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Application of Cobb-Douglas Function for Analyzing the Process of Agricultural Production: A Case Study from Sri Lanka

Lal Mervin Dharmasiri, Sri Lanka and V.S. Datye, Pune, India

Abstract

Agricultural productivity may be defined as the ratio of index of local agricultural output to the index of total input used in farm production. Productivity of agriculture has been examined from different perspectives, such as productivity of land, labour and capital. Different types of economic models that have been used for measuring agricultural productivity. such as : growth accounting technique; econometric estimation of production relationships and nonparametric models. Each model can be used to measure aggregate agricultural output. Each model has different data requirements and is suitable for addressing different questions and has strengths and weaknesses. The econometric model e.g. Cobb-Douglas function has the advantage of permitting hypothesis testing and calculation of confidence intervals to test the reliability of the estimations. In order to analyse agricultural production processes in Sri Lanka the Cobb-Douglas production function (Cobb and Douglas, 1928) *has been used* in this analysis. This model clearly measures the marginal contribution of each input to aggregate agricultural output. *It* is widely used to represent the relationship of an output to inputs i.e. input-output relationship.

Introduction

Most of the developing countries are confronted with the stupendous task of securing a continuous food supply to their people as a result of the rapid growth of it's population. They have been adopting new technologies to increase agricultural productivity for a few decades. They have succeeded in it at certain levels so far but some regions do not reach the optimum level of productivity. In the context of Sri Lanka, some regions perform better while other regions show poor or marginal prospects. These typologies are common in most of the developing countries in the world.

Agricultural productivity may be defined as the ratio of index of local agricultural output to the index of total input used in farm production (Shafi, 1984). Productivity of agriculture has been examined from different perspectives, such as productivity of land, labor and capital. Land is a permanent and fixed factor among other production factors such as labor and capital. Productivity of land is explained by production of crops in terms of output or yield per unit of land. Some of the developing countries have been attempting to increase the land productivity by using methods which some developed countries have adopted. The productivity of labour is a somewhat more competitive concept than land productivity (Shafi, 1984). It may be simply expressed by the hours of work needed to produce, e.g. a metric ton of paddy or cereals. But except where mainly monocultural agriculture is practiced such measurements have a limited meaning and more commonly labour productivity is measured by the total agricultural output per unit of labor.

Labour-input vs. agricultural output is an important parameter of determining productivity of labor. Total labor force, number of man hours scarified for farming and market value of labor are very important factors of labor productivity while considering monetary value added per man hour or man day. However, agricultural labor productivity may be enhanced through training, demonstrating and increase of wages etc,. Capital may be utilized in the agricultural production process. It is generally utilized for the purchase of land, for land reclamation, drainage, irrigation process, livestock purchase, feeds, seeds, fertilizers, chemicals, agricultural implements and machinery (tangible goods) etc. Capital may be an important component for determining productivity of land, which further refers to enhancing efficiency of land. Efficiency refers to the properties and qualities of various inputs, the manner in which they are combined and utilized in production.

Measuring Agricultural productivity

Kendall (1939), Stamp (1958), Sapre and Deshpande (1964), Enyedi (1964), Khusro (1964), Bhatia (1967), Shafi (1984), Singh Jasbir (1972), Hussain (1976) and Vanloon, Patil and Hugar (2005) have been attempting to measure agricultural productivity by using different parameters. Apart from these methodologies, three different types of economic models that have been used for measuring agricultural productivity: (1) growth accounting technique (2) econometric estimation of production relationships and (3) nonparametric models. Each model can be used to measure aggregate agricultural output. Each model has different data requirements and is suitable for addressing different questions and has strengths and weaknesses.

Growth accounting technique involves compiling detailed accounts of inputs and outputs, aggregating them into input and output indices to calculate a Total Factor Productivity (TFP) index. Goksel and Ozden (2007) have applied the TFP with Cobb-Douglas production function in agriculture to analyze the agricultural productivity in Turkey.

