A Non-Parametric Analysis of Rice Production Efficiency in Sri Lanka

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Contributed paper prepared for presentation at the 56th AARES annual conference, Fremantle, Western Australia, February7-10, 2012

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Abstract
This article investigates the production efficiency of rice farming in Sri Lanka using cross section survey data of 90 farms. Past studies on rice farming have mostly focused on technical efficiency (TE). Here, we examine technical efficiency, allocative efficiency (AE) and cost efficiency (CE) using the data envelopment analysis (DEA) approach. On average, the farms were 87% technically efficient; irrigated farms were more efficient (88%) than rain-fed farms (82%). Average cost, allocative and scale efficiencies were 73%, 84% and 87%. Bias corrected TE estimate suggests an expected output expansion of 25% with a given input combination in order to become fully efficient as opposed to 16% based on the original estimates. In addition, a second stage Tobit regression shows that efficiency is influenced by farm size, water security, ownership, seed quality, family labour endowment and female labour participation.

Key words: technical efficiency, cost efficiency, bootstrap, rice farming, Sri Lanka

1. Introduction

Rice production efficiency has received substantial attention in recent empirical literature, especially in the South and South-East Asian regions. This is partly because of its crucial role in food security and the economic development of agricultural sectors in the regions (Balcombe, et al., 2007, Coelli, et al., 2002, Dhungana, et al., 2004, Rahman, 2010, Rahman and Rahman, 2009, Rahman, et al., 2009, Tan, et al., 2010, Wadud and White, 2000, Yao and Shively, 2007). A key observation across empirical studies in the regions is that decline in farm profitability can be related to disparities in technical efficiency across farms. This suggests that an improvement in technical efficiency is essential for the ultimate survival of rural agriculture.

As in other parts of Asia, rice is the staple food and principal crop in Sri Lanka. It occupies the largest extent of land under any single crop[1]. The sector accounts for nearly 3 per cent of the country's Gross Domestic Production (GDP) and about 15 per cent of the agricultural GDP (CBSL, 2010). About half of the agricultural labour force is employed in the sector. Declining farm sizes and rising cost of production are the two major challenges facing rice production in Sri Lanka. Due to land fragmentation, approximately 50 per cent of rice production comes from small farms cultivating less than 1 acres and another 25 per cent comes from farms cultivating between 1 to 2 acres. Only 3% of paddy cultivations come from farms cultivating more than 5 acres (DCS, 2002). Timely availability of sufficient water is very important for cultivation as rice is a high water intensive crop. Rice is cultivated under

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[1] It accounts for more than 900,000ha and about 34% of total agricultural land area in Sri Lanka.

different water regimes and there is a greater variability in productivity among these regimes. Further, increasing cost of labour, machinery, fertilizer and agrochemicals has been an issue of serious concern over the years (Thiruchelvam, 2005a).

Despite the significance of the rice sector in the Sri Lankan economy, and the recent achievements of near self-sufficiency status in production, 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). According to Abeysiriwardena (2003), rice is the least profitable venture of all farming activities in Sri Lanka. Demand for rice is rising due to the growth of population by 1.1 per cent and per capita income by 15 per cent annually[2]. It is projected that the 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, the possible solution to this problem could come through either yield improvement or the efficient use of inputs, or a combination of both. However, empirical studies in Sri Lanka that focus on identifying whether there are any scope for improving production efficiency and what factors influence efficiency are still rare. As noted by Udayanganie, et al., (2006), there is a considerable gap in research in terms of measuring the productive efficiency of paddy cultivation in Sri Lanka.

Farmers in Sri Lanka are price takers in the output and factor markets and changes in these markets highly affects their decisions on input allocation, costs structure and ultimately farm income. While few of the available empirical studies have focused on the analysis of technical efficiency, it is important to investigate the cost efficiency and allocative efficiency of rice production.

The major objective of this study is to measure the production efficiency of the Sri Lankan rice sector using the DEA procedure. We compute the following efficiency measures: technical efficiency (TE), allocative efficiency (AE), cost efficiency (CE), scale efficiency (SE). We also estimate the bias-corrected technical efficiency estimates and investigate the factors that influence production efficiency differences in irrigated and rain-fed rice farms while controlling farm size, resource utilization and resource ownership.

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[2] Average per cent change in per capita GDP between 2000 and 2010 is 15%, with the years 2007 and 2008 achieving more than 21% change.

This study contributes to the literature on Sri Lankan's rice production economics in several ways. To the best of our knowledge, this is the first study to analyze TE, AE, CE and SE of rice production in Sri Lanka using the DEA approach. This is also the first attempt to apply the bootstrapping procedure to correct for the bias generated by the deterministic DEA model. No other study has measured the impact of the seed source, irrigation method, and date of planting on efficiency measures, which could be of interest to policy makers in most other Asian countries facing input market liberalization.

Results of this study have policy implications pertaining to better allocation and utilization of resources for rural development and food security in Sri Lanka. The results are expected to be of interest to policy makers in other Asian countries having similar background and issues. The next section reviews relevant literature on rice production efficiency. Section three describes the methods and data. Section four discusses the results followed by the concluding comments in section five.

