, 2020)

According to the frequency distribution, the number of paddy farmers is in the range 90%-100% of efficiency is 144. Only 1.5% of farmers are below 50% efficiency. The average technical efficiency of paddy farmers is 0.923 or 92.3%. That means only 7.7% of efficiency needs to be improved in paddy farmers. While high average technical efficiency could imply that a large majority of paddy farmers are technically efficient, it could also imply low variation among paddy farmers in Mahakanumulla VTCS.

Technical efficiency distribution by inefficiency determinants

In this study, plot size, age, experience, and land ownership were used as the inefficiency determinants of the farmers. Average values of estimated efficiency levels for different levels of these variables are presented to better understand the variation in the data.

Plot size

Plot size was categorized into eight categories as shown in Table 5. The frequencies, percentages, and average efficiencies of each size category of paddy land are shown in Table 5. It could be seen that smaller land plots have a higher average level of technical efficiency compared to larger land plots.

Table 5: Plot size vs. average efficiency and frequency distribution

Plot size (Acres)	Frequency	Percentage	Average efficiency
<=1	118	59	0.943
1-2	47	24	0.922
23	17	8.5	0.883
3-4	4	2	0.925
4-5	7	3.5	0.889
5-6	4	3	0.776
6-7	2	1	0.811

(Source: Field survey, 2020)

Age of the farmer

The age of the farmer was categorized into six categories according to the age intervals as 20-29, 30-39 ...70-80. The frequencies, percentages, and average efficiencies of each category are displayed in Table 6. According to Table 6, the highest number of farmers belong to the age category of 50s. It is about 61 farmers or 30.5% of the sample. Even though not statistically significant some increase in the average technical efficiency with age could be observed. The highest efficient farmers are in the age category between 60-69.

Farming experience

Paddy farming experience was categorized into six categories as shown in Table 7. The frequencies, percentages, and average efficiencies of each category are shown in Table 7.

Table 6: Age of the farmer vs. average efficiency and frequency distribution

Age	Frequency	Percentage	Average efficiency
20-29	10	5	0.893
30-39	29	14.5	0.887
40-49	48	24	0.917
50-59	60	30.5	0.925
60-69	40	20	0.956
70-80	12	6	0.94

(Source: Field survey, 2020)

According to Table 7, 52 farmers or 26% of the sample have 20 to 29 years of experience in paddy farming. More than 45% of farmers are having more than 30 years of experience in paddy farming. The average efficiency shows an increase with the farming experience.

Table 7: Farming experience vs. average efficiency and frequency distribution

Experience	Frequency	Percentage	Average efficiency
0-9	36	18	0.876
10 19	30	15	0.894
20-29	52	26	0.927
30-39	43	21.6	0.958
40-49	27	13.5	0.95
50-60	11	5.5	0.935

(Source: Field survey, 2020)

Land ownership

Land tenure is categorized into three categories as sole ownership, shared ownership, permits, and rented in. The frequencies, percentages, and average efficiencies under each ownership category are displayed in Table 8.

Table 8: Land ownership status vs. average efficiency and frequency distribution

Tenure status	Frequency	Percentage	Average Efficiency
Sole ownership	148	74.5	0.928
Shared	21	10.5	0.966
Permit	5	2.5	0.954
Rented in	25	12.5	0.853

(Source: Field survey, 2020)

According to Table 8, 74.5% of farmers are sole owners of the paddy land they cultivate. The average efficiency does not vary much according to the land ownership status. However, the average technical efficiency in rented land is lower than other status of land ownership even though it is not statistically significant.

Household size

The household size of the paddy farmer was categorized into five categories as shown in Table 9 based on the number of family members. The frequencies, percentages, and average efficiencies under each household size category are displayed in (Table 9). According to Table 9, 53% of farmers have a family with 5-8 members. It may be that when family size is high, income generated from paddy farming is not sufficient. Therefore, farmers may engage in other occupations and hence may put less effort to paddy farming. It could also be that when family size is bigger, the family income from other sources may also be high. Therefore, farmers may exert less effort on paddy farming which results in a lower efficiency level.

