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Total Factor Productivity, Efficiency, and Technical Change in Large Scale Tea Estates in Sri Lanka

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ABSTRACT

This paper applied a stochastic frontier model to measure total factor productivity growth, technical efficiency change, and technical change in tea production in the estate sector in Sri Lanka. Monthly data from 35 tea estates relating to the period 2005 to 2019 were used. Two functional forms with two distributional assumptions were tested. A Translog production frontier with the inefficiency term distributed as a truncated normal distribution was found to be the best fit for data. Results revealed that on average estate sector tea production operates 48% below the potential output indicating possibilities of increasing performance without any significant changes in inputs. Further, the overall rate of technical progress was estimated at 0.002 percent per year. The overall rate of technical efficiency change declined by 0.013 percent per year. The combined effect of slow technical progress, dominated by the fall in technical efficiency resulted in the decline in the total factor productivity in the corporate tea sector at a rate of 0.002 percent per year. This net effect of declining Total Factor Productivity raises concerns about the sustainability of the tea sector in Sri Lanka in the long run. Policies to shift up the production frontier and improvements in managerial practices to combat declining efficiency levels are recommended.

Keywords: *Stochastic frontier, Tea estate sector, Technical efficiency, Technical change, Total factor productivity change*

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Introduction

The tea industry in Sri Lanka plays a vital role in terms of its contribution to the national output, employment generation, and net foreign exchange earnings from its origin in 1867. Sri Lanka is the world's fourth-largest producer of tea and the third-highest valued tea exporter in the world. The tea produced in Sri Lanka, popularly known as "Ceylon Tea", ranks among the best available teas in international trade. Sri Lanka remains a key producer of superior quality tea in the global tea arena. Sri Lanka's tea industry has been the largest provider of employment, export earnings, and government revenue for more than a century (Jayasuriya, 1998). Ceylon tea export earnings account for 0.7 percent of Sri Lanka's Gross Domestic Product (GDP) (CBSL, 2020). As far as employment is concerned, the tea industry provides about 11% of direct and indirect employment opportunities for about 1.5 million labor force since tea production is highly labor-intensive (CBSL, 2018). Foreign exchange earnings from tea exports amount to US dollars 1,346 million, the second-largest contributor to the total export earnings of Sri Lanka, accounting for 11.3 percent of total export earnings in 2019 (CBSL, 2019).

However, the relative importance of Sri Lanka's tea industry has waned over the years. Accordingly, the relative contribution of the tea sector to GDP, foreign exchange earnings, and employment generation has been declining over the years. Moreover, the Sri Lankan tea industry has been steadily losing its share in the global market. Due to the aforementioned factors, Sri Lanka's tea industry is increasingly under threat on many fronts. Recent studies have found several problems that the Sri Lanka tea industry is currently facing such as the stagnant area under tea, low productivity, lower replanting rate, higher cost of production, and shortage of labor (Jayasuriya, 1998). According to the statistics of the Central Bank's Economic and Social Statistics of Sri Lanka (2010, 2020), tea production, area under tea cultivation, tea export quantity, and contribution of the tea sector to GDP in 2019 decreased by 5.4%, 9.9%, 5.2%, and 63.2% respectively compared to 2005. Moreover, the cost of producing tea in 2005 and 2019 were Rs. 168.41/kg and Rs. 483.79/kg respectively. It means that compared with the year 2005 cost of producing tea in 2019 has increased by 187%.

According to the statistics of the Central Bank Report (2019), about 24.5% of the total tea production in the country comes from the corporate sector. It is approximately 1/3 of the yield level compared with the smallholder sector. The tea cultivated extent in the corporate sector is shrinking. According to the statistics of the Ministry of Plantation Industry’s Plantation Sector Statistical Pocket Book (2012, 2018), the tea cultivated extent, the area replanted by the corporate tea sector, and the corporate tea sector's contribution to made tea production of the country in 2018 decreased by 18.6%, 35.4%, and 10.03% respectively compared to 2005. According to the Ministry of Plantation Industry’s Plantation Sector Statistical Pocket Book (2018), estate (RPC-manage estate) sector tea extent ownership has sharply declined from 2007 onwards due to various factors. This has declined at an average rate of 1,020 ha per annum throughout. Moreover, the replanting rate and new planting rate in the corporate tea sector are very low. In this background, it is important to understand the sustainability of this important sector. Moreover, it is apparent that the poor performance of the corporate tea sector aggravates the low production levels in the Sri Lankan tea industry. This implies that to increase production, raising productivity is of paramount importance. Further, productivity will become a key determinant of the future of Sri Lanka’s tea industry. Therefore, Sri Lanka needs to enhance the productivity of the tea industry to remain competitive in the global tea market, and tea producers have the main responsibility.

Productivity and efficiency analysis of the large-scale tea estates (RPC-manage estates) in Sri Lanka by giving special attention to Total Factor Productivity (TFP) growth is scarce in the literature. In this background, it is prudent to evaluate the trend of productivity and efficiency changes in the large-scale tea estates in Sri Lanka. Since productivity growth at the micro level has been considered a key factor to yield economic growth at the macro level in the long run, it is important to have a complete understanding of the productivity of the large-scale tea estates in order to draw more appropriate economic and industrial policies to revive the Sri Lankan tea industry in the long run. Further, due to the limitations that prevail in the partial factor productivity measures, in this study, we used TFP as a more accurate and comprehensive measurement. Therefore, this study will add value to the existing literature by estimating the TFP change, efficiency change, and technical change of the large-scale tea estates over the last 15 years (2005-2019), and also findings of the study will direct policymakers to identify the areas which require more attention when implementing policies to revive the corporate tea sector performance.

The rest of the paper is organized as follows. Section 2 describes the background of the study. Section 3 provides an overview of the method of analysis. Section 4 describes the empirical model specification, sample selection and study sites, variables used in the analysis, and hypothesis tests. Results are reported and discussed in Section 5 and conclusions and policy implications are drawn in Section 6.

