Production Efficiency and Technology Gap in Irrigated and Rain-fed Rice Farming Systems in Sri Lanka: Non Parametric Approach

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Abstract
The paper analyses the differences of technical, allocative, cost and scale efficiencies of irrigated and rain-fed rice farmers in Sri Lanka in two different perspectives; first, relative to a common *metafrontier*, defined as the boundary of an unrestricted technology set and second relative to *group frontiers* defined to be the boundaries of restricted technology sets in each group. Data envelopment analysis (DEA) metafrontier and group frontier approaches are used for cross section survey data of 90 farms. Rain-fed farms perform comparably with the irrigated farms based on the group frontier results. Rain-fed farmers may be operating as technically efficient as they could, given the existing production technology. However rain-fed farms move significantly towards inefficiency compared to the irrigated farms under the metafrontier technology. Results indicate that the irrigation shifts the rice sector production frontier to a higher level. In addition, a second stage bootstrapped truncated regression shows that efficiency differences between two regions are explained by the timely availability of the water to a significant extent. We suggest that future sectoral policies should be designed to address the efficiency enhancing factors such as irrigation, quality seed, land ownership and scale and female labour participation.

Key words: technical efficiency, cost efficiency, metafrontier, group-frontier, rice farming, irrigated, rain-fed, Sri Lanka

JEL Classifications: Q12, D24

1. Introduction

As in other parts of Asia, rice is the staple food and principal crop in Sri Lanka. It account for approximately 900,000 ha and 34% of total agricultural land area in Sri Lanka occupying the largest extent of land under any single crop. The sector accounts for nearly 15% of the agricultural GDP and about half of the agricultural labour force is employed in the sector (CBSL, 2010). Despite the significance of the rice sector in the Sri Lankan economy, the country has been facing widespread stagnation in paddy yields and declining profitability in recent years (IPS, 2011, Kikuchi, et al., 2000, Rafeek and Samarathunga, 2000, Weerahewa, et al., 2003). However, the demand for rice is rising due to the annual growth of population by 1.1% and per capita income by 15%[1]. It is projected that rice production should grow at the rate of 2.9% per year in order to meet the rising demand (DOA, 2011). Due to the scarcity of new arable land, area expansion is not a viable solution anymore; therefore, increase in rice production could come through per acre yield improvement by efficient use of inputs.

[1] The average percentage change in per capita GDP between 2000 and 2010 is 15%, with the years 2007 and 2008 achieving more than 21% change.

Rice is grown under a wide range of physical environments such as different elevations, soils and hydrological regimes. The rice lands in Sri Lanka are classified as irrigated (major and minor) and rain-fed based on the hydrological conditions, i.e., the surface water source, supply and use. The major cultivation season (Maha) is from October to March and the minor season (Yala) is from April to September. Those seasons are defined based on the two monsoon rains; North East monsoon and South West monsoon respectively (Dhanapala, 2000). Major irrigation schemes are those having a command area of more than 80 ha, where the water supply may be from a major tank, a river or a major stream diversion system. About half of the cultivated areas are under major irrigation schemes. Minor irrigation schemes are considered the schemes under village tanks that are natural or man-made water reservoirs, which consist of a command area of less than 80 ha. From the total extent of cultivations, about 20% comes under this category. There are about 18,000 village tanks in the country. The most critical problem in village tank systems in the dry and intermediate zones is the severe water scarcity during Yala season and insufficient rainfalls in the Maha season in certain times (Adhikarinayake, 2005).

From the total area of paddy lands, about 30% are cultivated under the rain fed cultivations. Rain-fed rice cultivations are often subject to water stress due to excess water (floods) and insufficient water (droughts). Light rainfalls as well as heavy rainfalls are detrimental for the cultivations (Adhikarinayake, 2005). Irrigation has been viewed as an essential and most critical factor determining the rice productivity (Kikuchi, et al., 2000, Mariano, et al., 2011). Timely availability of sufficient water is very important for the cultivation as rice is a high water intensive crop. There is a greater variability in rice yield and production efficiency among different water regimes (Dhanapala, 2000, Gunaratne and Thiruchelvam, 2002, Thiruchelvam, 2005a). These differences may be basically due to the choices of different sets of input-output combinations or technology sets. These choices of technology sets differ because of a combinations of reasons such as differences in physical, human and financial capital, economic infrastructure and resource endowments in which access to water plays a major role.

It is a common practise to measure the relative performance of farms within the irrigation groups. However, it is important to measure the performance of farms across groups and the existing technological gap between different groups. The main objective of this study is to examine the differences in production efficiency between irrigated and rain-fed rice farms in

Sri Lanka and to investigate the factors that influence production efficiency differences in irrigated and rain-fed rice farms while controlling for farm size, resource utilization and resource ownership.

This study contributes to the rice production efficiency and irrigation literature in several ways. First, this study investigates the technical efficiency (TE), allocative efficiency (AE), cost efficiency (CE) and scale efficiency (SE) in irrigated and rain-fed rice farming systems separately. We do this by defining *group frontiers* to be the boundaries of restricted technology sets in each group. Second, we make comparisons of production efficiencies across groups. We do this by measuring efficiency scores relative to a common *metafrontier*, defined as the boundary of an unrestricted technology set and calculate the technological gap ratio (TGR), allocative gap ratio (AGR), cost gap ratio (CGR) and scale gap ratio (SGR) in each group. We use non parametric DEA method in both the group frontier and metafrontier estimation. Third, we examine the impact of farm level characteristics on efficiency measures using bootstrapped truncated regression.

Results of this study have policy implications pertaining to better allocation and utilization of resources for rural development and food security in Sri Lanka where agricultural sector is characterized by different irrigation regimes. The results are expected to be of interest to policy makers in other Asian countries having similar background and issues. The paper is organized as follows. The next section briefly discusses the literature on rice production efficiency highlighting the comparative studies on efficiency differences in different water regimes. Section three outlines the theoretical framework for the methodology. Section four describes the methods and data. Section five discusses the results followed by the concluding comments in the final section.

2. Production Efficiency Differences in Different Water Regimes

Production efficiency is one of the popular methods of benchmarking the performance of economic entities in a similar industry. Technical efficiency measures the extent to which inputs are converted in to outputs relative to the best practice given the available technology. Allocative efficiency is related to selecting the mix of inputs that produces a given level of output at minimum cost given the available input prices. Economic efficiency is a product of TE and AE. Relaxing the assumption that all firms are fully efficient is used to estimate frontier production functions and to measure the technical efficiencies of firms relative to the best practice frontier using either parametric or non-parametric methods, or both (Coelli, et al., 2005).