Table 9: Household size vs. average efficiency and frequency distribution

Household size	Frequency	Percentage	Average efficiency
<=4 members	45	23	0.966
5-8 members	104	52.5	0.933
912 members	43	22	0.869
>13 members	6	3	0.772

(Source: Field survey, 2020)

CONCLUSIONS

The main objectives of this study were to assess the average level of technical efficiencies of paddy farmers in the Mahakanumulla VTCS and to identify determinants affecting technical efficiency. Among determinants of technical efficiency, the study was particularly interested in examining the effect of land ownership status and land plot size. The average level of technical efficiency among paddy farmers in the Mahakanumlla VTCS is very high at 92.3%.

Land plot size, age of the farmer, farming experience, household size and land ownership status were used in the inefficiency model. None of the variables were found to be statistically significant at 5% significance suggesting the homogenous nature of paddy farmers and farming in the Mahakanumlla VTCS. However, a slight variation in technical efficiency among paddy farmers could be observed suggesting mature, experienced farmers cultivating relatively small land plots and having small family sizes may be relatively more technically efficient than other paddy farmers in the Mahakanumulla VTCS.

ACKNOWLEDGEMENT

The study was funded by the AHEAD DOR received by the Department of Agricultural Economics and Business Management of the Faculty of Agriculture, University of Peradeniya.

DECLARATION OF CONFLICT OF INTEREST

Authors have no conflict of interest to declare.

REFERENCES

Abdulai, A. and Huffman, W. E. 1998. An Examination of Profit Inefficiency of Rice Farmers in Northern Ghana. Iowa State University, Department of Economics, Staff General Research Papers. No. 296.

Aigner, D.C.A., Knox, L. and Schmidt, P. 1977. Formulation and estimation of Stochastic Frontier Production Function Models. Journal of Econometrics, 6(1):21-37.

Battese, G. E. and Coelli, T. J. 1995. A Model for technical inefficiency effects in a Stochastic Frontier Production Function for panel data. Empirical Economics, 20(2):325–332. https://doi.org/10.1007/BF01205442

Coelli, T., Rao, D.S.P., O'Donnell, C.J. and Battese, G. 2005. An Introduction to efficiency and productivity analysis. 2nd Ed. Springer Publications.

Danso-Abbeam, G., Dahamani, A.M. and Bawa1, G.A.S 2015. Resource-Use-efficiency among smallholder groundnut farmers in Northern region, Ghana. American Journal of Experimental Agriculture 6(5):290-304.

Department of Census and Statistics, 2019, Annual Performance Report. 2019. https://www.parliament.lk/uploads/documents/paperspresented/performance-report-department-of-census-and-statistics-2019.pdf. Accessed 28 March 2020

FAOSTAT. 2020. www.fao.org/faostat. Accessed 10 April 2020

Geekiyanage, N. and Pushpakumara, D. K. N. G. 2013. Ecology of ancient tank cascade systems in island Sri Lanka. Journal of Marine and Island Cultures, 2(2):93–101. https://doi.org/10.1016/j.imic.2013.11.001

Konja, D., Mabe, F. N. and Alhassan, H. 2019. Technical and resource-use-efficiency among smallholder rice farmers in Northern Ghana.

Cogent Food & Agriculture, 5(1):16. https://doi.org/10.1080/23311932.2019.1651473

Mabe, F.N., Donkoh, S.A. and Al-hassan, S. 2018. Accounting for rice productivity heterogeneity in Ghana: The two-step Stochastic Metafrontier Approach. International Journal of Agricultural and Biosystems Engineering, 12(8):223–232. https://doi.org/10.1999/1307-6892/10009379

Meeusen, W. and Van Den Broeck, J. 1977. Efficiency estimation from Cobb-Douglas Production Functions with Composed Error. International Economic Review, 18(2):435-444. doi:10.2307/2525757

Shanmugam, K. R. and Venkataramani, A. 2006. Technical efficiency in agricultural production and its determinants: An exploratory study at the district level. Indian Journal of Agricultural Economics, 61(2):169–184.

Shantha, B.G.H., Asan, A. and Bandara, R.A.G. 2012. Efficiency and managerial ability of paddy farming under MI- NOR irrigation conditions: A Frontier Production Function Approach. The Journal of Agricultural Sciences, 7(3):14.

Ureta, B. E. and Evenson, R. E. 1994. Efficiency in agricultural production: The case of Peasant Farmers in Eastern Paraguay. Agricultural Economics, 10(1):27–37. https://doi.org/10.1016/0169-5150(94)90037-X