Background

In recent years, most economists and policymakers have paid attention to productivity studies because they believed that no effective economic development can be achieved in the absence of productivity growth. Various persons engaged in different fields have different perspectives on productivity definitions. An economist views productivity as the ability of factors of production to produce optimal output or as a ratio of output to input resources used in the production process. The productivity of the industry gives an idea about the efficiency of resource use in converting input to output. Producers who use relatively fewer inputs compete with others and thus productivity is a good indicator of the progress of any producer in the market (Ganewatta and Edwards, 2000).

According to the economist's perspective, productivity can be categorized as partial factor productivity and TFP which is the essence of the economic notion of productivity. The partial factor productivity is a conventional measure of productivity such as labor and capital productivity and these measures offer insights into the contribution of input growth to output expansion. When considered in isolation, these partial factor productivity measures can provide a misleading indication of overall productivity. Simply partial factor productivity means real output to single input used in the production process while the TFP index is considered as the ratio of output to all inputs used in the production process (Coelli et al., 1998). Moreover, TFP is a neoclassical tool and defines as output growth which is unexplained by the growth of inputs used in the production process. TFP determines how efficiently and intensely the inputs are utilized in production and also captures the effect of improvements in technology, as well as investments in infrastructure and research and development (Temoso et al., 2018). Further, TFP is a composite measure of changes in technology as well as changes in the efficiency with which known technology is applied to production (Coelli et al., 1998). Technical efficiency measures the ability of the firm to obtain the maximum output from given inputs. The measure of technical efficiency takes a value between zero and one. Furthermore, it compares the output of the considered firm to the output of a fully efficient firm using the same input vector. Technical change involves advances in technology that may be represented by an upward shift in the production frontier. Further, estimates of the rate of growth of TFP may help to explain the growth of a given sector.

In literature, there are two major methods for productivity estimation such as parametric and non-parametric methods. The stochastic frontier analysis (SFA) used in this study is the most commonly used parametric technique in productivity and efficiency analysis. Further, SFA has some additional advantages such as the flexibility of conducting hypothesis tests on parameters to identify the best functional form and the degree of inefficiency and also estimation of stochastic frontier production function using panel data dealing statistical noise effectively.

Many researchers have used SFA to assess the TFP and technical efficiency of diverse agricultural crop productions. For example, Coeli et al., (2003) conducted a study to measure the TFP growth, technical efficiency change, and technological change in Bangladesh crop agriculture using a translog stochastic frontier production function. This study employed panel data on 16 regions, for the 31 years from 1961 to 1992. Alam et al., (2011) conducted research to estimate TFP, technological progress, and technical efficiency changes of Bangladesh rice farms covering the data from three different periods; the pre-reform (1987) and the post-reform (2000 and 2004), using translog stochastic frontier production function. Li et al., (2011) applied the Cobb Douglas form of the stochastic frontier production function approach to analyze the TFP growth and the decomposition in Chinese agriculture since the 1980s using crop-specific panel data which covers 21 crops including tea. Bayarsaihan et al., (1997) applied the translog form of the stochastic frontier production function using farm-level input-output data from 48 state farms over the 14 years from 1976 to 1989 to analyze the efficiency, technological change, and productivity changes in Mongolian grain farming. Wondemu (2016) applied a stochastic input distance function to decompose and test the significance of economic efficiency improvement in boosting the productivity of small-scale farmers in Ethiopia.

Further, a large number of tea-producing nations around the world have used empirical studies to assess the tea sector performance using SFA. For example, Baten et al., (2010) estimated the inefficiency of tea industries in Bangladesh and identify the factors causing the technical inefficiency of tea industries by using the Stochastic Frontier Production Function for the panel data from 1990 to 2004, incorporating the technical inefficiency effect model. Katungwe et al., (2017) conducted a study to determine the technical efficiency of smallholder tea production in South-Eastern Malawi and identify sources of technical inefficiency using 230 smallholder tea farmers. A Cobb-Douglas Stochastic frontier model and Tobit Regression model were used in this study. Maity (2017) conducted a study to compare the performance of the tea industry of Assam and West Bengal of India between the pre-reform regime (2001/02 to 2006/07) and the post-reform regime (2007/08 – 2012/13). This study employed the Cobb-Douglas form of the stochastic frontier approach and introduced heterogeneity of tea gardens. Hong and Yabe (2015) researched to assess whether the existing technologies were efficient or not for tea farmers in the Nothern mountainous region of Vietnam using a cross-section data set of 258 randomly selected farms. Nguyen-Van and To-The (2016), estimated the translog specification of the stochastic production frontier methodology to assess the impacts of agricultural policy on technical efficiency in tea production in Vietnam using a survey database of 244 farm households in 2012. Das and Das (2020) estimated the Cobb-Douglas form of the stochastic production frontier to investigate the extent of inefficiency and the factors behind technical inefficiency in small tea gardens of Assam using a sample of 210 small tea growers from five districts. Hazarika and Subramanian (1999) estimated the Cobb-Douglas form of the stochastic frontier production function to decide whether to improve efficiency or to develop new technology to raise tea productivity in Assam using primary data from 67 estates.

