TROPICAL AGRICULTURIST, VOL. 163, 2015

TECHNICAL AND ALLOCATIVE EFFICIENCIES OF RICE FARMING UNDER MAJOR IRRIGATION IN MAIN RICE GROWING DISTRICTS OF SRI LANKA

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ABSTRACT

Stochastic frontier production functions of Cobb-Douglos form were estimated for 252 rice farms in *Yala* 2009 season and 248 rice farms during *Maha* 2009/10 season to measure technical and allocative in-efficiencies of rice farming under irrigated water regimes of Ampara, Pollonnaruwa, Anuradhapura and Hambantota districts, and to measure costs of these in-efficiencies to the rice farmers. Rice production of the farm was used as dependent variable, district differences were handled by intercept dummy variables, and land, labour, and capital were used as independent variables. The averages of technical efficiency were, 0.741 (*Yala*) and 0.825 (*Maha*), allocative efficiency were 0.848 (*Yala*), and 0.724 (*Maha*), and economic efficiency were 0.634 (*Yala*) and 0.606 (*Maha*) of the four districts. The potential cost savings/farm by eliminating both technical and allocative inefficiencies range from Rs. 27,000 in Polonnaruwa district to Rs. 43,200 in Anuradhapura district during *Yala* season, and from Rs. 37,500 in Ampara district to Rs. 49,600 in Polonnaruwa district during *Maha* season. The potential aggregate cost savings for the four districts by eliminating both technical and allocative inefficiencies are Rs billion 7.7 for *Yala* season, Rs. billion 18.8 for *Maha* season, and Rs. billion 26.5/annum.

Key words: Allocative efficiency, technical efficiency, economic efficiency, rice farming,

INTRODUCTION

Efficiency of rice farming is a subject that has been researched repeatedly and periodically over time in Sri Lanka because of the importance of rice as the staple food, the majority of Sri Lanka farmers depend on rice farming for livelihood, and raising efficiency of rice farming is vital for poverty alleviation of rural masses. There are some studies that estimated the efficiency of rice farming relative to the best performance among peer groups. These studies, in general, have provided evidence on the existence of substantial technical inefficiency on average with wide differentials in the level of inefficiencies in the rice sector of Sri Lanka (Ekanayake, 1987; Ekanayake and Jayasuriya, 1987; Ekanayake and Jayasuriya, 1989; Karunarathna and Herath, 1989; Gunarathne and Thiruchelvam, 2002; Thiruchelvam, 2005; Thibbatuwawa *et al.,* 2012; Aruna Shantha *et al.,* 2012; Aruna Shantha *et al.,* 2013) and differences of efficiency according to land size and land tenure (Bogahawatte, 1982; Udayanganie *et al.,* 2006; Thibbatuwawa *et al.,* 2012).

Findings of some of these studies also imply that the efficiency differentials widen when the growing environment is associated with higher levels of risk (Ekanayake, 1987; Gunarathne and Thiruchelvam, 2002). Most of the above studies have used Stochastic Frontier Production Function framework in measurement of efficiency. Exceptions are Bogahawatte, (1982) profit function; Karunarathna and Herath (1989) Corrected Ordinary Least Square Frontier and, in general, they have overlooked measurement of allocative inefficiency component. Thibbotuwawa *et al.,* (2012) have measured technical and allocative components of efficiency of Sri Lankan rice farming within Data Envelopment Analysis framework. However, using data of 90 farmers, Thibbotuwawa *et al., (2012)* have covered three water regimes (major irrigated, minor irrigated, and rainfed) in 6 districts. Obviously, the differences in intrinsic characteristics of the districts and water regimes that affect conversion efficiency of inputs in to yield lead to measurement errors of technical efficiency in such a grouping of districts and water regimes. Most of the above studies are location specific, and no attempts have been made to estimate the aggregate costs of inefficiencies to the society. The current study uses relatively larger samples than of previous studies and cover four most important major irrigated districts of the country to measure technical and allocative efficiencies within Stochastic Frontier Production Function Framework and aggregate costs of these inefficiencies to the society. Accordingly, the objectives of the present study are to measure technical and allocative inefficiencies of rice farming under irrigated water regimes in Ampara, Pollonnaruwa, Anuradhapura and Hambantota major rice growing districts, and to measure costs of these inefficiencies to the rice farmers during *Yala* and *Maha*, seasons.