Nonparametric models use linear programming techniques to calculate TFP. An advantage of the nonparametric approach is that it does not impose restrictive assumptions on production technology. The major disadvantage is that since the models are not statistical, they cannot be statistically tested or validated.

The econometric estimation of production relationships, which will be applied in this analysis is based on either the "production function" or the "cost function". An advantage of this model is it permits quantifying the marginal contribution of each input to aggregate production. For example, one can determine the impact of one-percent increase in fertilizer use on overall agricultural production, holding all other inputs constant. Many researchers use the Cobb-Douglas production function, despite some of its limitations. Jorgenson *et al.* (1987) used a cost function approach for each major sector of the US economy to estimate rates of sectoral productivity growth and concluded that productivity growth has been more rapid in agriculture than in other sectors. Lewis *et al.* (1988) used a production function approach to calculate productivity growth rates for agriculture and for the reminder of the Australian economy (industry plus service) and concluded that the rate of productivity growth in agriculture had been higher than for the reminder of the economy.

The Cobb-Douglas production function (Cobb and Douglas, 1928) which will be utilized in this analysis is widely used to represent the relationship of an output to inputs i.e. input-output relationship.

All these three models have strengths and weaknesses. The use of growth accounting technique imposes several strong assumptions about technology. A disadvantage is that the statistical methods cannot be used to evaluate their reliability.

The econometric model e.g. Cobb-Douglas function has the advantage of permitting hypothesis testing and calculation of confidence intervals to test the reliability of the estimations. This model clearly measures the marginal contribution of each input to aggregate agricultural output. If the functional form is more flexible, a further advantage is that fewer restrictive assumptions about technology are imposed. A disadvantage of the econometric model is that it requires more data than the other models.

Methodology

The decision-making process of any production can be supported by the analysis of three distinct relationships.

1. Factor-Product relationship or Input-Output relationship:

   The producer identifies best input-output relationship which minimizes input effort.

2. Resources-Resources relationship or Factor-Factor relationship:

   The producer identifies best factor-factor relationship which minimizes input effort.

3. Product-Product relationship:

   The producer identifies best product – product relationship which maximizes the output.

Although the Cobb-Douglas Production Function has frequently been used in the analysis of agricultural production process, it was initially used for manufacturing industry in USA by H. Douglas and C.W. Cobb (Semasinghe 1998, 28). For production, the function is

$$\boldsymbol{Y = AL^{\alpha} K^{\beta}},$$

where:

- Y = total production (the monetary value of all goods produced in a year)
- L = labor input
- K = capital input
- A = total factor productivity

α and β are the labor and capital's share of output respectively. These values are constants and determined by the available technology.

Further, if: $\alpha + \beta = 1$, returns to scale are constant

if $\alpha + \beta < 1$, returns to scale are decreasing

if $\alpha + \beta > 1$, returns to scale are increasing

The return to scale refers to "a technical property of production that examines changes in output subsequent to a proportional change in all inputs". The Cobb-Douglas function can also be transformed as a log linear function as given below:

$$\log Y = A + \alpha \log L + \beta \log K$$

The manifestation of the production function in any production will be determined by the nature of factors (inputs) utilized and the extent of input combination. The production function, therefore, may be expressed from two approaches.

1. Short-run Production Function in which only one or two factors are kept constant while other factors are changed in the production process.
2. Long-run Production Function in which all factors are changed and substituted in the production process.

In this analysis, the production function will be considered as Long-run Production Function as the data permit such an analysis. Based on the Cobb-Douglas production Function, the following function will be employed in this analysis.

$$\log Y = A + \alpha \log L + \beta \log C$$

where,

1. $logY$ = log value of total production (the monetary value of defined agricultural production produced in a season)
2. $logL$ = log value of the total land harvested
3. $logC$ = log value of aggregate cost of inputs (fertilizer, seeds, chemicals, labour, transport, tax etc)
4. A = efficiency parameter
5. α and β are the coefficients associated with lead harvested and share of input cost in the output.*

Many studies focused on explaining cross-country differences in agricultural productivity, used econometric analyses relying on a Cobb-Douglas production function. Attention would be paid to analyze agricultural productivity by using the Cobb-Dougla's production function coefficient and the return to scale (Dharmasiri, 2009; 87).