There is a large body of literature measuring the rice production efficiency. Stochastic frontier analysis (SFA) and Data Envelopment Analysis (DEA) methods are the most frequently used methods in analyzing productive efficiency. Most of the studies have been done using SFA (Bäckman, et al., 2011, Balcombe, et al., 2007, Ekanayake and Jayasuriya, 1987, Gedara, et al., 2012, Karunarathne and H.M.G.Herath, 1989, Khan, et al., 2010, Mariano, et al., 2011, Rahman, 2010, Rahman and Rahman, 2009, Rahman, et al., 2009, Tan, et al., 2010, Thiruchelvam, 2005b, Udayanganie, et al., 2006, Villano and Fleming, 2006, Yao and Shively, 2007) while some others have used DEA (Balcombe, et al., 2008, Brazdik, 2006, Chemak, et al., 2010, Coelli, et al., 2002, Dhungana, et al., 2004, Latruffe, et al., 2008, Oude Lansink and Silva, 2004, Thibbotuwawa, et al., 2012). There are a few comparative studies of the productive efficiency based on SFA and DEA (Christopher, et al., 2008, Wadud, 2003, Wadud and White, 2000).

However, very few studies have examined the differences in production efficiency and the factors explaining the efficiency differences between irrigated and rain-fed regimes (Kelemework, 2006, Makombe, et al., 2007, Makombe, et al., 2011, Mariano, et al., 2010, Thibbotuwawa, et al., 2012, Tilahun, et al., 2011, Yao and Shively, 2007). All these studies have estimated TE alone except for Thibbotuwawa, et al., (2012) who focused on AE,CE and SE as well (Table 1).

Table 1: Recent efficiency studies examining the difference in efficiency between different irrigation regimes

Authors	Year	Country	Model	Efficiency measures
Sri Lanka				
Gunaratne and Thiruchelvam	2002	Sri Lanka	Stochastic	TE
Thibbotuwawa et al.	2012	Sri Lanka	DEA metafrontier	TE, AE,CE, SE
Thiruchelvam	2005	Sri Lanka	Stochastic	TE
Other Countries				
Kelemework	2006	Ethiopia	Stochastic	TE
Macombe et al.	2011	Ethiopia	Stochastic	TE
Marino et al.	2011	Philippines	Stochastic	TE
Tilahun et al	2011	Ethiopia	Water use efficiency	Water use efficiency
Yao and Shively	2007	Philippines	Stochastic	TE

Source: Authors own literature search

Both Makombe, et al. (2011) and Makombe, et al.(2007) showed that irrigation shifts the agricultural production frontier to a higher level in Ethiopia. They suggested focusing on strategies like changes in production technology and optimizing input use for the agricultural development in the rain-fed sector. Kelemework (2006) showed that the rain-fed farmers in Ethiopia are more efficient than irrigated farmers with respect to their own frontiers. Tilahun, et al. (2011) emphasized the importance of gradual transformation of rain-fed farms to irrigation for the efficient use of resources. Marino et al. (2010) suggested that the rain-fed farms were able to achieve almost the same level of productivity compared to the irrigated farms. In general, all these highlighted the importance of directing more resources towards the irrigation schemes due to higher marginal productivity of inputs in these areas.

There are a few studies that have evaluated the production efficiency differences in different agricultural water management systems in Sri Lanka. Gunaratne and Thiruchelvam (2002) and Thiruchelvam (2005a) have undertaken a comparative analyses between major and minor schemes concluding that the major irrigated farms are in a relatively advantageous position than the minor irrigated farms. However, no focus has been given to explain efficiency differences between irrigated and rain-fed scenarios except the recent study by Thibbotuwawa, et al., (2012). They compared the efficiency differences and concluded that major irrigated farms are the most efficient and rain-fed farms are the least efficient on average. However, their comparison of productive efficiency is purely based on metafrontier DEA method disregarding the technological gaps in different systems.

3. Conceptual Framework

Production efficiency is one of the popular methods of benchmarking and comparing the performance of economic entities in a similar industry. This discussion of efficiency of a firm began with the Farrell (1957) who proposed that the efficiency of a firm consists of two components; TE and AE. TE measures the extent to which inputs are converted in to outputs relative to the best practice given the available technology. AE is related to selecting the mix of inputs that produces a given level of output at minimum cost given the available input prices. Economic efficiency is a product of TE and AE. Frontier production functions are commonly used to measure the production efficiencies of firms relative to the best practice frontier using either parametric or non-parametric methods, or both (Coelli, et al., 2005).

Estimating a single frontier for all farms regardless of whether these are irrigated or not would be one option. This meta-frontier would assume that all farmers have access to the same technology and the differences in production performance would purely be attributed to differences in efficiency. The other option assumes irrigated and rain-fed farmers are operated under different production technologies. We use both the meta-frontier and the group frontier models in efficiency estimation and the technological gap ratios are subsequently calculated.

Following Farell's approach, consider a firm utilizing two inputs, x_1 and x_2, to produce a single output y, under the assumption of constant returns to scale[2], so that the production frontier is $y = f(x_1, x_2)$. The isoquants[3] of the fully efficient firm in the Figure 1 permits the measurement of technical efficiency. Two group frontiers are defined by the isoquants G_1G_1 and G_2G_2. Assuming, the two groups are not-exhaustive that the other technological sets may be possible, the metafrontier could conceivably be the convex frontier M_1M_1.

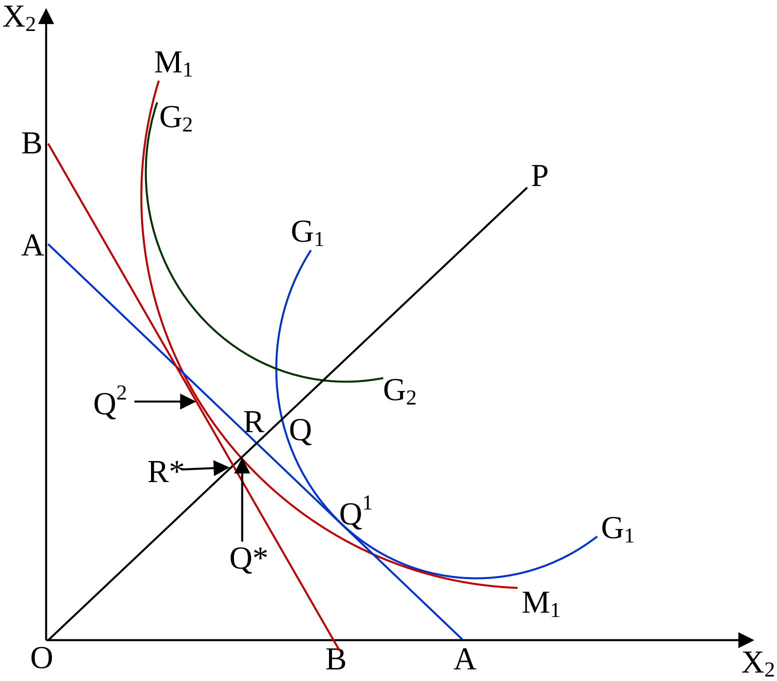

Figure 1: Efficiencies under metafrontier and group frontier technological sets

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[2] The relationship between output *y* and inputs *x*1 and *x*2 does not change as the inputs increase.
[3] Isoquant shows the alternative combinations of inputs which can used to produce a given level of output.