METHODOLOGY

The stochastic frontier production function model proposed by Aigner *et al.*, (1977) and Meeusen and van den Borek (1977), and further developed by and Coelli (1996) is used to measure efficiency of production in this study. In his seminal paper on productive efficiency, Farrell (1957) introduced two indexes of technical efficiency: one in input output (output oriented technical efficiency or $TE^{[o]}$) space and the other in the input input space (input oriented technical efficiency or $TE^{[i]}$). Technical efficiency index ($TE^{[i]}$), allocative efficiency index (AE), and associated economic efficiency (EE) index in input input space (Kopp 1981; Karagiannis *et al.*, 2003) are used in this study to measure efficiency of production.

The method of measuring allocative and technical efficiencies, in input-input space is depicted in Figure 1 for a two-factor case of production. *AB* Efficient Unit Isoquant represents the various combinations of the two factors, X_1 and X_2 used by technically perfectly efficient firm of an industry to produce an output, *P*. Any firm producing an output *P* cannot be positioned in between *AB* and the origin *O*. *Q* and *S* respectively are two technically efficient and inefficient firms that produce an output *P*. These two firms lie on a "Fixed Inputs Use Proportion Ray" (OT) where inputs X_1 and X_2 are used in the same ratio. a technically and allocatively efficient firm lies on *AB* " Efficient Unite Isoquant" on the point which touches the price line