Besides that, SFA has recently been used in the Sri Lankan context too to measure the tea sector's technical efficiency. For example, Shyamalie *et al.*, (2020) conducted a study to determine the technical efficiencies of tea smallholders in Sri Lanka's low country by estimating stochastic frontier production functions for both functional forms such as Cobb- Douglas functional form and translog functional form. This study relied on primary data from 300 tea smallholders representing 68 tea inspector regions. Basnayake and Gunaratne (2002) conducted research to estimate the technical efficiency of tea smallholdings and determinants of inefficiency in the Mid Country Wet Zone of Sri Lanka using 60 smallholder tea farmers. Maximum likelihood estimates of the stochastic frontier model were estimated for green leaf yield using Cobb- Douglas and translog models. Jeewanthi and Shantha (2021) investigated the technical efficiency of smallholder tea farmers in Sri Lanka by employing a stochastic production frontier using a sample of 120 smallholder tea farmers. Jayakody and Dishanka (2019) used the Cobb-Douglas Stochastic production frontier model by incorporating the technical inefficiency effect model to estimate the level of technical efficiency in the tea smallholding sector using 200 smallholder farmers in Rathnapura District. Premaratne et al., (2018) conducted research to identify the determinants of the technical efficiency of smallholder tea farmers under the UTZ certification system in Sri Lanka by employing a stochastic production frontier using a sample survey of 75 smallholder tea farmers supported by the UTZ program. Madushan et al., (2020) carried out research to identify the technical efficiency levels of the high-grown tea estates in Sri Lanka using panel data set from 2005-2018 covering seven tea estates in the Nanuoya region in Dimbula planting District. To estimate efficiency, stochastic frontier production functions of Cobb Douglas and Translog forms were employed with two distributional assumptions on the firm-specific inefficiency term as exponential and half-normal. Kodagoda and Dharmadasa (2020) conducted a study to find out the technical efficiency of organic tea smallholders in the Uva region of Sri Lanka using 100 tea smallholders who were drawn from the population of organic tea smallholders in the Diyathalawa region. The Cobb-Douglas and Translog functional forms of the stochastic frontier production function with inefficiency effects were employed in this study to measure the technical efficiency and its determinants.

Methodology

Theoretical Framework

Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977) independently proposed the stochastic frontier production function model. This study used a stochastic frontier approach to estimate the TFP in the corporate tea sector in Sri Lanka. Because, the stochastic frontier approach was recommended for agricultural applications (Coelli 1995a, b; Ferrara and Vidoli 2017). Many earlier studies have used the same approach for TFP analysis (Abeysekara and Prasada, 2021; Alam et al., 2011; Arazmuradov et al., 2014; Coelli et al., 2003; Hayatullah, 2017; Kim, 2010; Kim and Han, 2001 and Shahabinejad et al., 2013). The stochastic frontier production function for panel data can be written as:

$$Y_{it} = \exp(x_{it}\beta + V_{it} - U_{it}) \qquad (1)$$

Where Y_{it} is green leaf production in time *t* (*t*=1, 2, …, 15) for estate *i* (*i*=1, 2, …, 35); β is the vector of parameters to be estimated; the V_{it} s are the error component and are assumed to follow a normal distribution, $N(0,\sigma_v^2)$ the U_{it} s are non-negative random variables, associated with technical inefficiency in production, which are assumed to arise from a normal distribution with mean, μ and variance, σ_u^2 which is truncated at zero. The error component U_{it} can be assumed to have a variety of distributions such as half normal, truncated normal, etc. The technical efficiency of production for the ith estate at the tth period can be predicted using equation (2) (Coelli et al., 1998; 2003):

$$TE_{it} = E[\exp(-U_{it})/V_{it} - U_{it})] \qquad (2)$$

Technical efficiency change (EC_{it}) is then calculated as:

$$EC_{it} = TE_{it}/TE_{is} \qquad (3)$$

Where ‘s’ and ‘t’ are two adjacent time periods and t = s+1.

An index of technical change (TC_{it}) between two adjacent periods ‘s’ and ‘t’ for the ith estate can be directly calculated from the estimated parameters of the stochastic production frontier. First, partial derivatives of the production function are evaluated with respect to time using data for the ith estate in periods, s and t. Then, the geometric mean of these two partial derivatives is used to calculate the technical change index between the adjacent periods s and t. When dealing with a translog function, this is equivalent to the exponential of the arithmetic mean of the log derivatives (Coelli et al., 1998). That is;

$$TC_{it} = \exp\left\{\frac{1}{2}\left[\frac{\partial \ln Y_{is}}{\partial s} + \frac{\partial \ln Y_{it}}{\partial t}\right]\right\} \qquad (4)$$

The indices of technical efficiency change and technical change obtained by using equations (3) and (4) respectively can be multiplied to obtain Total Factor Productivity Change (TFPC) (Coelli et al., 1998);

$$TFPC_{it} = EC_{it} * TC_{it} \tag{5}$$

Which is equivalent to the decomposition of the Malmquist index suggested by Fare *et al*., (1985) (Coelli et al., 1998; 2003).

Empirical Application

Sample Selection and Study Sites

This study used a multistage sampling method. The unit of analysis is a tea estate in the corporate tea sector. Tea is grown in Sri Lanka at three elevations viz high, medium, and low elevation. The population is all the large-scale tea estates covering the three elevations. Thus, the first stage in sampling was the elevation. Secondly, tea estates were selected from each elevation probability proportionately to the extent. The total sample size was restricted to 35 tea estates considering the margin of error, confidence interval, and sample heterogeneity fixed at 0.1, 95%, and 50-50 respectively while optimizing the cost and time functions. Production data on monthly basis for the last 15 years (2005-2019) were collected creating a panel dataset.

Description of Data and Variables

The data for the analysis were drawn from monthly financial reports kept at the estates. Data relating to inputs used in tea cultivation and the output were collected. Wherever, there is a lack of quantities, values in monetary terms were obtained. All such monetary values were converted to constant values by deflating with the Colombo Consumer Price Index. The description of the variables collected is given in Table 1.