Now, for a given firm under the technological set of the Group 1(G_1G_1) using quantities of inputs (x_1^p, x_2^p) defined by point "P" to produce a unit of output y^p, the level of technical efficiency, is defined as the ratio OQ/OP. Thus, $(1-OQ/OP)$ which lies between the value of 0 and 1 is the technical inefficiency of the firm and it measures the proportion by which x_1^p, x_2^p could be reduced (holding the input ratio x_1/x_2 constant) without reducing the level of output. Point Q, on the other hand, is technically efficient since it already lies on the efficient Isoquant (Coelli, et al., 2005). However, under the metafrontier technological set, technical efficiency of the firm "P" is defined by the ratio $OQ*/OP$.

If the input price ratio represented by the slope of the isocost line[4] of the Group 1, AA, in figure 1, is known, then AE under the technological set of the group 1can be calculated at point P, as the ratio $wx^{q^1}/wx^q = OR/OQ$ where w represents the vector of input prices and x^q and x^{q^1} represent the input vectors associated with the technically efficient point Q and the cost minimizing point Q^1 respectively. The allocative inefficiency is shown by $1-OR/OQ$ or RQ/OQ where the distance RQ is the reduction in production costs which would occur if production occurred at Q^1; the allocatively and technically efficient point, rather than Q; the technically efficient, but allocatively inefficient point (Worthington, 2001). Under the metafrontier technological set, allocative efficiency of the firm "P" is given by the ratio $wx^{q^2}/wx^{q^*} = OR^*/OQ^*$ where w represents the vector of input prices and x^{q^*} and x^{q^2} represent the input vectors associated with the technically efficient point Q^* and the cost minimizing point Q^2 respectively.

In the presence of price information, it would be possible to measure the CE as well. Let x^p is the observed vector of inputs at point P. Hence, CE or the total economic efficiency i.e. the ratio of input costs associated with x^p and x^{q^1} at points P and Q^1 respectively is equal to $wx^{q^1}/wx^p = OR/OP$. The cost reduction achievable is the distance RP which is obtained from moving from P to Q^1. Under the metafrontier technology, CE of the firm at point P is equal to $wx^{q^2} / wx^p = OR^* / OP$. Moving from P to Q^2, the firm can achieve the cost reduction

[4] showing the different combinations of inputs that can be purchased with a given cost outlay

equivalent to the distance R^*P. Technical, allocative, cost and scale gap ratios can be calculated by the respective efficiency ratios of metafrontier group frontier. These ratios are always greater than or equal to zero and less than or equal to one; and equality at one holds when the group frontier coincides with the metafrontier for the input and output vectors, x and y.

Parametric SFA and/or non parametric (DEA) methods are used to estimate the efficient Isoquant and the Isocost line using sample data in order to estimate the efficiency associated with the rest of the firms in the sample relative to the efficient frontier. In general, despite the advantages of DEA over Stochastic Frontier Analysis (SFA)[5], most empirical studies have used SFA method. In this study, we use the data envelopment analysis (DEA) approach to compute the production efficiencies under the metafrontier and group frontier technologies.

4. Methods

First, technical, scale, allocative and cost efficiencies are estimated for the irrigated and rain-fed samples separately to examine the production efficiencies in the two group frontiers. The estimation of the metafrontier then follows, by applying the DEA methodology on the data set obtained by pooling all observations for farms from both the groups. Average efficiency estimates are calculated for each regime under the metafrontier and the gap ratios are calculated. Further, t-tests are employed to see the efficiency differences in two groups. We use the input orientation[6] in this study since farmers have more control over inputs than outputs. Finally, the estimated efficiencies by the full sample are used to identify what factors explaining efficiency differences between irrigated and rain-fed regions using truncated regression analysis.

4.1 Technical Efficiency

The efficiency measurement method used in this paper is derived from those presented in Coelli et al. (2002). Three scale assumptions are generally employed in estimating production frontier: constant returns to scale (CRS), variable returns to scale (VRS)[7] and non increasing

[5] See Coelli et al. (2005) for a more detailed explanation

[6] With input-oriented DEA, the linear programming model is configured to determine how much the input use of a farm could contract if used efficiently in order to achieve the same output level.

[7] CRS reflects that output will change by the same proportion as inputs are changed while VRS reflects that production technology may exhibit increasing, constant and decreasing returns to scale.

return to scale (NIRS). Even though we focus on VRS in our study as it is more common to assume that agriculture would be subject to VRS, TE scores based on the CRS and NIRS are also calculated in order to estimate SE.

Following Coelli et al. (2002), assume that there are n farms which produce m outputs using k different inputs (n=90, m=1 i.e. rice and k=5 representing seed, fertilizer, chemicals, labour and machinery in our case). For the i^{th} farm, input and output data are represented by the column vectors x_i and y_i. The data for all n farms are represented by $k \times n$ input matrix, X and $m \times n$ output matrix, Y. The Constant Return to Scale (CRS) input oriented DEA model for the i^{th} farm can be expressed as,

$$\textit{Minimize}_{\lambda}\ \theta_i \qquad (1)$$

$$\textit{Subject to:} \quad \begin{array}{l} \theta_i x_i - \lambda X \geq 0 \\ \lambda Y - y_i \geq 0 \\ \lambda \geq 0 \end{array}$$

where θ is a scalar and λ is a $n \times 1$ vector of input and output weights. For Variable Return to Scale (VRS), convexity constraint, $n1'\lambda = 1$ is added, where $n1$ is a $n \times 1$ vector of one. The input technical efficiency score (θ) gets a value $0 \leq \theta \leq 1$. If the θ value is equal to one, the farm is on the frontier and hence technically efficient. This paper applies smoothed homogeneous bootstrap procedure[8] following Simar and Wilson (2000) to get bias corrected efficiency scores and their confidence intervals.