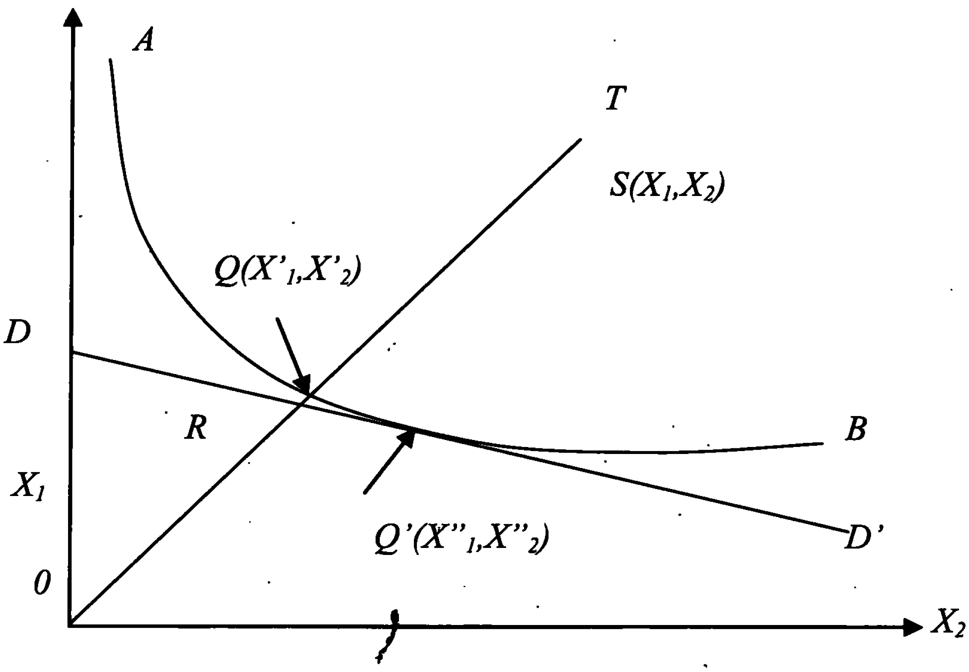

Figure 1. Measurement of efficiency in input-input space

The input based technical efficiency (hereafter $TE^{[i]}$) of the firm *j* is given as, $TE_j^{[i]}$=C'/C, where, C_j, and respectively are the cost of firm *j* and the cost of firm *Q* which is a technically efficient firm that produces, output *P* using inputs in the same proportion as firm *j*. Since same input proportions are used by the efficient firm (*Q*) and inefficient firm (*j*), input based technical efficiency ($TE_j^{[i]}$) is given also by the vector norm formula *OQ/OS*. $TE_j^{[i]}$ and output based technical efficiency ($TE_j^{[o]}$)=Y_j/Y^*_j) are equal when the return to scale is constant and otherwise they are not (Kopp, 1981). Allocative Efficiency of the firm j has been defined as: $AE_j^{[i]}$=C"/C' where, C" is the cost of firm Q' (a technically and allocatively efficient firm with the same output level as of firm j) and C' is as given above. Since measurements are made along the fixed input use proportion ray, OT, $AE_j^{[i]}$ is represented also by the vector norm formula *OR/OQ*. Economic- Efficiency *(AE)* index indicates possibility of cost reduction feasible by eliminating both technical and allocative inefficiencies. The *EE* of a firm is given by $EE_j^{[i]}$=C"/C_j where, C"and C_j are as given above. By definition, *EE* is equal to product of $TE^{[i]}$ and $AE^{[i]}$ and given also by the vector norm formula *OR/OS*.

Since fixed factor proportions are assumed in estimating TE[i] and TE[o], they are free from the effects of factor pricing. The advantage of measurement of allocative efficiency in input-input space is that the AE indices always lie in the range of 0-1. Further, the product of AE and TE results in Economic Efficiency (Kopp, 1981).

Specification of the analytical model

The following Cobb-Douglos stochastic frontier production function model was used.

$$\ln Y_j=\alpha+\sum^{3}_{k=1}\theta_k D_k+\sum^{3}_{i=1}\beta_j \ln X_{ij}+v_j-u_j \text{.......................} (1)$$

Where y_j is the output of j^{th} farmer, $D_k=\{0,1\}$, k, is a dummy variables that takes value of 1 for k^{th} district and 0 for other districts, Xij are denoted as: Landj is the land extent used by j^{th} farmer, $Labor_j$ is amount of labor used for production operations excepting labor used for water management and transport operations, $Capital_j$ is the operating expenditure incurred on all inputs excepting any costs on land, labor, and resources cost of transport of the produce. ε_j is a composit error tem where $\varepsilon_j=v_j-u_j$: is an error term assumed to be distributed identically and independently as N $(0,\sigma_v^2)$ that reckons random variation of output, and u_j, is one sided (uj≥0) error term that reckons variation of output due to inefficiency. In this paper u_j is assumed to follow a half normal distribution (u. N $(0, \sigma_u^2)$. The efficiency parameter $\gamma=(\sigma_u^2/\sigma_u^2+\sigma_v^2)$ lies between 0 and 1, and if $\gamma=0$, the difference between farmer's production and production estimated by the frontier function is entirely due to statistical noise. Conversely, $\gamma=1$ indicates that the difference of actual and estimated production is entirely due to less than efficient use of technology.

Data and assumptions used for the study

All input use and output data needed to compute cost of production and profitability, collected by the Socio-Economics and Planning Center, Department of Agriculture for Cost of Cultivation studies of paddy farming during the above two seasons are processed and used for this study. The sample for Yala 2009 season includes data collected from randomly selected 252 farms under irrigated water regimes of four districts (Ampara, Polonnaruwa, Anuradhapura, and Hambantota) that represent 57% of the rice grown area under major irrigated water regime during that season. The sample for Maha 2009/10 season under major irrigated water regime includes data collected from randomly selected 248 farms of four districts (Ampara, Polonnaruwa, Anuradhapura, and Hambantota) that represent 54% of the rice grown area under major irrigated water regime during Maha season. The variable 'capital' is a composite variable formed by aggregating operating expenditure incurred on material inputs (herbicides, fertilizer, and pesticides) and services of machinery. The cost components of 'capital' are valued at the costs incurred by the farmer, and costs of 'own' seed, and services of own machinery are valued at market prices of similar inputs. Lands were mostly owned by the farmers and were rarely rented in. The paddy lands Act of 1958 and subsequent Agrarian Services Acts prescribe a land rent of 25% of the output. Accordingly, value of 25% of the farm output was considered as the land rent for farmers whose gross margin is above 25% of the value of output, and farmer's gross margin was attributed as the land rent for farmers whose gross margin was less than 25% of the value of output.