While the significance of specific inputs varies across studies using the production function approach, these studies have found in general that increased use of conventional inputs, are the most important factors in explaining growth in agricultural productivity.

Assumptions

1. We have assumed that in any district, the minimum total value is equal to 1. This has been done as a pre requisite to avoid minus values in the calculation.
2. It is also assumed that the minimum values do not enforce any impact on the results.
3. The market values represent the total cost caused to the farmers, for the input variables namely labour, fertilizers, seeds, land rent and transport etc.

In this analysis, our attention is mainly focused upon the identification of the spatial and temporal patterns of agricultural productivity. For this requirement, two measurements have been employed by using same set of data. The two measurements are (1) total Standard Coefficient of the Return to Scale (SCRS) and (2) Cobb-Douglas Coefficient (CDCO).

* The production elasticities of price (PEP), elasticity of houshold extend (PEH), SCRS and CDCD.

1. Productivity Regions in Sir Lanka

Application of the Cobb-Douglas production function for measuring agricultural productivity is more useful in reviewing the spatial differentiation in agricultural activities in Sri Lanka* were compiled with the total production (in kg's), total land harvested (hectares), input cost and farm gate prices (Rs./Kg) of ten selected crops of paddy, *kurakkan* (type of millet), maize, manioc, green gram, sweet potatoes, potatoes, green chilies and onions in *yala* in 2008 and *maha* seasons in 2008/2009. Since the tables are much longer, they are not attached herewith.

In *yala* 2008, the return to scale of the marginal productivity has shown a remarkable picture in productivity pattern of the country. The means of the Production Elasticity of Prices (PEP) and the Production Elasticity of Harvested extent (PEH) in *yala* season were 0.326 and 0.726 respectively demonstrating the lower deviation within the data. It is further elaborated with the standard deviations i.e. 0.655 and 0.287 respectively in the season mentioned. The sum of the PEP and PEH which counted as a Standard Coefficient of the Return to Scale (SCRS) is further strengthening the phenomena. The total mean and deviation of SCRS were 1.05 and 0.54 receptivity in *yala* season. Ranking method based on the normal distribution explains the spatial distribution pattern of agricultural

Table 3: Agricultural productivity categories based on Standardized Coefficients of Return to Scale (SCRS) Yala Season – 2008

Ranking Coefficient	Productivity grade	Number of districts	Percentage of total number of districts in the country
2.55 over	Very High	1	3.85
2.54 – 2.09	High	2	7.69
2.08 – 1.24	Medium	21	80.77
1.23 – 0.94	Low	-	-
0.93 less	Very low	2	7.69

Source: Compiled by Author

Table 4: Agricultural productivity categories based on Cobb-Douglas Coefficient (CDCO) yala Season – 2008

Ranking Coefficient	Productivity grade	Number of districts	Percentage of total number of districts in the country
3.70 over	Very High	3	11.54
3.69 – 3.01	High	4	15.38
3.00 – 0.15	Medium	17	65.38
0.14 – 0.98	Low	1	3.85
0.97 less	Very low	1	3.85