Table 1. Description of Variables

Variable	Unit	Description
Estate green leaf amount /Production	kg	Includes all varieties of green tea leaves
Labor cost	Rs.	This includes all the costs incurred in each estate for the fieldwork, cultivation, and tea plucking based on the constant price of 2013
Mature tea extent	ha	Mature tea extent of each tea estate
Fertilizer cost	Rs.	Total value of fertilizers used in each estate based on the constant price of 2013
Chemical cost	Rs.	Total value of chemicals used in each estate up to plucking stage based on the constant price of 2013

Model Estimation and Hypothesis Tests

Following extant literature, variables representing a time trend and its square were introduced into the stochastic production frontier to facilitate the estimation of technical change and efficiency change. By interacting time trend (t) with the inputs, a non-neutral technical change (biased technical change) was allowed in the model. The time squared variable in this model allowed for non-monotonic technical change (Alam et al., 2011). Thus, the estimated, Cobb-Douglas and the Translog forms of the production frontiers are as below.

$$\ln Y_{it} = \beta_0 + \sum_{n=1}^{N} \beta_n \ln X_{nit} + \beta_t t + \frac{1}{2}\beta_{tt} t^2 + V_{it} - U_{it} \qquad (6)$$

Where, i=1, 2, …, I and t=1, 2, …, T, and

$$\ln Y_{it} = \beta_0 + \sum_{n=1}^{N} \beta_n \ln X_{nit} + \frac{1}{2} \sum_{n=1}^{N} \sum_{n=1}^{N} \beta_{nj} \ln X_{nit} \ln X_{nit} + \sum_{n=1}^{N} \beta_{tn} t \ln X_{nit} + \beta_t t + \frac{1}{2} \beta_{tt} t^2 + V_{it} - U_{it} \tag{7}$$

Where 'ln' denotes the natural logarithm, Y_{it} stands for production (green leaf amount) of the i^{th} estate in year t, the letter, N (N=4) stands for the number of inputs used, and $\ln X_i$ are the natural log of extent, fertilizer, chemical, and labor. The variable t denotes time. Zero values in variables become a major problem in the estimation of log-linear production functions as zero values cannot be converted to logarithms. To overcome this issue, dummy variables were used for the variables that have zero values such as fertilizer and chemicals following the procedure introduced by Battese (1997). Where $D_{2i}=1$ if $X_{ni}=0$ and $D_{2i}=0$ if $X_{ni}>0$ and $X_{ni}^{*}=\text{Max}(X_{ni}, D_{2i})$. β is a vector that collects unknown parameters to be estimated. In addition, ε_{it} is the composed error term where $\varepsilon_{it} = V_{it} - U_{it}$ with U_{it} >0. The random error V_{it} accounts for the stochastic effects beyond the estates' control, measurement errors as well as other statistical noise, and U_{it} captures production inefficiency due to factors that are under the control of an estate. There are number of distributional assumptions that could be made on the inefficiency term. In this study, two distributional assumptions of the inefficiency part of the error term were made and the results were cross-checked and tested.

a) The Half-Normal Distribution: the half-normal case imposes the following restrictions on the error term:
   $U_{it} = iidN^{+}(0, \sigma_u^2)$
   V_{it} and U_{it} are distributed independently of each other and the regressors.

b) Truncated-Normal Distribution: the truncated-normal case imposes the following restrictions on the error term:
   $U_{it} = iidN^{+}(\mu, \sigma_u^2)$

V_{it} and U_{it} are distributed independently of each other and the regressors and μ is nonzero mean for U_{it}.

Key facets of the parametric stochastic frontier approach are imposing assumptions on the error components of the model and specifying the functional form representing the production technology. A series of formal hypothesis tests were conducted to determine the distribution of the random variables associated with the existence of technical inefficiency and the residual error and the functional form that best fit the data, to ensure that the model specification correctly represents the data. The first two hypotheses were used to find the best fit distributional assumption of the inefficiency term for each functional form assumed. The third hypothesis was tested using the results (accepted hypothesis) of the first and second hypothesis tests to find the suitable functional form of the production frontier. The Fourth hypothesis test was conducted to check whether there was a technical inefficiency effect in the model and the fifth hypothesis was tested to check whether there was a technical change over time. Finally, sixth hypothesis test was performed to check whether this model exists constant return to scale. Therefore, the following hypotheses were tested.

Test 1: $H_0 : u_i = iidN^{+}(0,\sigma_u^2)$, The null hypothesis specifying that the half-normal distribution of the Translog production frontier better fits the model as opposed to the alternative case which assumes truncated normal distribution of the Translog frontier for the u_i.

Test 2: $H_0 : u_i = iidN^{+}(0,\sigma_u^2)$, The null hypothesis specifying that half-normal distribution of the Cobb-Douglas production frontier better fits the model as opposed to the Cobb-Douglas frontier with the truncated normal distribution of the u_i.

Test 3: $H_0 : \beta_{jk} = 0$, The null hypothesis that identifies a suitable functional form between the restrictive truncated normal Cobb-Douglas frontier and the less restrictive truncated normal Translog production function. It specifies that the coefficients on square and interaction terms of input variables are not statistically different from zero. The Cobb-Douglas production frontier is a special case of the Translog frontier in which the coefficients of the second-order terms are zero, i.e. $\beta_{jk} = 0, j \le k = 1,2,...6$

Test 4: $H_0 : \gamma = 0$, The null hypothesis is that the inefficiencies are not stochastic and that the technical inefficiency effects are not present in the model at every level, so the joint effect of these variables on technical inefficiency is statistically insignificant. If the null hypothesis is not rejected, the stochastic frontier model could be reduced to the OLS specification.

Test 5: There is no technical change over time $H_0 : \beta_t = \beta_{tn} = ...\beta_{ti} = 0$

Test 6: $H_0 : \sum_1^4 \beta_i = 1$, The null hypothesis specifies that there exist constant returns to scale in the production function. A Wald test was used to test whether the production function shows constant, increasing, or decreasing returns to scale.

A Generalized log-likelihood ratio (LR) test was used to test which specification better fits the data. The Generalized log-likelihood ratio test is given by:

$$LR = -2[\ln\{L(H_0)\}/\ln\{L(H_1)\}] = -2[\ln\{L(H_0)\} - \ln\{L(H_1)\}]$$

Where $L(H_0)$ and $L(H_1)$ are the values of the likelihood functions under the null (H_0) and alternative (H_1) hypothesis, respectively. The computed test statistics should be compared with critical values of the mixed chi-square distribution proposed by Kodde and Palm (1986).