Estimation of the model

Frontier 4.1 software (Coeli, 1996) was used to estimate the model. The output based technical efficiency index $[TE_j^{[o]}]$ is given by the software. The input based technical efficiency for a double log frontier production function is given as $[TE]_j^{[i]}=[TE_j^{[o]}]^{(1/\Sigma\beta i)}$ where, $\Sigma\beta_i$ is the sum of estimated production elasticities or scale coefficient. The allocative efficiency of the firm j is estimated by minimizing the cost of the firm at the firm's output level relative to the stochastic frontier production function. Accordingly, allocative efficiency (AE_j) of the firm j is measured by the following equation,

$$AE_j=\exp[-\ln[\Sigma^m_{(1=0)}P_iX_{ij}]+[\ln\hat{Y}_j-\alpha_0/(\Sigma^m_{(i=1)}\alpha_i]-(\Sigma^m_{(i=1)}\alpha_i\ln\alpha_i/P_i)/(\Sigma^m_{(i=1)}\alpha_i)+\ln\Sigma^m_{(i=1)}\alpha_i]......(2)$$

where, P_i is the price of the i^{th} input, and other variables are as defined before.

Estimates of potential cost savings

Cost savings feasible for each farm firm by raising technical efficiencies to unity are estimated as where, C_j is the total cost of production of farmer j and is the potential cost savings for farmer j with raising his technical efficiency to unity.

Cost savings feasible for each farm firm by raising allocative efficiencies to unity are estimated as , where is the potential cost savings for farmer j by eliminating his allocative inefficiency. Then sample sums of cost savings are made, and these sums are divided by sum of district sample extent (ha) to estimate average cost savings Rs/ha for the district. Subsequently, the aggregate costs of inefficiencies at district levels are estimated by multiplying per hectare savings by gross harvested extent for the particular season.

RESULTS AND DISCUSSION

Descriptive statistics of the sample

The averages of land, labor and capital indicates that farms in Ampara are relatively large during both *Yala* and *Maha* seasons, and more or less equal in other districts except in Anuradhapura district during *Yala* season where farm size was relatively small (Table 1). A detailed presentation of the descriptive statistics for district case studies are given in SEPC (2010).

Table 1. Arithmetic means of independent variables.

District	*Yala* 2009			*Maha* 2009/10		
	Land ha	Labor (md)	Capital (Rs)	Land (ha)	Labor (md)	Capital (Rs)
Ampara	1.3	45	55,725	1.4	59	63,890
Anuradhapura	0.5	34	17,755	0.9	68	34,567
Hambantota	1.0	48	47,550	0.9	45	47,635
Polonnaruwa	0.8	48	31,510	1.0	70	40,500
Average	1.0	44	41,700	1.1	61	50,885

Note : md = Man days

Estimated production functions for irrigated farms

The intercept terms in frontier production functions of both *Maha* and *Yala* seasons are significant. The exponential values of the dummy variable coefficients exhibit the level of productivity differences among districts. The exponential values of dummy coefficients are 0.99 for Polonnaruwa, 1.13 for Hambantota, and 0.85 for Anuradhapura in *Yala* season and 1.06 for Polonnaruwa, 1.22 for Hambantota, and 1.17 for Anuradhapura during *Maha* season. With the same level of input use in farms of Ampara district, yields in farms of Polonnaruwa district are lower by 15% during *Yala* season, and 17% higher during *Maha* season whereas yields in Hambantota district are higher by 13% in *Yala* season, and 22% higher in *Maha* season (Table 2). The coefficients for land, labour, and capital, which are elasticities of production, have expected positive signs, and are highly significant during both seasons except in the case of labor during *Yala* season where the level of significance is only 10%. Land has the largest elasticity, capital has the second largest elasticity, and labour has the smallest elasticity in both *Yala* and *Maha* seasons (Table 2). Having the largest elasticity coefficient for land is acceptable as Sri Lanka has expanded paddy production mainly through area expansion. Having the second largest elasticity coefficient in either season for capital also is easily explicable as the adoption of mechanical harvesting and threshing and substitution of manual weeding by herbicides that use capital intensively would lead to high elasticity of capital. The importance of labour is low with the flexibility of substitution of labour by capital services in the form of mechanization and agrochemicals.