2. Literature Review on Rice production Efficiency

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). A number of studies have examined the efficiency of rice farmers in developing countries. Stochastic frontier analysis and Data Envelopment Analysis method are the most frequently used methods in analyzing efficiency and factors explaining efficiency. Some of the recent studies in rice farming in Asian region are summarized in Table 1.

-Insert Table 1-

The studies have estimated the efficiency measures and examined the managerial and socio economic factors that explain efficiency differences across farms in the same region and/or in different regions and over time. Most of the studies have focused on socio-economic issues like age, farm managers' experience, education attainment, farm size, land ownership and labour use among others to analyse the determinants of technical efficiency. Most studies showed greater efficiency differences across farms. However, the results of these studies are mixed and inconclusive.

For example, some studies (Bäckman, et al., 2011, Brazdik, 2006, Khan, et al., 2010, Rahman and Rahman, 2009, Rahman, et al., 2009, Tan, et al., 2010, Vu, 2008, Wadud, 2003) showed a positive significant relationship between farm size and productive efficiency while some others (Balcombe, et al., 2008, Wadud and White, 2000) found a positive and insignificant relationship. The relationship was negative in the case of Balcombe, et al., (2007) and Yao and Shively (2007). Most studies showed a positive significant relationship between ownership and efficiency (Coelli, et al., 2002, Mariano, et al., 2011, Rahman and Rahman, 2009, Yao and Shively, 2007). Rahman (2010) estimated high efficiency for tenants than the owner operators.

Excessive use of family labour is found to increase efficiency (Brazdik, 2006, Dhungana, et al., 2004, Rahman and Rahman, 2009), and a positive relationship is found between hired labour and efficiency (Yao and Shively, 2007). Negative relationship between large families and efficiency is found in Coelli et al (2002) while Rahman (2010) finds a positive relationship. Negating the popular notion on female labour use in developing countries, some studies finds that female labour input significantly improves technical efficiency (Dhungana, et al., 2004, Rahman, 2010).

Very few studies have estimated rice productive efficiency and its determinants in Sri Lanka (Ekanayake and Jayasuriya, 1987, Gunaratne and Thiruchelvam, 2002, Karunarathne and H.M.G.Herath, 1989, Thiruchelvam, 2005b, Thiruchelvam, 2005a, Udayanganie, et al., 2006). While Gunaratne and Thiruchelvam (2002) has undertaken a comparative analysis between major and minor schemes, all the other studies have been confined to the major irrigation areas[3] in Mahaweli Systems[4]. All the studies have used stochastic frontier method while none of the studies has given any attention to non-parametric method. In summary,

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[3] Rice lands are classified as major irrigation, minor irrigation and rain-fed based on the water source. Major irrigation schemes are those having a command area of more than 80ha, where the water supply may be either from a major tank or a river or a major stream diversion system. Minor schemes are those under village tanks, which consist of less than 80ha. Rain-fed cultivations are those lands which are grown with rainfall.

[4] The Mahaweli basin is the largest river basin of Sri Lanka covering an area of over 10,000 Sq. Km. Several irrigation settlements were developed under the Accelerated Mahaweli Development Project namely System H, B, C, G, L, Uda Walawe and Victoria.

land ownership and land size have been highlighted as the most important factors positively influencing efficiency (Thiruchelvam, 2005b, Thiruchelvam, 2005a, Udayanganie, et al., 2006). Gunaratne and Thiruchelvam (2002) underscored the importance of water availability in improving technical efficiency by finding higher technical efficiency in major irrigation schemes compared to minor schemes. Ekanayake and Jayasuriya (1987) and Karunarathne and Herath (1989) finds no significant technical inefficiency among rice farmers at the head ends in Mahaweli System H.

In general, despite the advantages of DEA over Stochastic Frontier Analysis (SFA)[5], most empirical studies have used SFA method. This is partly because the traditional DEA approach is criticized for a lack of a solid statistical foundation and sensitivity to outliers. Ignoring the statistical properties in the estimators could lead to biased DEA estimates and misleading results. Bootstrapping DEA method introduced by Simar and Wilson (1998) provides a statistically sound solution to overcome these problems and allows estimation of bias corrected efficiency scores, variation and confidence intervals (Mugera and Langemeier, 2011). However, only a few empirical studies have measured the bias corrected technical efficiency estimates in rice farms (Balcombe, et al., 2007, Vu, 2008).

In summary, results of the efficiency analysis are mixed, inconclusive and biased towards estimating TE alone while neglecting other important aspects of efficiency like AE and CE. Consequently, the present paper contributes to fill the current gap in the efficiency literature by analyzing TE, bias corrected TE, AE, CE and SE and the factors determining the efficiency across rice farms in Sri Lanka.

3. Methodology

The efficiency measurement method used in this paper is derived from those presented in Wadud and White (2000), which are based on the method developed by Charnes et al. (1978) using Farrell’s (1957) seminal work of measuring technical efficiency and estimating production frontier. First, input oriented technical, scale, allocative and cost efficiencies are estimated as farmers have more control over inputs than the output. Then following the studies by Olson and Vu (2007) and Gocht and Balcombe (2006) based on the smooth bootstrap procedure for DEA proposed by Simar and Wilson (2000), bias corrected technical

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

efficiency are calculated. Finally, the estimated efficiencies are used to identify the impact of some resource utilization factors explaining performance differences among the farms using Tobit regression analysis.