Results and Discussion

Results of Model Selection Procedure

The results of the hypothesis tests using the LR test are presented in Table 2. As discussed in the methodology section, the first and second hypothesis tests were conducted to validate the distributional assumption of the inefficiency term (u_i) of the Translog and Cobb-Douglas frontiers, respectively. Under each functional form, two models were constructed corresponding to the distributional assumptions of half normal and truncated normal for the one-sided error term. The LR test was used to calculate the test statistic using the log-likelihood value of the stochastic frontier model assuming a half normal (H_0) and a truncated normal distribution (H_1) of the inefficiency term. The calculated LR statistic for the Translog functional form was 4832.07 at 1 degree of freedom which is greater than the $\chi^2_{0.95}$ critical value of 2.706 at 5% significance. Therefore, H_0 is rejected implying that the truncated normal model of the Translog frontier is preferred to half normal one. Further, the same test in the case of Cobb Douglas functional form returned an LR statistic in the order of 308.13 at 1 degree of freedom which is greater than the $\chi^2_{0.95}$ critical value of 2.706 at 5% significance. Therefore, H_0 is rejected implying that the truncated normal model of the Cobb-Douglas frontier is also preferred to the half-normal one.

A third test evaluated the best fit functional form from the two models under the first and second hypothesis tests (i.e., between Translog and Cobb Douglas models with truncated normal inefficiency terms). The calculated LR statistic was 568.69 at 14 degrees of freedom which is greater than the χ^2 critical value of 23.069 at 5% significance level. Therefore, the test rejected the Cobb-Douglas functional form. The test shows that square and interaction terms in the Translog model are significantly different from zero, thus the Translog model could not be reduced to the Cobb-Douglas specification. To test whether inefficiency effects are important in the model or whether an average Ordinary Least Squares (OLS) model is adequate to represent the data, both OLS average model and a maximum likelihood estimate of the best fit translog model with the truncated normal assumption of the inefficiency term was estimated. The computed LR statistic is 2106.34 at 1 degree of freedom which is greater than the χ^2 critical value of 2.706 at 5% significance level. Therefore, the null hypothesis that technical inefficiency effects are not present in the data was rejected at 5% significance level. Thus, the traditional average OLS production function is not a proper representation of the sample data. The calculated χ^2 value is 15.47 at 6 degrees of freedom in the fifth test is greater than the $\chi^2_{0.95}$ critical value of 11.911 at 5% significance show that there is technical change exists in the tea estate sector and there is a significant effect of time on production in tea estates. The computed Wald test statistic was 15.00 with a p-value of less than 0.0001 in the sixth test. Thus, the null hypothesis of constant returns to scale was rejected in the specified production function and has variable returns.

Table 2. Results of the Model Selection Procedure

Null Hypothesis	Test Statistic	Critical $\chi^2_{0.95}$	p-value	Decision
Distributional Assumption of the Inefficiency term				
Test 1: (Translog half-normal vs Translog truncated-normal)				
$H_0: u_i = iidN^+(0,\sigma_u^2)$	4832.07	2.706	0.0000	Reject H_0
Test 2: (Cobb-Douglas half-normal vs Cobb-Douglas truncated-normal)				
$H_0: u_i = iidN^+(0,\sigma_u^2)$	308.13	2.706	0.0000	Reject H_0
Functional Form				
Test 3:(Cobb- Douglas truncated-normal vs Translog truncated-normal)				
$H_0: \beta_{jk} = 0, j \le k = 1,2,...6$	568.69	23.069	0.0000	Reject H_0
Presence of Inefficiency Effects				
Test 4: $H_0: \gamma = 0$	2106.34	2.706	0.0000	Reject H_0
Presence of Technical Change				
Test 5: $H_0: \beta_t = \beta_{tn} = ...\beta_{ti} = 0$	15.47	11.911	0.0169	Reject H_0
Constant Returns to Scale				
Test 6: $H_0: \sum_1^4 \beta_i = 1$	Wald (χ^2)=15.00		0.0001	Reject H_0

Results of the Stochastic Frontier Estimation

Preceding test results have shown that the Translog function is a better fit than the Cobb-Douglas one. Therefore, the estimation results of the Translog form are presented in Table 3.

Table 3. Stochastic Production Frontier Estimation for the Tea Estate Sector in Sri Lanka

Name of the Variable	Translog Model	
	Coefficients	p value
Constant	3.655	0.000^{***}
Revenue extent (ha)	1.961	0.000^{***}
Labor (Rs.)	-0.374	0.003^{***}
Fertilizer (Rs.)	0.136	0.000^{***}
Chemical (Rs.)	0.070	0.004^{***}
Dummy-fertilizer	-0.068	0.256
Dummy-chemical	0.254	0.000^{***}
Time	-0.004	0.028^{**}
Revenue extent^2	0.327	0.000^{***}
Labor^2	0.167	0.000^{***}
Fertilizer^2	0.004	0.001^{***}
Chemical^2	-0.002	0.114
Revenue extent* Labor	-0.248	0.000^{***}
Revenue extent* Fertilizer	0.016	0.000^{***}
Revenue extent* Chemical	0.005	0.040^{***}
Labor* Fertilizer	-0.018	0.000^{***}
Labor* Chemical	-0.005	0.024^{**}
Fertilizer* Chemical	3.345×10^{-4}	0.399
Revenue extent*Time	2.326×10^{-4}	0.299
Labor*Time	1.055×10^{-4}	0.480
Fertilizer*Time	-2.110×10^{-5}	0.462
Chemical*Time	8.010×10^{-5}	0.022^{**}
Time^2	8.150×10^{-7}	0.048^{**}
Diagnosis statistics		
γ	0.609	0.000^{***}

Note: Log-likelihood=-991.92; Number of observations=4842; Number of years=15; Number of estates=35; ***=significant at 1 percent level ($p<0.01$); **=significant at 5 percent level ($p<0.05$); = variation in output accounted for technical inefficiency.