4.2 Scale Efficiency and Return to Scale

Scale efficiency is calculated by the ratio $SE = TE_{CRS} / TE_{VRS}$. Scale efficiency of 1 implies scale efficiency or CRS while SE < 1 indicates scale inefficiency that can be due to the existence of either increasing or decreasing returns to scale. To find out whether the firm is operating under increasing or decreasing return to scale, an additional DEA equation with NIRS is imposed with the restriction $n1'\lambda \leq 1$ for the CRS specification in equation (1). Therefore, $TE_{NIRS} = TE_{VRS}, TE_{NIRS} \neq TE_{VRS}$ *and* $TE_{VRS} = TE_{CRS}$ relationships indicate the existence of DRS, IRS and CRS respectively (Coelli, et al., 2005).

[8] Bootstrap procedure repeatedly simulates the data generating process by re-sampling the sample data and applying the original estimator to each simulated sample.

4.3 Allocative and Cost Efficiency

Cost Efficiency is related to the use of inputs that produces a given level of output at minimum cost given the available input prices. The VRS input oriented DEA model with cost minimization objective for the i^{th} farm can be expressed as,

$$Minimize_{\lambda x_i^*} \; w_i' x_i^*, \tag{2}$$

$$Subject\ to \quad \begin{aligned} & Y\lambda - y_i \geq 0, \\ & x_i^* - X\lambda \geq 0, \\ & n1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned}$$

where w_i' is a $n \times 1$ vector of input prices for the i^{th} farm and x_i^* is the cost minimizing vector of input quantities for the i^{th} farm, given the input prices w_i. The total cost efficiency of the i^{th} firm can be calculated as,

$$CE = w_i' x_i^* \,/ w_i' x_i \tag{3}$$

Allocative Efficiency (*AE*) is calculated residually as *AE*=*CE*/*TE*.

4.4 Truncated regression explaining the efficiency shifters

Use of regression model to determine the farm specific attributes in explaining inefficiency is a common practise in the literature with varying explanatory variables in different studies. Most of the early studies have used Tobit regression (Coelli, et al., 2002, Dhungana, et al., 2004, Wadud, 2003, Wadud and White, 2000). Those who have used Tobit specification in the second stage have justified their approach by the fact that the dependant variable, i.e. production efficiency estimates has a censored distribution lying between 0 and 1 and generally several efficiency estimates equal unity in a given application.

Some have proposed that OLS regression in the second stage yields consistent results than the Tobit regression (Banker and Natarajan, 2008, McDonald, 2009). Their main argument was that the efficiency scores are not generated by a censoring data generating process but are fractional data generating process and the Tobit estimation in this situation is inappropriate. However according to Simar and Wilson (2011), OLS estimation is consistent only under very peculiar and unusual assumptions on the data generating process and the truncated regression estimates the correct model with more consistent results. Simar and Wilson (2007) argued that single and double bootstrap truncated regressions performs better in terms of estimated confidence intervals.

The literature indicates that a range of farm characteristics determines the efficiency of farms including land size, tenancy, labour characteristics, farm experience, extension, infrastructure, household characteristics such as family size, age, education, etc. This study incorporates the water availability (which is the core in this research) through a dummy variable for water source with some other relevant farm characteristics such as seed quality, land extent and ownership, labour participation and machinery use. Timely availability of sufficient water is a prerequisite in rice cultivation, but it differs in different water regimes in Sri Lanka. It is expected that the farms in irrigation schemes are likely to have higher efficiency than those in rain-fed areas. Land fragmentation and consequent small holding cultivation[9], which is likely to have negative effects upon efficiency have become a serious issue of concern over the years.

A priori, land owners will have higher efficiency than the tenants (Coelli, et al., 2002, Mariano, et al., 2011, Rahman and Rahman, 2009, Yao and Shively, 2007), but the owners who cultivate lease lands are likely to have the highest efficiency assuming their entrepreneurial characteristics and risk loving behaviour. Based on the literature, it is expected that the family labour (Dhungana, et al., 2004, Rahman and Rahman, 2009) and female labour (Dhungana, et al., 2004, Rahman, 2010)will increase efficiency. Based on the intuitive understanding on machinery use, it is likely to increase efficiency.

Three separate bootstrapped truncated regressions are defined for the dependant variables; conventional TE, CE and AE as follows.

$$y_i^* = \beta_i z_i + \varepsilon_i \geq 0; \text{ for } i = 1, \cdots, n \text{ and } \varepsilon_i \to N(0, \sigma^2) \quad (6)$$

where y_i is either TE, CE or AE and z_i represents a vector of explanatory variables $i = (1, 2....8)$, z_1 =farm size, z_2 =irrigation dummy (Value is 1 if the farmer cultivates using

[9]Fragmentation of holdings is increasing. Farm size is decreasing. The average size of holdings less than 8 ha was 1.3 ha in 1946, 1.1 ha in 1962, and 0.8 ha in 1982 (Dent, D.L., and L.K.P.A. Goonewardene (1993) Resource Assessment and Land Use Planning in Sri Lanka: A Case Study, vol. 4. London, The Environmental Planning Group, The International Institute for Environment and Development.). This figure was 0.48 ha in 2002 based on the Agricultural Census 2002 by the Department of Census and Statistics of Sri Lanka.

irrigation, and 0 otherwise), z_3 = ownership dummy (Value is 1 if the farmer owns the cultivated land, and 0 otherwise; Value is 1 if the farmer leases the cultivated land, and 0 otherwise; Value is 1 if the farmer is cultivating owned and leased lands together, and 0 otherwise), z_4 =seed source dummy (Value is 1 if the farmer uses state produced seed, and 0 otherwise; Value is 1 if the farmer uses seeds produced by private companies, and 0 otherwise; Value is 1 if the farmer shares the seeds from other farmers, and 0 otherwise; Value is 1 if the farmer uses seeds from his previous season production, and 0 otherwise) z_5 = family labour use (%), z_6 = female labour participation (%) and z_7 = machinery use (%).

5. Data and Variables

Secondary data for the study comes from a sample survey of rice producers, conducted by the Institute of Policy Studies of Sri Lanka to collect 2007/08 Maha Season data. The total sample of 90 farms was randomly selected from six districts (15 each) to represent all the irrigation systems and climatic zones. Sixty and thirty farmers were selected from irrigated and rain-fed groups in order to reflect the farm distribution in each group. Selected districts where farmers practice irrigated cultivations are Ampara, Polonnaruwa, Kurunegala and Matara. Kegalle and Kalutara districts were chosen for rain-fed cultivations.