Source: Compiled by Author

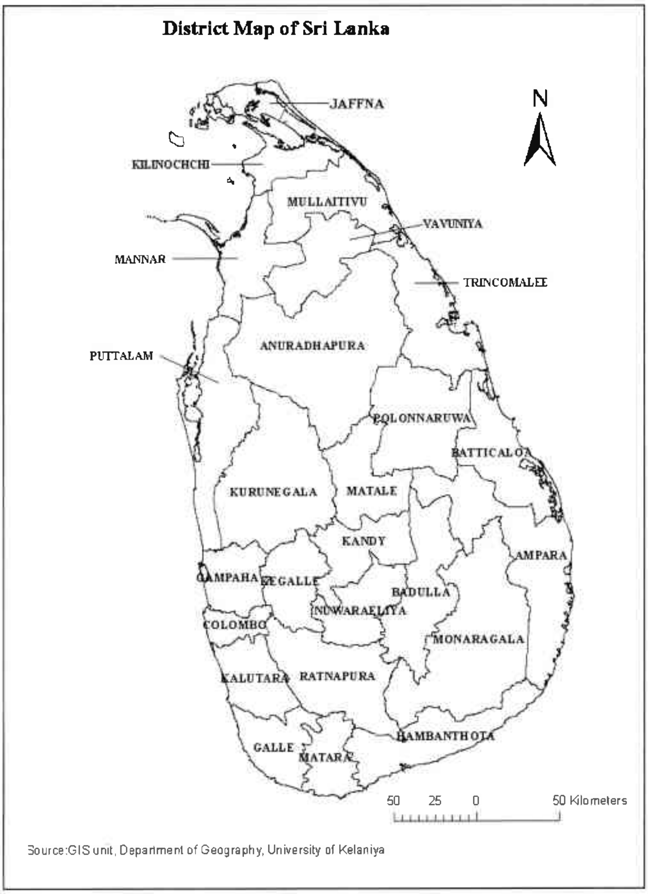

Fig. 1 Administrative map of Sri Lanka

productivity. At district level, wide range within the individual components can be identified when compared with the PEF than PEH.

Productivity ranks were categorized under the normal distribution as Very High level of Productivity (VH), High level of Productivity (H), Medium Level of Productivity (M), Low Level of Productivity (L) and Very Low Level of Productivity (VL).

There were eight districts with coefficients significant at 0.05. It means the increase of the harvested area would result the increase of crop yield. It is an important fact that all very high productive districts indicate significance at 0.05 level. According to Table 3, only one district namely, Badulla has recorded very high level of productivity during yala season by both the methods because of the high market price, average yield and number of crops cultivated during the season. In addition, two more Dry zone districts i.e. Kilinocchi and Vauniya have reported higher level of agricultural productivity during *yala* due to favorable climatic conditions for other field crops.

Table 1: Standardized Coefficients of Return to Scale (SCRS) and Coefficient of Cobb-Douglas Production Function (CDCO) in *Yala*, 2008

Districts	Production elasticity of price (PEP)	Production elasticity of harvested extent (PEH)	Standardized Coefficients of Return to Scale (SCRS)[1]	Rank of the SCRS	Coefficient of Cobb-Douglas Production Function (CDCO)[2]	Rank of the CDCO	Difference of SCRS & CDCO
Ampara	1.06*	0.405	1.465	M	2.437	M	0
Anuradhapura	1.014*	0.532	1.546	M	2.896	M	0
Badulla	3.602*	0.17	3.772	VH	5.875	VH	0
Batticaloa	1.173*	0.578	1.751	M	1.376	M	0
Colombo	1.097*	0.95	2.047	M	0.104	L	-
Galle	1.191**	0.754	1.945	M	0.067	VL	-
Gampaha	0.872	0.936	1.808	M	0.137	H	+
Hambanthota	0.956*	0.555	1.511	M	3.102	H	+
Jaffna	1.545*	0.419**	1.964	M	1.507	M	0
Kalutara	1.018*	0.827	1.845	M	0.218	M	0
Kandy	0.24	0.177	0.417	VL	1.117	M	+
Kegalle	1.32*	0.477	1.797	M	2.026	M	0
Kilinochchi	1.894*	0.531**	2.425	H	1.714	M	-
Kurunegala	0.768*	0.583	1.351	M	1.767	M	0
Mannar	1.271*	0.415**	1.686	M	3.438	H	+
Matale	0.889*	0.609	1.498	M	2.167	M	0
Matara	1.589*	0.459	2.048	M	1.326	M	0
Monaragala	0.707*	0.685	1.392	M	1.761	M	0
Mullaitivu	0.988*	0.449**	1.437	M	3.038	H	+
Nuwaraeliya	0.591*	0.882**	1.473	M	1.963	M	0
Polonnaruwa	1.152*	0.519	1.671	M	3.922	VH	+
Puttalam	0.642*	0.706	1.348	M	1.52	M	0
Ratnapura	1.08	0.24*	1.32	M	2.573	M	+
Trincomalee	0.163	0.21	0.373	VL	2.431	M	+
Vavniya	1.422*	0.811**	2.233	H	0.649	M	-
'H' Area	0.842*	0.42	1.262	M	3.854	VH	+