Technical Efficiency

Following Coelli et al. (2002), assume that there are n farms $(n = 1, 2, \dots, 90)$ which produce a single output m (m=1, i.e. rice) using k different inputs $(k = 1, 2, \dots, 5)$ representing seed, fertilizer, chemicals, labour and machinery. 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,

1.
$$\begin{aligned} & Min_{\theta_i \lambda_i} \theta_i \\ & s.t.\ Y\lambda - y_i \geq 0, \\ & x_i \theta_i - X\lambda \geq 0, \\ & \lambda \geq 0 \end{aligned}$$

where θ is a scalar and λ is a $n \times 1$ vector of constants. For Variable Return to Scale (VRS), convexity constraint, $n1'\lambda = 1$, is added, where $n1$ is a $n \times 1$ vector of one. According to Farrell's definition in Coelli, et al. (2005), 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.

Bootstrapping the TE estimates

This paper applies smoothed homogeneous bootstrap procedure following Simar and Wilson (2000) to get bias corrected efficiency scores and their confidence intervals. Bootstrap procedure repeatedly simulates the data generating process by re-sampling the sample data and applying the original estimator to each simulated sample. This enables the investigation of the sensitivity of efficiency scores to sampling variations (Mugera and Langemeier, 2011). The analysis is done in R statistical software using the FEAR package.

Scale Efficiency and Return to Scale

Scale efficiency is calculated by the ratio $SE = TE_{CRS} / TE_{VRS}$. SE = 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, $TE_{NIRS} = TE_{VRS}, TE_{NIRS} \neq TE_{VRS} \text{ and } TE_{VRS} = TE_{CRS}$ relationships indicate the existence of DRS, IRS and CRS respectively (Coelli, et al., 2005).

Allocative and Cost Efficiency

To measure the cost efficiency (*CE*), another DEA equation with cost minimization objective is imposed, where x_{mn}^{*} represents the cost minimizing vector of inputs *m* for the n^{th} farm given the input prices w_{mn}.

$$\begin{aligned} &Min_{\lambda x_i^*} w_i' x_i^*, \\ &s.t.\ Y\lambda - y_i \geq 0, \\ &x_i^* - X\lambda \geq 0, \\ &n1'\lambda = 1, \\ &\lambda \geq 0, \end{aligned} \tag{2.}$$

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

TE estimates were calculated assuming all the three return to scale (CRS, VRS and NIRS), but only VRS assumption was imposed measuring AE and CE estimates for the simplicity of the study.

Tobit Analysis 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. The dependant variable, i.e., production efficiency measure, has a censored distribution as it lies between 0 and 1. Hence, Tobit regression model using the maximum likelihood approach is the most consistent approach.

Three separate Tobit regressions were run taking VRS estimates of TE, AE and CE estimates as the dependant variable as follows.

3.
$$y_i^* = \beta Z_i + e_i$$
$$y = \begin{cases} y^* & if\ y^* < 1 \\ 1 & Otherwise \end{cases}$$

where y_i is DEA efficiency index and z_i represents a vector of explanatory variables $i = (1, 2 \ldots. 8)$. z_1 =farm size, z_2 =irrigation dummy, z_3 =date of sowing dummy, z_4 =seed source dummy, z_5 =ownership dummy, z_6 =machinery use, z_7 =family labour use (%), z_8 =female labour participation (%)

It is preferred using bias corrected TE estimates over the original estimates as the bias is larger than the standard deviation (Mugera and Langemeier, 2011). However, because the bias corrected measures of AE and TE were not readily available, the censored efficiency measures were used as dependent variables to achieve consistency over the three efficiency measures used in the analysis.

4. Data and Variables

The data used in this study comes from a survey of rice producers, conducted by the Institute of Policy Studies of Sri Lanka during March to May 2008 in three irrigation systems: major irrigation scheme, minor irrigation scheme and rain-fed in Sri Lanka. Samples were collected from six Agrarian Service Centre (ASC) Divisions in six Districts. Districts and ASC divisions were purposively selected to represent all the irrigation systems and climatic zones while 15 randomly drawn farm households were selected in each ASC division. Total sample is comprised of 90 farmers.

The rice lands in Sri Lanka can be categorized mainly as irrigated (major and minor) and rain-fed based on method of water supply or as Maha and Yala based on the cultivation season. The major cultivation season (Maha) is from October to March whereas the minor cultivation season (Yala) is from April to September (Dhanapala, 2000). The data for the present study comes from 2007/08 Maha Season. Major and minor irrigated cultivations are represented by Ampara, Polonnaruwa, Kurunegala and Matara districts while Kegalle and Kalutara districts represent rain-fed cultivation.

Data was collected on 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, date of sowing, method of irrigation and ownership type. 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. Some other fertilizers like Zinc, Kieserite and Ammonia are excluded because only a small proportion of farmers and in certain areas used these. 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 for tractors, threshers and combined harvesters, excluding the labour cost.