Table 2.Estimates of stochastic frontier production functions.

Variable	Frontier Production Function in	
	Yala 2009 season	Maha 2009/10 season
Intercept	3.444*** (5.563)	5.765*** (9.135)
Anuadhapura	- 0.0157 (- 0.2)	0.059 (1.556)
Hambantota	0.119** (2.025)	0.198*** (5.184)
Polonnaruwa	- 0.165** (-2.669)	0.156*** (4.15)
Ln Land	0.573** (6.746)	0.732*** (9.52)
Ln Labour	0.108* (1.776)	0.068*** (2.046)
Ln Capital	0.432*** (7.738)	0.198*** (3.246)
σ^2	0.25*** (7.08)	0.086*** (6.705)
Γ	0.847*** (7.08)	0.802*** (11.427)
Log likely hood Function	- 18.26	- 18.79

*** significant at 1% level, ** significant at 5% level * significant at 10% level; t ratios are in parenthesis.

The γ coefficients of 0.847 in *Yala* season and of 0.802 in *Maha* season indicate that major portion of the variation of output is explained by technical efficiency in both seasons.

Average efficiency estimates

There is a marked difference in average technical efficiencies between *Yala* and *Maha* seasons with an overall means of 0.741 for *Yala* and 0.825 for *Maha* (Table 3). Relatively high level of technical efficiency during *Maha* season is acceptable as lower levels of water constraints reduce management difficulties and enable farmers with relatively low management capabilities also to reach the production frontier. The average technical efficiency indexes indicate that about 26% of the resources cost during *Yala* season and about 17.5% of the resources cost during *Maha* season could be saved by raising technical efficiency. The variation of average technical efficiencies among districts within a season is very low, probably due to adequate representing of differences among districts within a season by the dummy variables in the models, and therefore, only the differences among farmers within the district are reckoned in measurement of efficiency (Table 3).

The estimated average allocative efficiency indices for districts range from 0.788 in Anuradhapura district to 0.915 in Hambantota district during *Yala* and from 0.693 in Polonnaruwa district to 0.762 in Anuradhapura ditrict in *Maha* with an overall average of 0.848 for *Yala* and 0.724 for *Maha* (Table 3). Accordingly, 15% of the cost at technically efficient point at *Yala* and 28% of such cost at *Maha* season, in general, could be saved by raising allocative efficiency. Implicit nature of prices makes estimation of allocative efficiency very difficult. Most of the farmers cultivate their own lands and use own labour and own capital in substantial proportions. Therefore, prices in many cases had to be estimated or assumed, and accuracy of measured efficiency indices depends on accuracy of estimated prices.

Economic efficiency is the product of the technical efficiency and allocative efficiency. The average Economic efficiency indices range from 0.567 in Anuradhapura to 0.702 in Hambantota district during *Yala* season and from 0.579

in Polonnaruwa district to 0.634 in Anuradhapura district during *Maha* season with overall means of 0.634 for *Yala* and 0.606 for *Maha* (Table 3). Accordingly, potential cost savings from reducing technical and allocative inefficiencies range from 30% to 43% *Yala* and 37% to 42% during *Maha* with overall averages of 37% for *Yala* and 39% for *Maha.*