*Indicates significance at the 0.05 level
** Indicates significance at the 0.01 level
[1] Sum of the PEF & PEH (SCRS)
[2] Efficiency parameters
Source: Data from the Census and Statistics and unpublished data from the HARTI

Table 2: Standardized Coefficients of Return to Scale (SCRS) and Coefficient of Cobb-Douglas Production Function (CDCO) in *Maha*, 2008/ 2009

Districts	Production elasticity of price (PEP)	Production elasticity of harvested extent (PEH)	Standardized Coefficients of Return to Scale (SCRS)[1]	Rank of the SCRS	Coefficient of Cobb-Douglas Production Function (CDCO)[2]	Rank of CDCO	Diffe-rance of SCRS & CDCO
Ampara	1.072*	0.324	1.396	M	1.79	M	0
Anuradhapura	0.995*	0.374	1.369	M	1.637	M	0
Badulla	1.26	1.21*	2.47	H	1.56	M	+
Batticaloa	1.138*	0.488	1.626	M	0.934	L	+
Colombo	0.014	0.72	0.734	L	0.09	VL	+
Galle	0.263	0.638	0.901	L	0.105	VL	+
Gampaha	0.664*	0.822	1.486	M	4.52	M	0
Hambanthota	0.795*	0.421	1.216	M	3.17	M	0
Jaffna	0.562	0.2	0.762	L	8.629	VH	+
Kalutara	0.067	0.721	0.788	L	0.179	L	0
Kandy	0.282	0.925*	1.207	M	6.9	H	-
Kegalle	0.359	0.548	0.907	L	0.714	L	0
Kilinochchi	0.379	2.82*	3.199	VH	8.882	VH	0
Kurunegala	0.995*	0.454	1.449	M	1.542	M	0
Mannar	0.356	3.26*	3.616	VH	7.082	VH	0
Matale	0.952*	0.611	1.563	M	0.988	L	+
Matara	0.503	0.506	1.009	L	0.763	L	0
Monaragala	0.546	0.634	1.18	M	1.303	M	0
Mullaitivu	0.807*	0.49	1.297	M	2.162	M	0
Nuwaraeliya	1.58	1.89	3.47*	VH	7.704	VH	0
Polonnaruwa	1.251*	1.458	2.709*	H	6.94	VH	-
Puttalam	0.307	2.49	2.797*	H	7.44	VH	-
Ratnapura	0.511*	0.765	1.276	M	0.793	L	+
Trincomalee	1.241*	0.473	1.714	M	0.869	L	+
Vavniya	1.21	2.41	3.62*	VH	7.41	VH	0
'H' Area	1.179*	0.401	1.58	M	2.001	M	0

*Indicates significance at the 0.05 level
[1] Sum of the PEF & PEH (SCRS)
[2] Efficiency parameters
Source: Data from the Census and Statistics and unpublished data from the HARTI

A significant fact was that 21 districts of the total 2b districts have reported medium level of productivity. Majority of these districts are located in the Dry and Intermediate zones of the country. Figure 1 illustrates the spatial distribution pattern of agricultural productivity by using the SCRC.

Table 4 shows that 3 districts have very high level of agricultural productivity during the *yala* season 2008. Number of very high level of productivity districts is higher when compared with the CDCO and the SCRC in the season. Badulla, Polonnaruwa and Mahaweli 'H' area show a very high level of productivity. Since the *yala* is normally the dry season, these three districts have been able to get better results mainly through the irrigation. There were four high productivity districts namely, Gampaha, Hambantota, Mannar and Mullaitivu in this season. Due to their proximity to the central market place in Colombo the farmers get high market price for their products. The Dry zone districts which record higher level of productivity have also a good potential for cultivating other field crops during the *yala*.