Table 2 shows the summary statistics for the irrigated and rain-fed cultivations separately due to the apparent differences in the yield of rice and per acre usage of certain inputs. As the table shows, overall farm size is quite small with maximum of 6.5 acres. Average farm sizes in the two systems are significantly different, i.e., 2.13 acres in irrigated and 1.22 acres in rain-fed. Average yield levels are no exception to this with 2,220 kg/acre in irrigated and 1794 kg/acre in rain-fed. There is no much difference in the per acre quantities of inputs except labour and machinery. Rain-fed cultivation is more labour intensive while in irrigated areas machinery use is significantly higher. Labour is relatively cheaper in irrigated areas due to surplus labour and lack of off farm activities.

-Insert Table 2-

5. Empirical Results

Analysis of production efficiencies

Summary statistics for the computed technical, cost, allocative and scale efficiencies are reported in Table 3. Initial estimates of average technical efficiency were 0.75, 0.87 and 0.76 for CRS, VRS and NIRS respectively. Twenty-eight farms (31 per cent) were fully efficient under the VRS, but this was much lower under the CRS and NIRS with 9 (10 per cent) and 13 (14 per cent) farms respectively. Minimum TE was 0.51 under VRS assumption and 0.32 under CRS and NIRS assumptions. This suggests that farms in the sample could have produced the same output with up to 68 per cent per cent fewer inputs. Rice cultivations under the major irrigation schemes have significantly higher TE scores compared to the minor irrigation schemes and rain-fed cultivations under all the three assumptions. This difference shows the significance of timely and sufficient availability of water resource. Rain-fed cultivations are frequently subject to higher variability of rainfall while water availability is more secured in major irrigation schemes.

The mean allocative efficiency score is 0.84 with minor (90 %) and major irrigation schemes (87 %) having higher efficiency than the rain-fed systems (76 %). 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 major and minor schemes, five and two farms are defining the frontier respectively, but no farm from the rain-fed systems. 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. Maximum possible cost reduction by proper input allocation is 48 per cent.

The average cost efficiency is 0.73 per cent with a minimum of 0.33 per cent. Seven farms, 5 from major and 2 from minor, are defining the frontier. This suggests that the farmers can reduce their input cost, on average, by 37 per cent without reducing their existing output and this reduction can go up to a maximum of 67 percent. Cost efficiency in rain-fed farms is significantly lower at 0.62, compared to 0.76 and 0.79 in minor and major irrigation farms. Average scale efficiency (SE) is 0.87 with only 10 per cent of the farms having a SE score of 1. However, many farms are closer to the frontier. Fifty six per cent of farms have a SE score higher than 0.90 and thirty-seven per cent of farms had an SE score higher than 0.95. Farms under major irrigation schemes are more scale and cost efficient. Information on whether farms operate at sub-optimal or super-optimal level can provide useful implications on potential farm resource distribution to maximize productivity. Of all the farms, only 21 per cent of farms were too large having DRS compared with 69 per cent being too small having IRS and 10 per cent at an optimal scale of operation.

-Insert Table 3-

Figure 1 shows the kernel density estimates of the TE, CE, AE and SE estimates under VRS. TE, AE and SE are more skewed towards the right, but the CE is more symmetrically distributed. Hence, farms tend to be more technically and scale efficient followed by AE and finally by CE. Based on the probability value of greater than 0.05 in the mean comparison test between TE and SE[6], mean difference is not statistically significantly different from zero, but the per cent of farms with a score of 1 is higher for TE (31%) compared with SE (10%). This implies that cost inefficiency is the most alarming issue that has to be given priority of all.

-Insert Figure 1-

Bias corrected technical efficiency

Applying the bootstrap procedure, the average bias corrected technical efficiency was 80 percent compared to the original technical efficiency as 86 percent. Therefore the average bias was 6 percent (Table 4). The maximum inefficiency under bias corrected TE was 52 per cent as opposed to 49 percent in original TE scores. There is an obvious variability in lower and upper bounds of corrected TE. However, Spearman's rank correlation of 0.95 between original and bias corrected efficiency estimates suggests a strong correlation of ranking of the two estimates. Based on the original TE estimate, an average farm could expand its output by about 15.5 per cent with a given input combination in order to become fully efficient. However, the bias-corrected TE suggested an expected output expansion of 24.5 per cent. The upper and lower bounds of the 95 per cent confidence interval (0.86 and 0.74) suggests that the average possible expansion of technical efficiency ranges from 16 per cent to 35 per cent.

Percentile results show that 50 per cent of the sample is having more than 17 per cent inefficiency and 25 per cent having more than 27 per cent inefficiency. Only five per cent of the sample is having less than 6 per cent inefficiency. Bias corrected efficiency results disaggregated based on the irrigation method follows the same pattern as original efficiency scores with higher inefficiency for rain-fed farms followed by minor and major.

-Insert Table 4-

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[6] Mean comparisons between the pairs, TE and AE; TE and CE; AE and CE showed significant mean differences unlike TE and SE.

Analysis of farm input use

Following Coelli et al (2002), over use of inputs were calculated by the average ratio of technically efficient input levels to cost efficient input levels for all five inputs separately[7]. As can be seen in Table 5, on average, all the inputs except fertilizer were overused by the farmers. Over use of labour is quite significant (63 per cent). However, this is not surprising as it is customary to work all the family members in an average small plot of land on top of using hired labour. Share of family labour in total labor is 52 per cent with 13% farms using more than 75 per cent. Moreover, this reflects the lack of off-farm opportunities in rural areas and inequitable development in favour of Colombo led Western province.