Empirical measurement of efficiencies and gap ratios requires data on the inputs and outputs for random samples of firms from the different groups having different technological sets. Data for the study includes the quantity and price of the output (rice), quantities and price of the inputs (seed, fertilizer, chemicals, labour and machinery) and some other cultivation related variables such as farm size, source of seed and ownership type collected in irrigated and rain-fed groups. The output is measured as kilograms (kg) of rice harvested and the price of output is the per kg selling price of rice. Seed is measured as the total physical quantity in kg and per kg price. The amount of fertilizer is measured as total kg applied and includes Urea, Muriate of Potash (MOP) and Triple Super Phosphate (TSP) which are the three major fertilizers used by the Sri Lankan farmers. Price of all the three fertilizers remain fixed at a subsidized level of Rs.7/kg. Chemicals are measured in liters and per liter price. Labour input is measured as the number of workdays per person for all hired and family labour. Weighted averages of the number of workdays and daily wage rate (Rs./day) of male and female workers are calculated. Total machinery quantity is measured in cost of machinery usage in rupees, excluding the labour cost.

Table 2 shows the summary statistics of inputs and output for the irrigated and rain-fed cultivation groups. There is a noticeable difference in the yield of rice and per acre usage of certain inputs. Average farm size of the total sample is 1.82 acres with maximum 6.50 acres and minimum 0.25 acres. As the table shows, on average irrigated farms are bigger (2.08 acres) than the rain-fed farms (1.32 acres). Average yield in irrigated farms is higher (2,141 kg/acre) than the sample average yield (2078 kg/acre) and the average yield in rain-fed farms (1903 kg/acre). Rain-fed cultivations are more labour intensive while irrigated farms are comparatively more mechanized. While no much difference in quantities of other inputs and input prices, labour is relatively cheaper in irrigated areas[10].

Table 2: Summary Statistics of Main Variables

	Irrigated				Rain-fed			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Rice yield (kg/ac)	2140.94	355.85	1400.00	3100.00	1902.98	404.57	800.00	2933.33
Seed (kg/acre)	40.22	4.20	24.00	53.33	41.34	6.33	30.00	60.00
Fertilizer (kg/acre)	159.02	31.87	102.67	224.00	154.24	34.84	65.00	213.33
Chemicals (lit/ac)	1.39	0.75	0.40	4.00	1.38	1.04	0.20	4.00
Labour (days/acre)	28.22	13.17	8.78	70.00	39.81	16.56	14.20	76.00
Machinery (Rs/acre)	9495.22	2267.26	2600.00	13560.00	9503.82	2369.74	4825.00	15800.00
Extent (ac)	2.08	1.47	0.25	6.50	1.32	0.90	0.30	3.50

6. Empirical Results

6.1 Group frontier results on production efficiencies

Summary statistics for the computed technical (conventional and bias corrected), cost, allocative and scale efficiencies based on the two group results are reported separately for the irrigated and rain-fed groups in Table 3. Estimates of average TE, AE, CE and SE were 0.87, 0.80, 0.69 and 0.92 respectively with minimum values 0.55, 0.39, 0.37 and 0.63 in irrigated areas. In rain-fed areas, TE, AE, CE and SE estimates were 0.92, 0.73, 0.67 and 0.92

[10] This may be due to the labour surplus and lack of off farm employment opportunities in these areas.

respectively on average. Minimum efficiency estimates in rain-fed areas were 0.62, 0.52, 0.48 and 0.63 for TE, AE, CE and SE. These results negate the popular notion that rain-fed farms are more inefficient compared to irrigated farms. There was no significant difference between irrigated and rain-fed farms in all efficiency measures based on the t-test results.

Table 3: Group frontier results on TE, AE, CE and SE for irrigated and rain-fed regions

	Irrigated					Rain-fed				
	TE	TE(bc)	CE	AE	SE	TE	TE(bc)	CE	AE	SE
=1.0	28.33	0.00	6.67	6.67	11.67	40.00	0.00	6.67	6.67	23.33
0.90-0.99	18.33	23.33	3.33	20.00	60.00	23.33	53.33	6.67	6.67	56.67
0.8-0.89	23.33	46.67	6.67	20.00	18.33	26.67	30.00	3.33	13.33	3.33
0.7-0.79	21.67	16.67	25.00	30.00	5.00	6.67	13.33	13.33	23.33	10.00
0.6-0.69	5.00	10.00	36.67	20.00	5.00	3.33	0.00	26.67	30.00	6.67
0.5-0.59	3.33	3.33	13.33	1.67	0.00	0.00	3.33	40.00	20.00	0.00
0.4-0.49	0.00	0.00	5.00	0.00	0.00	0.00	0.00	3.33	0.00	0.00
0.3-0.39	0.00	0.00	3.33	1.67	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.87	0.83	0.69	0.80	0.92	0.92	0.87	0.67	0.73	0.92
SD	0.13	0.10	0.14	0.13	0.09	0.10	0.09	0.15	0.13	0.11
Min	0.55	0.53	0.37	0.39	0.63	0.62	0.58	0.48	0.52	0.63
Max	1.00	0.95	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00
CRS (%)					11.67					23.33
DRS (%)					30.00					16.67
IRS (%)					58.33					60.00

Legend: TE is technical efficiency, TE (bc) is bias corrected TE, CE is cost efficiency, AE is allocative efficiency, SE is scale efficiency, IRS is increasing return to scale, DRS is decreasing return to scale and CRS is constant return to scale.

Based on the conventional TE estimate, an average farm in the irrigated group could expand its output by about 13 per cent with a given input combination in order to become fully efficient as opposed to 8 per cent in the rain-fed group. The bias-corrected TE suggested an expected output expansion of 17 per cent and 13 per cent in irrigated and rain-fed groups. Fourty per cent of farms were fully technically efficient in rain-fed regions as opposed to 28% farms in irrigated areas. Seven per cent of farms were allocatively and cost efficient in both the irrigated and rain-fed groups. Twenty three per cent of rain-fed farms were operating at the optimal scale, 60% of farms were too small and 17% of farms were too large. Irrigated sample results show that only 12% of farms were operating at the optimal scale, 58% of farms were too small and 30% were too large.

Results show that the farms in each group equally perform relative to the available technological set up in their own group. However, the results suggest that farms could have produced the same output with using fewer inputs, better mix of inputs, less costs and changing the scale of operation in both irrigated and rain-fed areas. Especially, there is a significant level of cost and allocative inefficiency in the farms in both the groups. However, these results do not show the possible technical, allocative, cost and scale gaps between the two groups unlike metafrontier results.