There are seventeen districts, mostly located in the Dry and Intermediate zones which report medium level of productivity in *yala*. Even though, Nuwaraeliya district is located in the upcountry which has favorable environment for vegetable cultivation, it has recorded medium level of productivity during the season.

possible to find much dissimilarity when SCRC and the CDCO are compared. There are 13 districts having similarities between the SCRC and CDCO while 10 districts have positive and another 3 districts have negative figures. The computational error may perhaps be due to unreliability or unavailability of data. However, we can conclude that there are some similarities between the two variables which have proven the linear relationship between the SCRC and the CDCO during the *yala* season in 2008.

The marginal returns of the agriculture have been showing an impressive pattern of agricultural productivity in the country. When the market price or harvested extent of crops increases the production also increases to a certain extent indicating the positive relationship between the variables. The mean values of the PEP and the PEH signify remarkable differences from 0.74 to 1.00. As such, the range of these figures indicates the differentiation of the two components. The highest PEP was recorded in Nuwaraeliya district, while the lowest in Colombo and Kalutara districts. As against the PEP for the average yield, the PEH is also showing a different pattern. Mannar, Puttaluam and Vauniya districts have been reporting the extreme high values of the PEH, indicating the sensitive relationship between yield and harvested extent. However, Jaffna district has the minimum value PEH, which may be due to the population pressure, civil unrest or some other reasons.

Standard deviation of the PEP and the PEH vary from 0.43 to 0.85 respectively. When the total figures of both components are considerered the mean value 1.74 shows a big difference from the above mentioned values because of the different market behavior and agricultural performance throughout the country.

Table 5 shows that four districts have reported very high level of productivity. Three of them, i.e. Killinocchi, Mannar and Vauniya are located in the Dry zone and the other, i.e. Nuwaraeliya is in hill country. As mentioned earlier, Nuwaraeliya is famous for other field crops, mainly vegetables. Fifty per cent of the districts have reported medium level of SCRS during the *maha* season. They were mostly located in the

Dry and intermediate zones and have a potential for better agricultural production. The districts may be categorized as moderate productivity zone of the country.

Five of them are located in the densely populated areas of the Western and Southwestern coastal zone of the country. Another important fact is that there were no districts representing very low level of productivity.

Computed coefficient values for the *maha* season (2008/2009) are shown in Table 2. The mean and the standard deviation of the coefficient values are 3.32 and 3.12 respectively which indicate the lower range and concentration around the mean value. The most important fact is that seven districts have reported very high level of productivity in agriculture. Six of them are located in the Dry zone. These districts are Jaffna, Vauniya, Killinocchi, Mannar, Pollonnaruwa, Puttalam and Nuwaraeliya. All districts have favorable geographical and non-geographical conditions for agriculture. In particular, more than eighty percent of the people of the district belong to the rural sector and are mostly engaged in agriculture or agriculture related activities. The market price and the total production of the commodities were also higher than traditional paddy resulting in very high level of productivity in *maha* season.

Kandy is the only district which has reported higher level of productivity in *maha* season. But there are nine more districts which have reported medium level of productivity. Most of these districts are located in Dry or Intermediate zone of the country. Monaragala, Mullative, Anuradhapura, Ampara, Badulla and Mahaweli 'H' area as well as Hambantota district have also reported medium level of productivity indicating that these areas are having a very good potential for agriculture in particular 'other field crops'.