Machinery, chemicals and seed over use were 30%, 36% and 22% respectively. Input over use is relatively higher in rain-fed than irrigated areas except in chemicals. Surprisingly, fertilizer overuse is on average only 8 per cent even with a subsidy of about 90 per cent of the market price. However, in the average overuse is 19 and 15 per cent in minor and rain-fed areas as opposed to 1 percent underuse in major irrigated areas. This may be attributed to the differences in infrastructure and poor targeting of the fertilizer subsidy. Thus, it is not incorrect to highlight that the fertilizer subsidy may encourage overuse.

-Insert Table 5-

Results showed that the most of the farmers have overused inputs and employed an incorrect input mix. The overuse of different inputs has different impacts on the efficiency measures. Table 6 shows the Tobit regression results showing the relationship between excess use (i.e. the difference between real input use and the cost efficient input level) of different inputs and efficiency measures. According to the results, excess use of fertilizer, labour and machinery has negative significant impact for both the TE and CE, while seed over use has a positive significant impact. Results of labour and machinery overuse are similar for AE as well, but fertilizer overuse is completely reverse with positive insignificant results. Relatively higher negative impact of fertilizer overuse on TE and CE may have significant policy implications on state fertilizer subsidy scheme which is intended to encourage more fertilizer use for higher yield.

-Insert Table 6-

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[7] Input use ratio shows the input overuse by a technically efficient farm relative to the cost efficient farm for a given output. Ratio of one indicates that the farm is both technically and cost efficient and no input overuse

Factors explaining efficiency differences

Efficiency scores were regressed on the farm level factors using a Tobit model. Farm size (acres), irrigation method (dummy), seed source (dummy), date of sowing (dummy), seed source (dummy), land ownership (dummy), machinery cost (% total cost), family labour (% total labour) and female labour (% total labour) were used as the explanatory variables. District dummy was excluded from the model as its higher correlation with the irrigation method[8].

Tobit results of the factors explaining efficiency estimates are presented in Table 7. Farm size coefficient is positive for both TE and CE, which indicates larger farms are more efficient than smaller farms (i.e., able to produce output and at a lower cost while using same level of input as smaller farms). This can be attributed to greater access by the large farmers than smaller farmers to input resources like irrigation, quality seeds, fertilizer and services like credit, research and extension. 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 and because of the majority having DRS. According to the irrigation results, rain-fed farms are least efficient in all three efficiency measures, while Major irrigated farms are the most efficient in TE. The major reason may be that rain-fed and minor irrigation cultivations are often more prone to water stress due to the uncertainty and variability of the rainfall and timely unavailability of water than major irrigation cultivations. This may suggest that availability of water is a key factor determining efficiency.

Early planters tend to be more efficient than the late planters in all three efficiency measures, though this relationship is insignificant. This may be more related to the timely availability and accessibility to the major input resources. Also relatively cheaper labour due to the availability of surplus labour, may contribute for the higher cost efficiency. Results of the seed source dummy indicates that the use of seed from private traders significantly improves efficiency but the use of own seed seems to be significantly reduce efficiency than using state produced seed. This could primarily be attributed to the quality of seed, which is often believed to be poor if self produced. Private seed companies are more concerned about the quality of their product and equipped with sufficient resources, modern technology, expertise and infrastructure to produce high quality seeds.

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[8] Correlation coefficient between irrigation method and district was 0.82.

Tenancy results indicate that the owner operators are more technically efficient than tenants are. This may be attributed to the over-use of inputs such as labour. There is a significant gap between tenants and owner operators economically and socially. 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. In addition, this could be due to poor land quality as landowners may rent out poor land and retain the high quality land for their own use. Tenants are allocatively and cost efficient than landowners. This could be because they are more cost conscious in selecting and allocating inputs than relatively rich land owners.

Use of machinery improves the allocative and cost efficiencies. Negative and significant relationship between machinery use and technical efficiency contradicts the popular notion that the mechanization and technological improvement leads to efficiency enhancement. On the other hand, excessive machinery use in small plots might have the potential of diminishing the technical efficiency. However, it is too early to hypothesize that technical efficiency of small land plots can be improved by substituting some machinery with labour. This could be a subject of further research.

The share of family labour endowment to total labour has positive impact on all three efficiency measures. This could be because family labour put more effort on taking care of the plants and this increases the efficiency of some other inputs. Female labour participation significantly improves the TE and CE. A plausible explanation for this could be females are used only for some specialized activities like planting and manual harvesting. This suggests that labour specialization is useful for enhancing the productive efficiency.

-Insert Table 7-

Relationship of CE with TE and AE

Based on the results, there were 21 farms that were TE, AE and CE and 7 farms with only TE. However, there were no farms either fully AE or/and CE without TE. Thus, it is interesting to see whether CE induces the AE and TE. Table 8 shows the Tobit regression results showing the relationship between TE, AE and CE. Results indicate that both TE and AE lead to CE, but AE has the highest impact on CE. The relationship between TE and AE is negative. Hence, in order to achieve CE, there should be a proper balance between AE and TE, i.e. not only reduction of input but also correct input balance is required.