A total of 17 coefficients out of 23 are significantly different from zero at the 5 percent level, showing the importance of some of the interactions and non-linearity among variables. Six direct effects, four squared terms, and six cross products have coefficients significantly different from zero. This further indicates the rejection of the Cobb-Douglas specification as an adequate representation of corporate sector green leaf production in Sri Lanka.

Before interpreting the results of the stochastic frontier analysis further, it is worth noting the partial elasticities with respect to each input used in production. Because of the presence of square and interaction terms in the model, to verify how an input variable affects the output, elasticities[1] were computed and are reported in Table 4.

Table 4. Elasticity Values of the Input Variables

Variable	Elasticity	P Value	Chi^2 Value
Labor	3.006	0.000	1861.070
Extent	1.844	0.000	508.110
Fertilizer	0.032	0.000	100.320
Chemical	0.018	0.000	52.460

The production technology used in the estate sector tea production shows increasing returns to scale (sum of the input elasticities >1). When the returns to scale[2] value is greater than one, the increase in output outweighs the increase in inputs. Then as the results suggest, production at a larger scale would increase production in the estate sector. In other words, in large-scale tea estates, green leaf production (output) increases in a greater proportion than the increase in inputs.

All elasticity values show positive signs and hence increases in these variables would lead to an increase in the output. Labour and extent have the largest elasticity values and hence the largest impact on production. Therefore, they can be regarded as the most crucial factors for tea production based on the

[1] For the translog the elasticities are functions of the estimated coefficients and the values of the input variables. The output elasticity (E_{nit}) expression in translog frontier is presented as $E_{nit} = \frac{\partial \ln Y_{it}}{\partial \ln X_{nit}}$.

[2] Returns to scale *(RTS)* from the translog specification can be obtained as $RTS_{it} = \sum_n E_{nit}$. See Coelli et al., 2003; Hong and Yabe, 2015; Shiu and Heshmati, 2006 for more information on elasticity and returns to scale calculation from a translog production frontier.

data set used for this study. According to Table 4, the output elasticity of labour is 3.006, showing that a 1% increase in labour use will increase green leaf production of the estate sector by 3.006%. This strong relationship is clear in Figure 1.

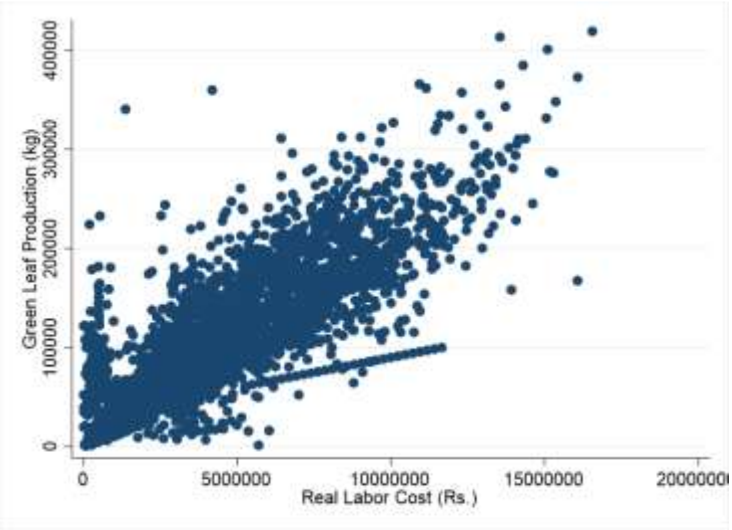

Figure 1. Relationship with Labor and Green leaf production

Tea production is a highly labour-intensive activity in Sri Lanka, as mechanization in the plucking of tea is not practiced in most tea estates. Labour is increasingly becoming a scarce factor in today's plantation crop production, although, plantations keep their own labour within the estates. The sector faces difficulties in the face of the outmigration of labour and because of increasing cost stemming from union activities and political pressure to increase wages. In addition to that, Sri Lanka's labour productivity is much lower compared to other tea-producing countries (GOSL, 1995). Labour productivity is much lower in RPC-managed estates where labour unions have strongly resisted higher working norms compared to smallholdings. Higher overheads due to the cost involved with various social benefits provided to estate workers as well as rigidities in the labour market led to the high cost of production in the estate sector. A practical solution to the use of labour is indeed a priority. Increases in labour use efficiency become a key in the profit maximization of these firms.

Elasticity value with respect to the extent is also more than one, showing that it is highly elastic. This shows the importance of using all lands available for use in production. Figure 2 shows that the revenue extent/ mature extent (mean over estates) has risen slowly during the study period in the estates. Because expanding into new areas is difficult as land is limited, there are two possibilities. The first is to optimize existing lands through proper land management by replanting tea with a view to keeping the best balance between mature (yielding) and immature extents. The second is to plant tea in abandoned/uncultivated lands in tea estates suitable for tea cultivation. Some tea extents give very poor yields due to vacancies (lack of tea bushes) and therefore, consolidation of low-yielding fields by in filling vacancies is also important.