According to Table 6 there were seven districts which have shown low level of agricultural productivity. They are Kegalle, Kalutara, Matale, Ratnapura, Trincomalee and Batticaloa districts. In general, most of these districts do not have good potential for food crop except for perennial crop cultivation. It was difficult to explain why Batticaloa district has low level of productivity in the *maha* season. Perhaps, the reasons may be the low market prices for the food crops and the lesser cultivated area. Two more districts, i.e. Galle and Colombo have reported very low level of productivity in *maha* season. It is true that these districts

Table 5: Agricultural productivity categories based on Standardized Coefficients of Return to Scale (SCRS) *Maha* Season – 2008/ 2009

Ranking Coefficient	Productivity grade	Number of districts	Percentage of total number of districts in the country
Over 6.91	Very High	4	15.38
5.42 – 6.90	High	3	11.55
1.23 – 5.41	Medium	13	50.00
0.25 – 1.22	Low	6	23.07
below 0.24	Very low	-	-

Source: Compiled by Author

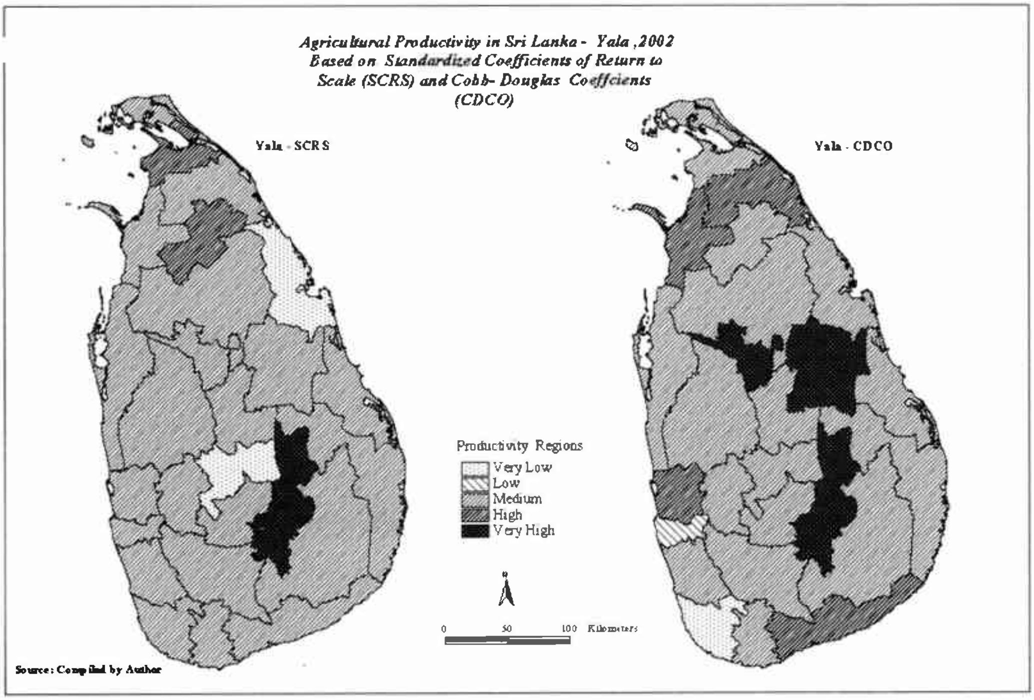

Fig. 2 and 3: Illustrates that six districts have reported lower level of productivity in terms of the SCRS: Colombo, Galle, Kalutara, Kegalle, Matara and Jaffna

Table 6: gricultural productivity categories based on Cobb-Dougles Coefficient (CDCO) Maha Season – 2008/ 2009

Ranking Coefficient	Productivity grade	Number of districts	Percentage of total number of districts in the country
Over 2.79	Very High	7	26.92
2.35 – 2.78	High	1	3.84
1.12 – 2.34	Medium	9	34.61
0.68 – 1.11	Low	7	26.92
below 0.67	Very low	2	7.71

Source: Compiled by Author

are located in the commercial part of the country and most of the lands are allocated for commercial activities and residential uses. On the one hand, many cultivated lands are being fragmented and converted into commercial uses due to the high demand for land in the Western part of the country. On the other hand, people give low priority for agriculture due to the SCRS from agriculture than non-agricultural activities in the area. The present trends have been showing change in the economic activities of the people from primary to secondary or tertiary due to commercialization.