-Insert Table 8-

6. Conclusions

This study analysed technical, allocative, cost and scale efficiencies of Sri Lankan rice farmers. Production efficiencies were measured using Data Envelopment Analysis method under assumptions of constant return to scale, variable return to scale and non-increasing return to scale. Allocative and cost efficiency estimates were measured under variable return to scale assumption.

The results indicate considerable degree of inefficiency in Sri Lankan rice farms. On average, farms tend to be more technically (0.87) and scale efficient (0.87), than allocative efficient (0.84) or cost efficient (0.73). In general, farms under major irrigation schemes are relatively more efficient than minor irrigation and rain-fed farmers. This shows the importance of timely availability of water in improving technical efficiency. Bootstrapping method was employed to determine the sensitivity of DEA VRS technical efficiency estimates to sampling variation and to correct for the bias inherent in the deterministic measurement. The average bias-corrected technical efficiency estimate was 0.80 with 0.12 confidence interval width on average.

Allocative and cost inefficiency can be attributed largely to overuse of labour, chemicals and machinery. Overuse of labour reflects the lack of off-farm employment opportunities in rural areas. This suggests the need for policies that promote the creation of off-farm employment to take off excess labor from farming. Machinery use is quite common among farmers at all scale levels. Over use of machinery reduces farm TE while more machinery usage enhances allocative efficiency. Hence, there should be a correct balance between employing machinery and labour in small land plots. We can infer from overuse of fertilizer that subsidizing fertilizer encourages overuse but the high over-use in rain-fed and minor irrigation areas than the major irrigation areas may partly explain the so-called poor targeting and infrastructural differences in different regions. Though it is too early to come to an extreme conclusion that subsidizing fertilizer has to be eliminated, it is suggested to rectify the targeting issue and infrastructural differences between regions to make it more effective.

These efficiency estimates were employed in the second step Tobit regression to evaluate factors influencing the inefficiency. Results indicate that increasing land size, irrigation water and ownership enhance TE. These have very important policy implications on the viability of rural agriculture, as the sector currently consists of a large number of small farms and tenant cultivators. From a policy perspective, any policy or programme to address the inefficiency in the rice sector should take in to consideration the relationship of farm size, water availability and ownership issue with the TE. In order to achieve economic of scale, cultivation systems approach (Eg: Yaya system) should be promoted to organize small scale cultivations in to comparatively larger organized collective systems with the collaboration of the government, farmer organizations and the private sector. Existing tenurial and land legislations should be reviewed in order to find a better solution for inefficiencies associated with land fragmentation and tenancy.

Seed source results suggest that the use of quality seed is of high importance in maximizing efficiency, so that the transformation of state seed production should be done with extreme care in order not to deteriorate the seed quality. Private sector participation in the seed industry should be increased. Self seed rice production by the farmers should be discouraged unless it is coupled with sufficient extension services and training on quality seed rice production. Use of more family labour and female labour should be encouraged especially in small scale farms. Female labour should be attracted to the rice cultivation by minimizing the wage gap between male and female labour and creating a hired labour market for female labour, while labour specialization should be promoted.

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Table 1: Recent frontier efficiency studies on rice cultivation in Asia

Authors	Year	Country	Model	Efficiency measures
Other Asian countries				
Wadud and White	2000	Bangladesh	Stochastic and Non-parametric	TE
Coelli et al	2002	Bangladesh	Non-parametric	TE, AE, CE, SE
Wadud	2003	Bangladesh	Stochastic and Non-parametric	TE, AE, CE, SE
Dhungana et al.	2004	Nepal	Non-parametric	TE, AE, CE, SE
(Villano and Fleming)	2006	Philippines	Stochastic	TE
Brazdic	2006	Indonesia	Non-parametric	TE
Yao and Shively	2007	Philippines	Stochastic	TE
Balcombe et al	2007	Bangladesh	Stochastic	TE
Balcombe et al	2008	Bangladesh	Non-parametric	TE
Vu	2008	Vietnam	Stochastic and Non-parametric	TE, SE
Rahman and Rahman	2008	Bangladesh	Stochastic	TE
Rahman et al.	2009	Bangladesh	Stochastic	TE
Rahman	2010	Bangladesh	Stochastic	TE
Tan et al.	2010	China	Stochastic	TE
Khan et al.	2010	Bangladesh	Stochastic	TE
Backman et al.	2011	Bangladesh	Stochastic	TE
Marino et al.	2011	Philippines	Stochastic	TE
Sri Lanka				
Ekanayake and Jayasuriya	1987	Mahaweli ‘H’	Deterministic and Stochastic	TE
Karunarathna and Herath	1989	Major Irrigation	Stochastic	TE
Gunaratne and Thiruchelvam	2002	Major & Minor	Stochastic	TE
Thiruchelvam	2005	Mahaweli ‘H’	Stochastic	TE
Thiruchelvam	2005	Major & Minor	Stochastic	TE
Udayanganie et al.	2006	Major	Stochastic	TE