Feasibility of cost savings and impact on farm profitability

The average cost savings per farm feasible by eliminating technical efficiencies have a range starting from Rs. 18,700 in Polonnaruwa district to Rs. 26,590 in Ampara district during *Yala* and Rs. 16,335 in Anuradhapura district to Rs.21,490 in Polonnaruwa district during *Maha.* The average cost of economic inefficiency per farm is Rs. 33,000 in *Yala* season, and Rs 45,460 in *Maha* season. The average cost savings by eliminating allocative inefficiencies are relatively small during *Yala* season: the averages range from Rs 5,540 in Hambantota district to Rs 11,925 in Ampara district. In contrast, the potential cost savings feasible by eliminating allocative inefficiencies during *Maha* season is relatively high: the values range from Rs 17,425 in Anuradhapura district to Rs 29,505 in Ampara district. The average cost savings by eliminating both technical and allocative inefficiencies are relatively small during *Yala* season: the averages range from Rs 26,580 in Hambantota district to Rs 38,700 in Anuradhapura district. In contrast, the potential cost savings feasible by eliminating both technical and allocative inefficiencies during *Maha* season are relatively high: the values range from Rs 33,760 in Anuradhapura district to Rs 50,635 in Ampara district (Table 4).

Table 3.The arithmetic means of technical efficiencies.

District	***Yala* 2009 season**			***Maha* 2009/10 season**		
	TE	**AE**	**EE**	**TE**	**AE**	**EE**
Ampara	0.734	0.855	0.633	0.820	0.72	0.602
Anuradhapura	0.722	0.788	0.567	0.825	0.762	0.634
Hambantota	0.759	0.915	0.702	0.835	0.730	0.614
Polonnaruwa	0.755	0.827	0.631	0.811	0.693	0.579
Mean of Districts	0.741	0.848	0.634	0.825	0.724	0.606

Relatively low allocative efficiencies during *Maha* season and associated higher potential cost savings by eliminating allocative inefficiencies have caused the potential cost savings by eliminating both technical and allocative inefficiencies to be high during *Maha* season.

Aggregate cost savings for districts

The potential aggregate cost savings are relatively high in Ampara district, followed by Polonnaruwa district because of the relatively large rice extents cultivated in these two districts. Similarly, the potential cost savings by eliminating technical/allocative inefficiencies are relatively high in *Maha* season due to higher aggregate extent cultivated during that season. It is observed that the cost savings feasible for these major rice growing districts by eliminating both technical and allocative inefficiencies are substantial in magnitude (Table 5).

Table 4. The potential average cost savings per farm with eliminating inefficiencies

District	*Yala* 2009 Potential cost saving by raising*			*Maha* 2009/10 Potential cost saving by raising*		
	TE	AE	EE	TE	AE	EE
Ampara	26,590 (69%)	11,925 (31%)	38,515	21,180 (42%)	29,505 (58%)	50,685
Anuradhapura	22,785 (74%)	7,915 (26%)	30,700	16,335 (48%)	17,425 (52%)	33760
Hambantota	25,210 (82%)	5,540 (18%)	30,750	18,375 (43%)	24,375 (57%)	42,750
Polonnaruwa	18,710 (70%)	7,870 (30%)	26,580	21,490 (44%)	27,450 (56%)	48,940
Average	23,990 (73%)	9,010 (27%)	33,000	19,740 (43%)	25,720 (57%)	45460

*Percentages from potential cost savings from eliminating technical and allocative inefficiencies are in parenthesis

Table 5. The potential aggregate cost savings with raising efficiencies

District	*Yala* 2009 potential xot saving (Rs. billion) by raising			Maha 2009/10 Potential cost saving (Rs billion) by raising			Both seasons potential cost saving (Rs billion) by raising		
	TE	AE	EE	TE	AE	EE	TE	AE	EE
Ampara	2.1	1.0	3.1	3.1	4.3	7.4	5.2	5.3	10.5
Anuradhapura	0.6	0.2	0.8	1.2	1.3	2.5	1.8	1.5	3.3
Hambantota	1.2	0.3	1.5	0.9	1.2	2.1	2.1	1.5	3.6
Polonnaruwa	1.6	0.7	2.3	3.0	3.8	6.8	4.6	4.5	9.1
Total	5.5	2.2	7.7	8.2	10.6	18.8	13.7	12.7	26.5

*Extents Source – Department of Census and Statistics (2014).