Computed values of the SCRS and CDCO indicate some dissimilarities (see

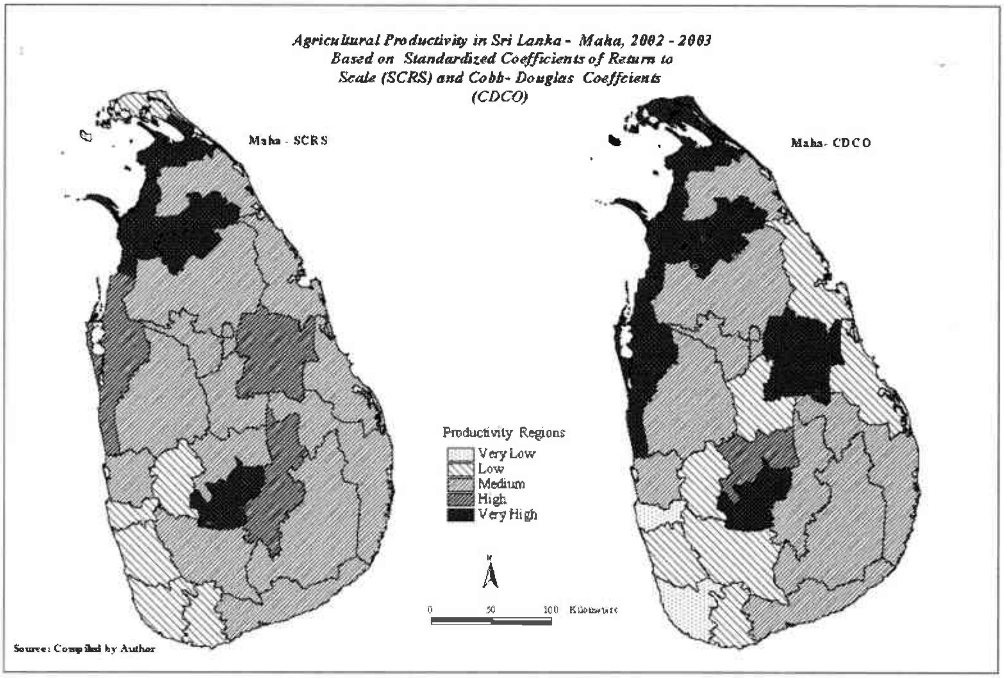

Fig. 4 and 5: tttt

the last column of the Table 2). However, fifteen districts have shown differences in neither SCRS nor CDCO. Eleven districts have differences between two components i.e. eight of them have positive while three have negative. Positive figures indicated in Badulla, Batticaloa, Galle, Jaffna, Matale, Ratnapura and Trincomalee districts are due to the differentiation in market prices and crop yield. Puttalam, Pollonnaruwa and Kandy districts have negative figures.

Conclusion

The agricultural productivity outcomes of the *yala* and *maha* obtain from SCRS and CDCO are explained. The analysis proves that the PEP gives positive relationships with the respective component. Unlike the PEP, the PEH does not show correlation with the respective component i.e. yield. It explains that the PEH is not good for analyzing the spatial productivity differentiation of an area. However, the SCRS and CDCO can be utilized for analyzing further the productivity variation.

Following findings can be drawn from the SCRS and CDCO analysis.

1. Difficult to find similarities between the two techniques i.e. SCRS and CDCO,
2. There is a positive relationship between the market price of crop production and its yield,
3. There is no significant relationship between the harvested area and the yield,
4. The CDCO analysis gives us a normal distribution pattern than SCRS analysis,

5. Absence or unreliable data give a wrong and unusual productivity pattern. Hence, it is suggested that the variables be selected carefully,

Finally, it is possible to suggest that the SCRS and CDCO analysis can be employed for measuring spatial productivity differentiation to a certain extent. Sometimes, it is necessary to start with some assumptions to avoid complications.

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Dr. Lal Mervin Dharmasiri
Senior Lecturer
Sri Lanka. *(sisilel@yahoo.com)*

Dr. VS Datye
Professor
Department of Geography,
University of Pune, Pune India.