Source: Authors own literature search

Table 2: Summary Statistics of Main Variables

	Irrigated				Rain-fed			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Quantities								
Rice (kg/ac)	2220.38	412.20	1568.00	3175.00	1794.09	313.49	1120.00	2240.00
Seed (kg/acre)	40.09	3.91	24.00	50.00	41.80	9.34	30.00	80.00
Fertilizer (kg/acre)	163.32	33.65	65.00	224.00	145.85	37.08	120.00	304.00
Chemicals (lit/ac)	1.63	1.03	0.00	4.40	1.32	1.40	0.00	5.50
Labour (days/acre)	18.13	9.16	7.60	55.84	33.59	14.00	12.68	79.36
Machinery (Rs/acre)	9579.71	2528.42	2600.00	16100.00	8969.28	1975.49	4166.67	14800.00
Prices								
Rice (Rs/kg)	31.83	6.08	20.00	55.00	32.17	1.97	25.00	35.00
Seed (Rs/kg)	27.80	7.51	18.00	42.50	29.36	7.08	17.50	54.00
Fertilizer (Rs/kg)	7.00	0.00	7.00	7.00	7.00	0.00	7.00	7.00
Chemicals (Rs/kg)	1248.11	412.53	0.00	2250.00	1182.16	514.01	0.00	2000.00
Labour (Rs/day)	519.72	50.25	443.49	635.26	553.98	43.50	448.04	600.00
Other								
Family labour (% of labour))	48.74	18.63	5.97	92.98	57.44	21.88	9.62	95.35
Female labour (% of labour)	20.37	19.21	0.00	56.52	7.38	11.02	0.00	41.67
Machinery (% of total cost)	41.96	10.14	8.04	59.50	30.50	9.54	17.57	54.44
Labour (% of total cost)	39.25	12.94	16.67	83.46	57.65	12.27	26.12	74.72
Farm size (acres)	2.13	1.46	0.25	6.50	1.22	0.83	0.25	3.00
Ownership (Binary)	0.60	0.49	0.00	1.00	0.60	0.50	0.00	1.00

Table 3: Technical, Allocative, Cost and Scale Efficiency Estimates

	TEcrs	TEvrs	TEnirs	CEvrs	AEvrs	SE
Mean	0.75	0.87	0.76	0.73	0.84	0.87
SD	0.16	0.13	0.17	0.15	0.12	0.15
Min	0.32	0.51	0.32	0.33	0.52	0.36
Max	1.00	1.00	1.00	1.00	1.00	1.00
IRS (%)						68.89
DRS (%)						21.11
CRS (%)						10.00
Irrigation						
Major	0.83	0.91	0.85	0.79	0.87	0.91
Minor	0.69	0.85	0.70	0.76	0.90	0.82
Rain-fed	0.66	0.82	0.66	0.62	0.76	0.81

Table 4: Bias corrected Technical Efficiency Scores

	TEvrs	TEvrs Bias corrected	Bias	Variance	UB	LB
Mean	0.8653	0.8031	0.0621	0.0023	0.8607	0.7391
SD	0.1270	0.1091	0.0277	0.0022	0.1263	0.0967
Min	0.5134	0.4814	0.0289	0.0004	0.5108	0.4514
Max	1.0000	0.9517	0.1285	0.0083	0.9980	0.9132
Percentile						
1th	0.5134	0.4814	0.0289	0.0004	0.5108	0.4514
5th	0.6112	0.5790	0.0342	0.0006	0.6083	0.5428
25th	0.7753	0.7287	0.0422	0.0009	0.7714	0.6945
50th	0.8859	0.8318	0.0531	0.0014	0.8810	0.7447
75th	1.0000	0.8913	0.0777	0.0030	0.9941	0.8031
95th	1.0000	0.9353	0.1272	0.0081	0.9951	0.8661
Irrigation						
Major	0.9065	0.8359	0.0706	0.0030	0.9017	0.7612
Minor	0.8493	0.7902	0.0591	0.0020	0.8446	0.7361
Rain-fed	0.8240	0.7686	0.0554	0.0018	0.8197	0.7096

Note: Results of the bootstrap efficiency estimates with 5000 replicates

Table 5: Input use ratios

	Level of input use				
	Seed	Fertilizer	Chemicals	Labour	Machinery
Mean	1.22	1.08	1.36	1.63	1.30
SD	0.33	0.22	1.08	0.80	0.41
Min	0.82	0.60	0.00	0.70	0.41
Max	2.38	1.75	5.44	5.44	2.60
Over using farms (%)	68.89	56.67	52.22	76.67	73.33
Major	1.19	0.99	1.64	1.31	1.29
Minor	1.18	1.19	1.19	1.50	1.33
Rain-fed	1.28	1.15	1.01	2.17	1.30

Note: Ratio between cost efficient and technically efficient input levels $(x^* / \theta x)$

Table 6: Relationship between excess input use and efficiency measures

	Technical Efficiency (VRS)	Allocative Efficiency (VRS)	Cost Efficiency VRS
Intercept	94.4130*	90.1934*	84.8071*
	(1.3859)	(1.3393)	(1.4564)
Seed	0.0045*	0.0021	0.0056*
	(0.0020)	(0.0019)	(0.0021)
Fertilizer	-0.0152*	0.0048	-0.0084*
	(0.0030)	(0.0029)	(0.0032)
Chemicals	0.0003	0.0005	0.0007
	(0.0007)	(0.0007)	(0.0007)
Labour	-0.0005*	-0.0011*	-0.0014*
	(0.0001)	(0.0001)	(0.0001)
Machinery	-0.0010*	-0.0004*	-0.0012*
	(0.0002)	(0.0002)	(0.0002)