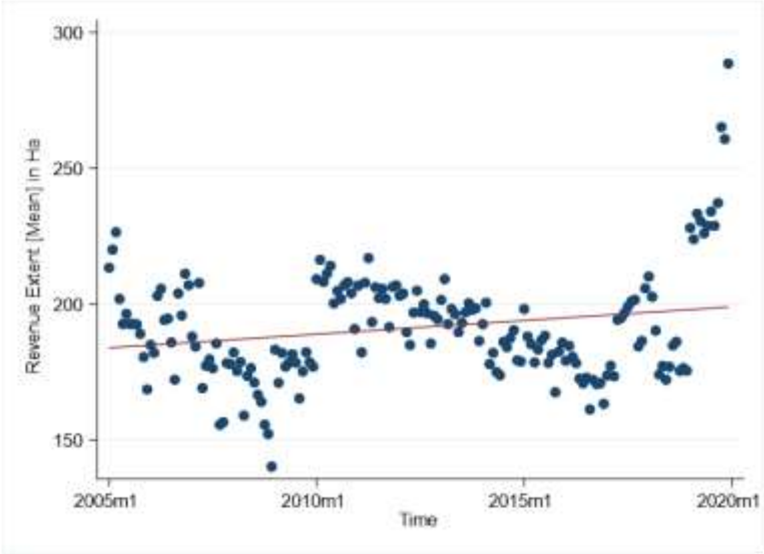

Figure 2. Variation of Mean Revenue Extent of Tea in the Sample Estates in the Study Period

Fertilizer is a key input in tea production. As the vegetative part of the tea bush is harvested, the removed nutrients need to be added to the soil to get a continuous harvest. However, fertilizer elasticity showed a value of less than 1, showing an inelastic response. Equivalent results were seen in the case of the use of chemicals in tea. These low partial elasticities show that the use of these inputs has not been able to increase production at greater levels. Interestingly, the studied estates have reduced the application of fertilizers over the years but they have increased the application of other chemicals (Figure 3). The impact of fertilizer and chemicals being less than the impact of labor use has also been reported by Basnayake and Gunaratne (2002) in smallholder tea cultivation in Sri Lanka. In that study, the production elasticity with respect to fertilizer was reported as 0.062 while the chemical use elasticity was found to be 0.004. Nguyen-Van and To-The (2016) studied tea production in Vietnam did not find a significant effect of chemical fertilizer on tea production. However, Madhushan *et al*., (2020) reported a significant effect using high-grown teas in Sri Lanka.

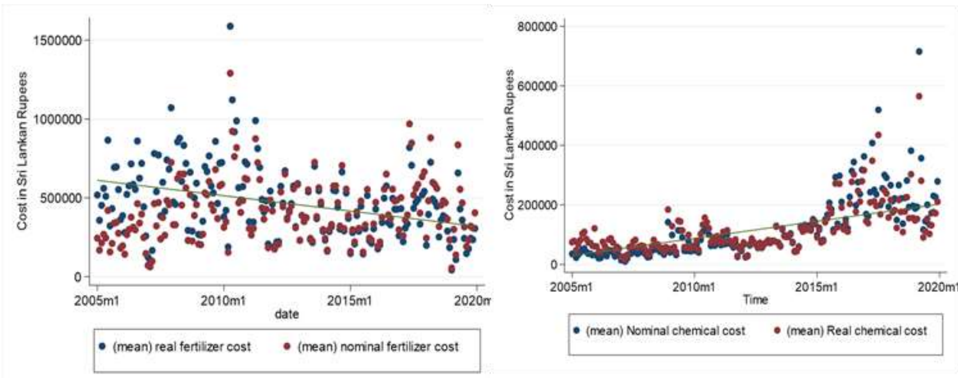

Figure 3. Expenses on Fertilizer and Chemicals in the Studied Estates: 2005-2019

Technical Efficiency

The value of γ (Variation in output accounted for technical inefficiency) is statistically significant, implying that 60.9% of the variation in the composite error term is due to the inefficiency component (Table 3). This implies that there is a potential for further increase in green leaf production in the corporate sector plantations (output) without increasing inputs by simply improving the production efficiency at the estate level.

The mean, minimum and maximum values of the technical efficiency are given in Table 5.

Table 5. Description of the technical efficiency values for the period 2005-2019

Year	Technical Efficiency			
	Mean	Std. Dev.	Min	Max
2005	0.55	0.107	0.37	0.75
2006	0.54	0.109	0.36	0.75
2007	0.54	0.141	0.36	0.97
2008	0.53	0.142	0.35	0.97
2009	0.51	0.146	0.26	0.97
2010	0.54	0.164	0.25	0.96
2011	0.54	0.167	0.24	0.96
2012	0.53	0.164	0.23	0.96
2013	0.52	0.165	0.23	0.96
2014	0.51	0.167	0.22	0.96
2015	0.50	0.169	0.21	0.96
2016	0.49	0.173	0.21	0.96
2017	0.48	0.177	0.20	0.96
2018	0.48	0.182	0.19	0.96
2019	0.54	0.206	0.19	0.96
Mean	**0.52**	**0.163**	**0.19**	**0.97**

The tea estate sector is 52% technically efficient which means that on average a typical tea estate had operated 48% below the potential output during the period of 2005-2019. Further, the least performing estate was performing at 19% which is about 81% below the maximum potential of output. The best practice estate operates just 3% below the maximum possibility frontier (Table 5). Baten et al., (2010) found using panel data that tea production efficiency in Bangladesh was 59%, which is closer to the average value found in this study. Shyamalie et al., (2020) revealed that the low country tea smallholders' average technical efficiency was 68.81%. Basnayake and Gunaratne (2002) pointed out that the mean technical efficiency of the tea smallholdings sector in the Mid Country Wet Zone was found to be 64.60 %. However, Premaratne et al., (2018) reported a 90% level of efficiency using data from smallholder farmers. A more recent study by Madhushan et al., (2020) reports a level of technical efficiency in high-grown tea estates to be 86.9%, however, with a smaller sample of estates.

Total Factor Productivity and its Decomposition

Percentage change measures of technical efficiency, technical change, and TFP change were calculated for each estate using estimates of the stochastic frontier. The changes in TFP, technical efficiency, and technical change for the period from 2005 to 2019 are shown in Figure 4. Positive values with increasing trend in the calculated technical change indicate an improvement of technology during the period of study. Slight growth in trend (technical progress) can be seen (Figure 4). The rate of technical progress was estimated at 0.002 percent per year.