6.2 Metafrontier results on production efficiencies

Table 4 shows the efficiency differences reported for irrigated and rain-fed farms separately based on the metafrontier results. On average, irrigated farms are more technically efficient (87%) compared to rain-fed farms (81%). Minimum TE estimate of 53% (rain-fed) and 55% (irrigated) shows that that the rain-fed farms could have reduced the input levels up to 47% to produce the same output compared to 45% by irrigated farms. Twenty eight per cent of irrigated farms were fully technically efficient as opposed to 20% of rain-fed farms.

Table 4: Metafrontier results on TE, AE, CE and SE for irrigated and rain-fed regions

	Irrigated					Rain-fed				
	TE	TE(bc)	CE	AE	SE	TE	TE(bc)	CE	AE	SE
=1.0	28.33	0.00	6.67	6.67	10.00	20.00	0.00	0.00	0.00	13.33
0.90-0.99	18.33	21.67	3.33	16.67	66.67	10.00	13.33	3.33	10.00	60.00
0.8-0.89	23.33	38.33	3.33	21.67	13.33	26.67	36.67	10.00	26.67	6.67
0.7-0.79	21.67	20.00	28.33	31.67	5.00	20.00	23.33	10.00	36.67	10.00
0.6-0.69	5.00	15.00	35.00	20.00	5.00	13.33	13.33	20.00	13.33	6.67
0.5-0.59	3.33	5.00	15.00	1.67	0.00	10.00	10.00	40.00	13.33	3.33
0.4-0.49	0.00	0.00	5.00	0.00	0.00	0.00	3.33	16.67	0.00	0.00
0.3-0.39	0.00	0.00	3.33	1.67	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.87	0.80	0.69	0.80	0.93	0.81	0.76	0.61	0.75	0.91
SD	0.13	0.11	0.14	0.13	0.09	0.15	0.13	0.13	0.12	0.12
Min	0.55	0.52	0.37	0.39	0.63	0.53	0.49	0.44	0.52	0.57
Max	1.00	0.95	1.00	1.00	1.00	1.00	0.95	0.99	0.99	1.00
CRS (%)					10					13.33
DRS (%)					25					10
IRS (%)					65					76.67

The mean allocative efficiency score is 0.80 in irrigation schemes compared to 0.75 in rain-fed systems. A majority of the farms in this study are not allocative efficient, i.e. these farms did not make the correct allocation of inputs to produce the output at minimum costs. From the irrigated group 7 per cent farms are defining the frontier, but no farm is defining the frontier from the rain-fed group. These scores indicate that there is a lot of space to reduce production cost by being more rational in allocating inputs especially in rain-fed systems.

Cost efficiency in rain-fed farms is significantly lower at 0.61, compared to 0.69 in irrigated farms with minimum 0.44and 0.37. This suggests that irrigated farms can reduce their input cost, on average, by 31% without reducing their existing output and this reduction can go up to a maximum of 63%. Rain-fed farms can reduce their input cost, on average, by 39% to produce the same level of output and this reduction can go up to 56%. Seven per cent of irrigated farms are defining the frontier as opposed to no farms from the rain-fed group.

Average scale efficiency estimates are 0.93 (irrigated) and 0.91 (rain-fed) with only 10% (irrigated) and 13% (rain-fed) farms operating at the optimal scale. Of irrigated farms, only 25 % of farms were too large having DRS compared with 65% being too small having IRS. Ten percent of rain-fed farms were too small and 77% were too large. However, many farms are operated closer to the frontier in both categories. There was significant difference between irrigated and rain-fed farms in technical and cost efficiency measures based on the t-test results. Results suggests that rain-fed farms could have become more efficient by using fewer inputs, better allocation of inputs, reducing costs and achieving the proper scale than irrigated farms.

Figure 2 shows the kernel density estimates of the TE, CE, AE and SE for the grouped and full samples in irrigated and rain-fed areas. Kernel density curves show that the rain-fed farms shift towards the left i.e. farms become more inefficient when moving from the group frontier estimation to metafrontier estimation. Irrigated farms do not show significant deviation while moving from the group frontier estimation to metafrontier estimation. TE, AE and SE are more skewed towards the right, but the CE is more symmetrically distributed for all the samples and all the regimes. This implies that cost inefficiency is the most alarming issue that has to be given priority of all.

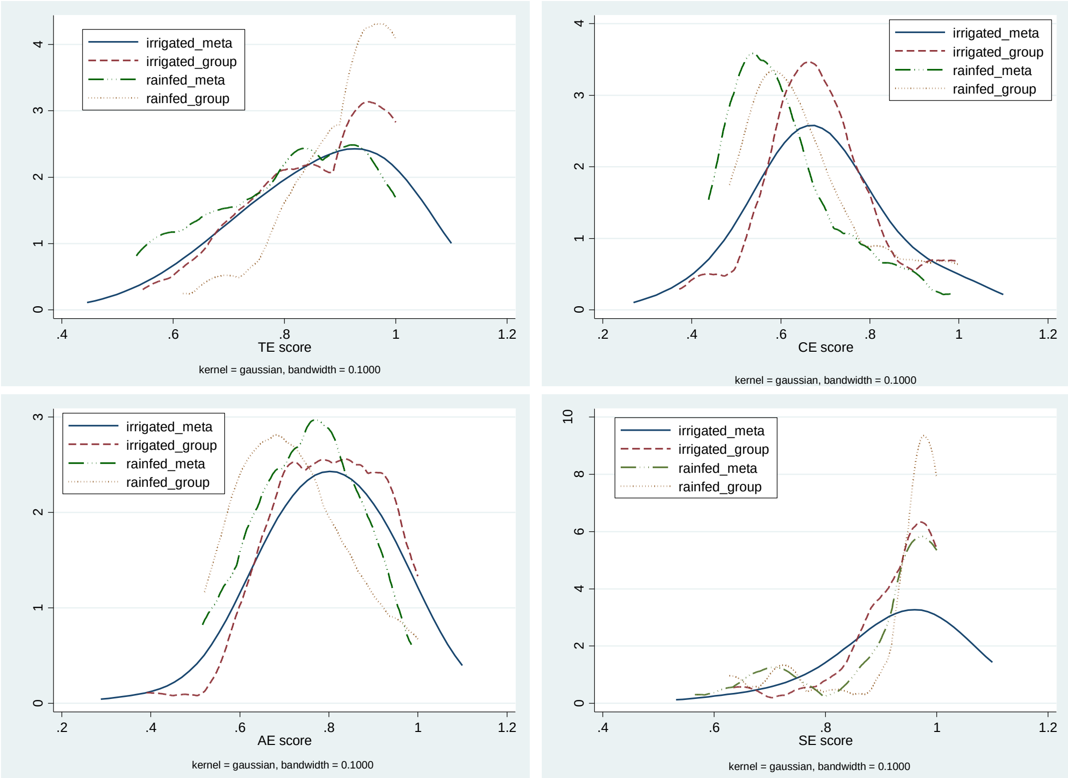

Figure 2: Kernel distribution of efficiency scores in irrigated and rain-fed farms

6.3 Production gap ratios: TGR, CGR, AGR and SGR

A technology gap ratio measures the ratio of the output for the frontier production function for a group relative to the potential output defined by the metafrontier function, given the observed inputs (Assaf and Matawieb, 2010). This procedure can be applied to measure the cost, allocative and scale gap ratios as well. Table 5 compares the cost, technological, allocative and scale gap ratios between irrigated and rain-fed groups.