Note: * indicates significance at the 5% level (P<0.05)

Table 7: Impact of Farm Size and Resource Ownership and Use on Production Efficiency

Variables	Technical Efficiency (VRS)	Allocative Efficiency (VRS)	Cost Efficiency VRS
Intercept	1.0530*	0.5795*	0.6391*
	(0.0578)	(0.0620)	(0.0775)
Farm size	0.0207	-0.0164	0.0041
	(0.0107)	(0.0115)	(0.0143)
Irrigation			
Minor	-0.0604*	0.0662*	0.0056
	(0.0302)	(0.0324)	(0.0405)
Rain-fed	-0.0998*	-0.0721*	-0.1463*
	(0.0267)	(0.0286)	(0.0358)
Date of sowing			
Intermediate	-0.0008	-0.0201	-0.0234
	(0.0228)	(0.0244)	(0.0305)
Late	-0.0147	-0.0549	-0.0593
	(0.0364)	(0.0390)	(0.0488)
Seed source			
Private	0.0695*	0.0454	0.1080*
	(0.0287)	(0.0308)	(0.0385)
Other farmers	0.0076	0.0273	0.0417
	(0.0313)	(0.0336)	(0.0420)
Self	-0.0735*	0.0180	-0.0381
	(0.0253)	(0.0271)	(0.0339)
Tenancy	-0.0437*	0.0351	0.0010
	(0.0200)	(0.0215)	(0.0269)
Machinery usage	-0.0056*	0.0058*	0.0005
(% total cost)	(0.0011)	(0.0012)	(0.0015)
Family labour	0.0008	0.0012*	0.0018*
(% total labour)	(0.0005)	(0.0006)	(0.0007)
Female labour	0.0022*	-0.0008	0.0012
(% total labour)	(0.0008)	(0.0009)	(0.0011)
Log likelihood	93.5859	87.2438	67.1410
Pseudo R^2	0.5977	0.4546	0.6466

Note: * indicates significance at the 5% level (P<0.05)

Table 8: Average Marginal Effects of TE, AE and CE

	Cost Efficiency (VRS)	Technical Efficiency (VRS)
Intercept	-0.7665* (0.0163)	0.9179* (0.0134)
Technical Efficiency (VRS)	0.8346* (0.0131)	
Allocative Efficiency (VRS)	0.9178* (0.0133)	-1.0769* (0.0229)
Cost Efficiency (VRS)		1.1727* (0.0185)

Note: * indicates significance at the 5% level (P<0.05)

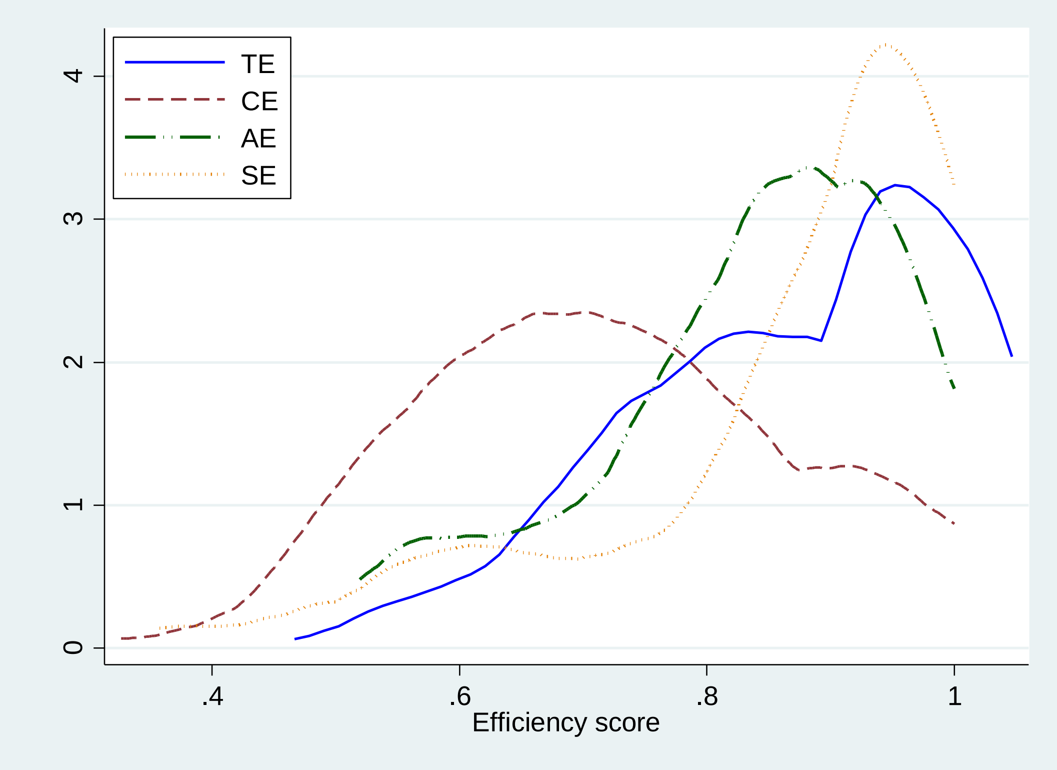

Figure 1: Kernel Distribution of Efficiency Scores