CONCLUSIONS

Although, fairly high levels of technical, allocative, and economic efficiency levels for the two seasons is observed, it is evident that costs savings possible by eliminating technical and allocative inefficiencies are considerable at individual farmer level and district aggregate level. Therefore, programmes for reduction of technical and allocative inefficiencies such as extension programmes, farmer business schools could lead to increase of farm incomes The aggregate welfare gain estimates in the four districts indicate that economically rational investment to disseminate technology among farmers could be justified.

REFERENCES

Aigner, D.J., Lovell, C.A.K. and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. Journal of Econometrics, 6: 21-37.

Aruna Shantha, A, B.G.H. Ashan Ali, and R.A.G. Bandara. 2012. Efficiency of paddy farming under minor irrigation conditions: a frontier production function approach. The Journal of Agricultural Sciences, 7 (3): 144-157.

Aruna Shantha, A.B.G.H. Ashan Ali, and R.A.G. Bandara. 2013. Technical efficiency of paddy farming under major irrigation conditions in the dry zone of Sri Lanka: a parametric approach. Australian Journal of basic and applied sciences, 7(6), 104-112.

Bogahawatte, C. 1982. The efficiency of farm holding size and tenancy status in Girithale, Polonnaruwa district of Sri Lanka, Sri Lanka Journal of Agrarian Studies, 3 (2): 110-116.

Coelli, T. J. 1996. A guide to frontier version 4.1: a computer program for stochastic frontier production function and cost function estimation. CEPA working paper 96/97, Department of Econometrics, University of New England, Amirdale.

Department of Census and Statistics. 2014. Paddy Statistics. Retrieved from http:www.statitics.gov.lk/agriculture/index.htm., Department of Census & Statistics, Colombo 07, Sri Lanka.

Ekanayake, S.A.B. 1987. Location specificity, settler type and productive efficiency: a study of the Mahaweli Project in Sri Lanka. The Journal of Development Studies, 22: 509-521.

Ekanayake, S.A.B. and S.K. Jayasuriya.1987. Measurement of firm-specific technical efficiency: a comparison of methods. The Journal of Agricultural. Economics, 18, 3; 115-122.

Ekanayake, S.A.B. and S.K. Jayasuriya.1989. Change, adjustment, settler type, and the role of specific experience: evidence from Sri Lanka rice farming. Australian Journal of Agricultural Economics, 33, 2; 123-135.

Farrell, M.J. 1957. The measurement of productive efficiency, Journal of Royal Statistics Society Series A, 120: 253-281.

Gunarathna, R.U.M.S. and. S .Thiruchelvam. 2002. Comparative study of technical efficiency of paddy farming under major and minor irrigation schemes in Anuradhapura district. Tropical Agricultural Research, 14: 341-351.

Karagiannis, G.,V. Tzouvelekas and A. Xepapadeas. 2003. Measuring irrigation water efficiency with a stochastic production frontier – an application to greek out of season vegetable cultivation. Enviorenment and Resources Economics, 26:57-72.

Karunarathne, M.A.K.H.S.S. and H.M.G Herath. 1989. Efficiency of rice production under major irrigation conditions: a frontier production function approach. Tropical Agricultural Research, 1: 142-158.

Kopp, 1981. The measurement of productive efficiency: a reconsideration, Quarterly. Journal of Economics, 97: 477-503.

Meeusen, W. and van den J. Boreck. 1977. Efficiency estimation from Cobb-Douglas production functions with composed error, International Economic Review. 18: 435-444.

Thibbotuwawa, M, Mugera, A. and B .White. 2012. A non-parametric analysis of rice production efficiency in Sri Lanka. Contributed paper for presentation at the 56th AARES annual conference, Fremantle, Western Australia, Feb 7-10, 2012.

Thiruchelvam, S. 2005. Efficiency of rice production and issues related to costs of production in the districts of Anuradhapura and Polonnaruwa. Journal of National Science. Foundation of Sri Lanka, 33(4): 247 - 256.

Udayanganie, D., P. Prasada, S. Kodithuwakku,, J . Weeraheva and C. Little. 2006. Efficiency of the agrochemical input usage in the paddy farming systems