Table 5: Average cost, technology, allocative and scale gap ratios*

		Mean	SD	Min	Max
Irrigated	TGR	1.0000	0.0000	1.0000	1.0000
	CGR	0.9934	0.0129	0.9348	1.0000
	AGR	0.9934	0.0129	0.9348	1.0000
	SGR	1.0000	0.0274	0.9296	1.0000
Rain-fed	TGR	0.8867	0.1146	0.5498	1.0000
	CGR	0.9145	0.0466	0.8289	0.9853
	AGR	1.0000	0.1413	0.8529	1.0000
	SGR	0.9874	0.0513	0.8107	1.0000

*Ratio between metafrontier and group efficiency estimates
Legend: TGR is technology gap ratio, TGR (bc) is bias corrected technology gap ratio, CGR is cost gap ratio, and AGR is allocative gap ratio

The average technology, cost and scale gap ratios for the rain-fed group is less efficient than the irrigated. The results show that the irrigated group are producing their full potential output and operating their full potential scale relative to the metafrontier technology. Also, these farms have achieved nearly full potential cost reduction and input combination. However rain-fed farms are producing 88% of their potential output and operating at 91% of potential cost reduction relative to the metafrontier technology. These results confirms that even though the farms in the region performs better relative to their own group frontier technology, there remains a technological and cost gap that prevents rain-fed farms from achieving much better efficiency results compared to the irrigated farms. Figure 3 shows the empirical cumulative distribution function (ECDF) for the separate pairs (Irrigated CGR vs. Rain-fed CGR, Irrigated TGR vs. Rain-fed TGR, Irrigated AGR vs. Rain-fed AGR and Irrigated SGR vs. Rain-fed SGR). This figure confirms the existing cost and technological gap between irrigated and rain-fed groups.

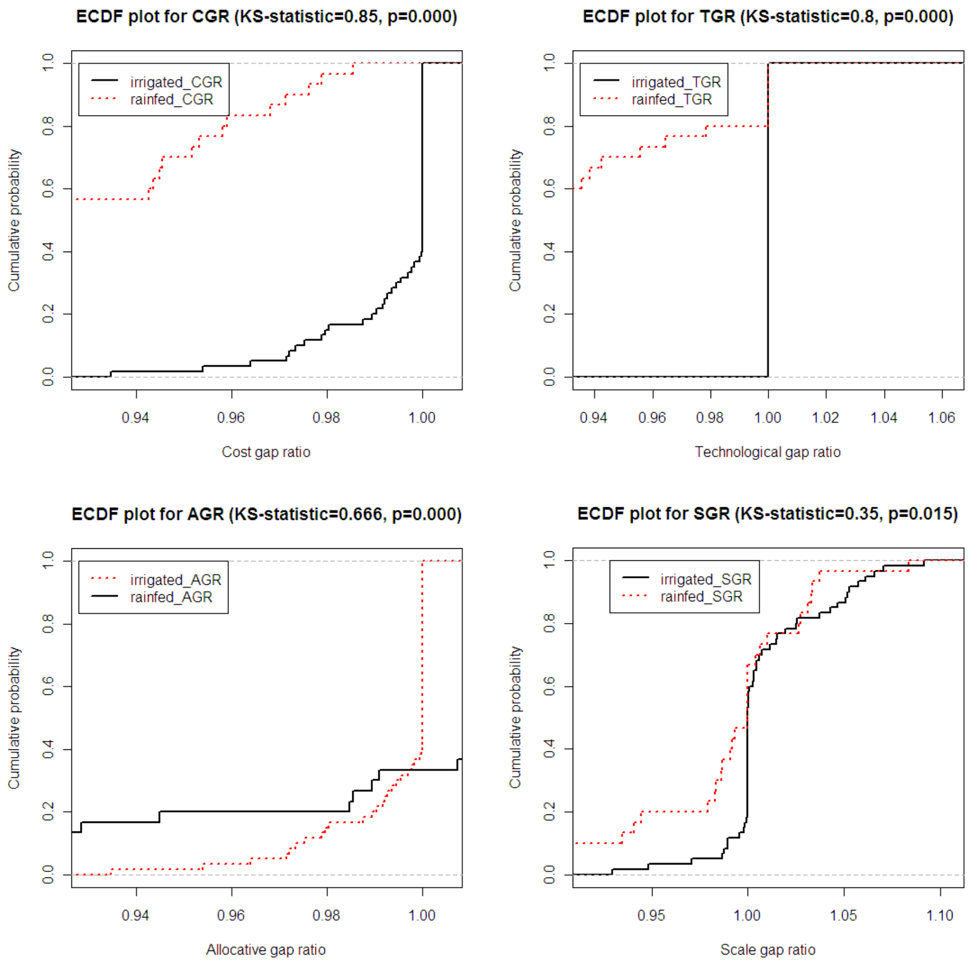

Figure 3: Cumulative efficiency distribution of CGR, TGR, AGR and SGR

6.4 Truncated regression analysis

Truncated regression results of the factors explaining efficiency estimates are presented in Table 6 separately for the metafrontier and group-frontier. Most of the variables are significant and the metafrontier results show some consistency with the group frontier results based on the magnitude and the direction of the estimates.

Table 6: Factors affecting Production Efficiency: Bootstrapped# Truncated Regression

Variables	Metafrontier			Group-frontier		
	Technical Efficiency	Cost Efficiency	Allocative Efficiency	Technical Efficiency	Cost Efficiency	Allocative Efficiency
Intercept	0.9143**	0.4829**	0.5041**	0.7840**	0.4580**	0.6005**
	(0.8061)	(0.0854)	(0.0594)	(0.0594)	(0.0840)	(0.0844)
Irrigated farms						
Rain-fed	-0.0775**	-0.0634*	-0.0016	0.0499*	-0.0045	-0.0502
	(0.0358)	(0.0338)	(0.0249)	(0.0261)	(0.0347)	(0.0346)
Farm size	0.2067	0.0090	-0.0136	0.0259*	0.0125	-0.0126
	(0.0174)	(0.2198)	(0.0161)	(0.0150)	(0.0220)	(0.0180)
State seed						
Private	0.2805	0.0077	0.0124	0.0291	0.0049	-0.0208
	(0.0454)	(0.0426)	(0.4694)	(0.0401)	(0.0421)	(0.0488)
Shared	-0.0432	0.0158	0.0589*	-0.0520	0.0193	0.0691**
	(0.0415)	(0.0345)	(0.0342)	(0.0365)	(0.0360)	(0.0348)
Self	-0.0697**	0.0297	0.0944**	-0.0456	0.0316	0.0700**
	(0.0339)	(0.0313)	(0.0293)	(0.0296)	(0.0325)	(0.0326)
Tenant operator						
Owners	0.0041	0.0105	0.0045	0.0216	0.0217	0.0007
	(0.0277)	(0.0271)	(0.0235)	(0.0251)	(0.0282)	(0.0255)
Machinery use	-0.0045*	0.0092	0.0058**	-0.0024	0.0007	0.0035*
(% total cost)	(0.0018)	(0.0020)	(0.0017)	(0.0016)	(0.0020)	(0.0019)
Family labour	0.0011	0.0014*	0.0008	-0.0015**	0.0017**	0.0007
(% total labour)	(0.0007)	(0.0008)	(0.0006)	(0.0006)	(0.0008)	(0.0007)
Female labour	0.0028**	0.0031**	0.0009	0.0032**	0.0036**	0.0010
(% total labour)	(0.0009)	(0.0009)	(0.0008)	(0.0008)	(0.0009)	(0.0009)
Log likelihood	63.29	63.67	77.97	75.64	61.62	67.83
Prob>chi^2	0.0005	0.0001	0.0000	0.0001	0.0028	0.0013
Wald chi^2(9)	31.02	33.04	40.91	34.61	25.28	27.20
Observations	89	89	89	89	89	89

Note: ** significant at 5% level * significant at 10% level # Number of bootstraps=5000

Compared to the irrigated farms, the rain-fed farms are less efficient in all three efficiency measures under the metafrontier technology and in CE and AE in group frontier technology. The major reason may be that rain-fed cultivations are often more prone to water stress due to the uncertainty and variability of the rainfall and timely unavailability of water than irrigated cultivations. This may suggest that availability of water is a key factor determining efficiency. These results conform to the popular belief that irrigation shifts the production frontier to a higher level (Gunaratne and Thiruchelvam, 2002, Makombe, et al., 2007, Makombe, et al., 2011, Thiruchelvam, 2005a, Tilahun, et al., 2011).

The positive coefficient for farm size variable with the TE and CE under the both technological settings indicates larger farms are able to produce more output per input use and at a lower cost relative to smaller farms. Lower AE of large farms relative to small farms may be due to poor selection of input mix due to increased access to various inputs. Use of seed from private traders significantly improves efficiency but the use of own and shared seed seems to significantly reduce TE than using state produced seed. The reason could primarily be the higher quality of seed produced by private seed producers, which is often lacking if self produced.

Land ownership results indicate that the owner operators are more efficient than the tenants. These findings are similar to the findings of the studies done by Coelli, et al. (2002), Marino, et al. (2011), Rahman and Rahman (2009) and Yao and Shively (2007). These results may be attributed to the over-use of inputs such as labour by the tenants and timely availability and accessibility to the major input resources by the land owners. Due to the lack of off-farm economic activities, tenants and their families tend to spent most of their time cultivating their small rented land.

Increased machinery use improves the allocative and cost efficiencies. On the other hand, excessive machinery use in small plots might have the potential of diminishing the technical efficiency. The share of family labour and female labour endowments to total labour has a statistically significant positive impact on all the efficiency measures. The former may be due to that family labour put more effort on taking care of the plants and this increases the efficiency of some other inputs. Studies by Dhungana, et al. (2004) and Rahman and Rahman (2009) find similar results. A possible explanation for the latter could be Females are used only for certain activities so that labour specialization stimulates more production efficiency. These comply with the results obtained by Dhungana, et al. (2004) and Rahman (2010).

7. Conclusion

The study analysed the differences of technical, allocative, cost and scale efficiencies of irrigated and rain-fed rice farmers in Sri Lanka in two different perspectives; first, relative to a common *metafrontier*, defined as the boundary of an unrestricted technology set and second relative to *group frontiers* defined to be the boundaries of restricted technology sets in each group. We find, first, there are inefficiencies associated with input use, input cost, input allocation and the scale of cultivation in both the irrigated and rain-fed groups. On average, farms tend to be more technically and scale efficient, than allocative efficient or cost efficient. Cost efficiency is the most alarming issue of all.

Second, we find rain-fed group performance is comparable with that of irrigated group i.e. farms in the two groups are equally efficient relative to the farms in the same region. Third and most importantly, we find that rain-fed farms move significantly towards inefficiency compared to the irrigated farms under the metafrontier technology. Thus, there is a considerable degree of inefficiency in rain-fed rice farms compared to the irrigated rice farms in all efficiency measures. Results indicate that the irrigation shifts the rice sector production frontier to a higher level and the rain-fed farmers may be operating as technically efficient as they could, given the existing production technology.

This suggests that the agricultural development in the rain-fed sector should focus on the strategies that shift the production frontier to higher levels. As the expansion of the irrigated systems in rain-fed areas is not possible in the short run due to technical and financial constraints, productive efficiency of the rain-fed system needs to be improved by managing the efficiency enhancing factors such as farm size, seed quality and ownership issue. Further suitable management and agronomic practices such as integrating rain-fed and irrigated farming and synchronizing cropping calendars to suit the water availability is recommended.

Promoting cultivation systems approach which organizes small scale cultivations in to comparatively larger collective systems with the collaboration of the government, farmer organizations and the private sector, would be a possible solution to inefficiencies attached with the small lands. Private sector produced seed use is efficiency enhancing primarily due to the high quality resulting from improved resources and expertise. Expanding state seed production and encouraging private sector participation in seed paddy production are required in order to replace low quality informal sector seed use with the high quality formal sector seed use. Considering the cost of production aspects associated with private sector produced seeds, self seed production should have to be incorporated with sufficient extension services and training on quality seed rice production. Use of more family labour and female labour was found to be efficiency enhancing and should be encouraged especially in small scale farms in rain-fed regions.

Using time series data coming from the same sample of farmers over the both agricultural seasons and incorporating other important variables such as land quality, agricultural extension, credit, weather conditions and other household characteristics (age, experience, education, etc.) in the second stage regression can be done to increase the robustness of the results.

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