Efficiency change has declined during the study period. The overall rate of technical efficiency change decline was 0.013 percent per year. Because of this declining technical efficiency, a policy to increase efficiency is needed, which might include improvements in learning-by-doing processes and in managerial practices (Kim and Han, 2001). Since the decline in efficiency change is slightly greater than that of the growth in the technical change, the TFP change has declined over the study period. This is because the TFP change is calculated as the product of efficiency change and the technical change (equation 5). The opposing effects of efficiency decline and technical progress resulted in an estimated decline of TFP change at 0.002 percent per year. This net effect of declining TFP reflects the inadequate replanting, inconsistent fertilizer applications, senility of tea bushes, high wages, shortage of labour, high cost of production, and low profitability of the estate sector. Among them, low productivity of labour and high labour cost is one of the critical factors affecting long-term commercial viability and the overall productivity of the corporate sector tea plantations. Inadequate replanting in the estate sector is another factor that affects low productivity levels. Kelegama (2010) reported that the corporate sector should replant about 3% annually to sustain the long-term viable level of tea production. This net effect of declining TFP raises concerns about the sustainability of the tea estate sector in Sri Lanka.

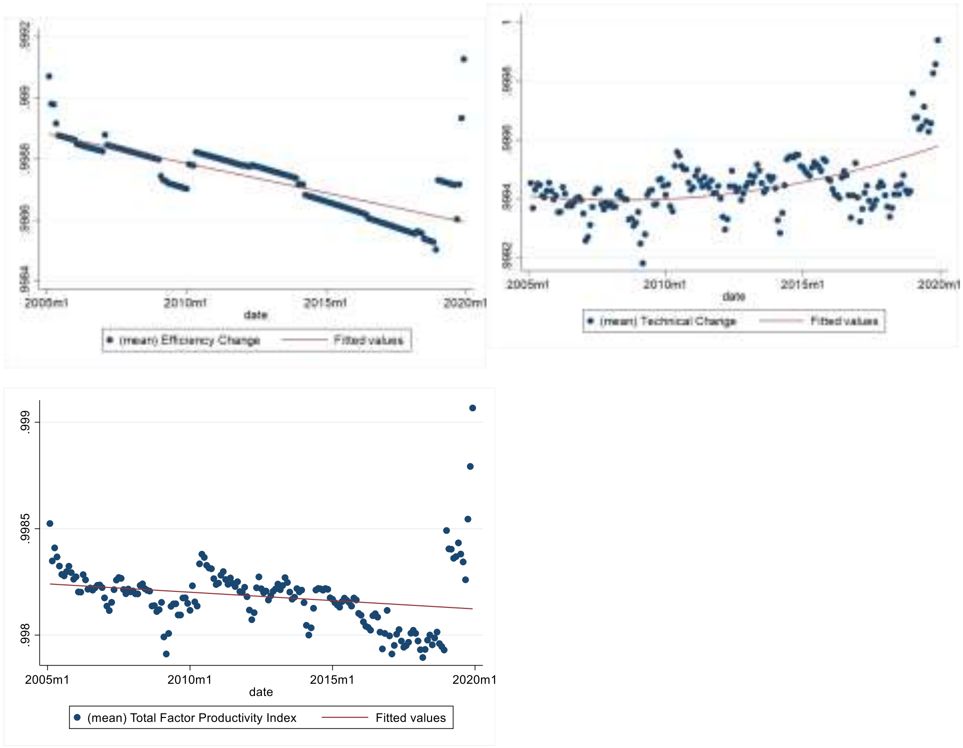

Figure 4. Technical change, Efficiency Change, and Total Factor Productivity Change in the Tea Estates from 2005 to 2019

Conclusions and Policy Implications

This study used monthly panel data for 15 years (2005-2019) to investigate the technical efficiency change, technical change, and TFP change in the large-scale tea estates in Sri Lanka using a stochastic frontier approach. Despite slow technical progress, TFP change and technical efficiency change declined over the study period. The opposing effects of efficiency decline and technical progress resulted in an estimated decline of TFP change at 0.002 percent per annum. Moreover, the findings of the study revealed that the corporate tea sector is 52% technically efficient which means on average estate sector tea production operates 48% below the potential output. This implies that there is a potential to further increase in corporate sector tea production without increasing its inputs. Moreover, the attainment of technical efficiency is necessary (although not sufficient) prerequisite for attaining optimum economic performance in the tea industry. Further, declining TFP raises concerns about the sustainability of the Sri Lankan tea industry which can be overcome if slow technical progress and declining technical efficiencies are dealt with. To combat slow technical progress, policies to induce technological innovation are recommended to shift up the production frontier. In addition, and more importantly, policy measures to increase efficiency are required, which might include improvements in managerial practices in the estate sector and improvements in labour markets.

Sri Lanka must direct its policies to revive the corporate tea sector. If not, there is a possibility of replacing the tea produced in Sri Lanka by other cultivations soon. Private companies will involve in tea cultivations only if there is profitability from it. The declining efficiency, slow technical progress, and the declining TFP is signaling a loss of profitability in this sector. Revival is contingent upon the following policy measures:

1. *Invest in policies to promote innovation*: Because of slow technical progress, policies to induce technological innovation should be recommended to shift up the production frontier. There are research institutions for the development of tea cultivation and processing in Sri Lanka. These are funded by the national budget and there have been fewer allocations from the national budget to research and development in this sector in recent times. The revival of research not only in these government-funded institutions but also in the corporate sector is important. Not only policies to promote innovation, but to promote adoption of such innovations is also necessary. Although new varieties/cultivars suitable for different elevations, new site-specific fertilizer mixtures, and soil nutrient management strategies have been introduced, they seem to have not been appropriately adopted in tea plantations. In addition, mechanization is slow in this sector and should be accelerated to combat ever-rising labor scarcity in tea cultivation.

2. *Improve formal training of managers*: To combat declining technical efficiency, improvements in managerial practices are needed. Training of plantation managers is typically done at the estate level by their senior managers. However, formal training

in plantation management is critical for future success. New management models that build upon age-old traditions need to be developed. Therefore, policies to improve the training and development of personnel in this sector are necessary.

3. *A sustainable productivity-based Revenue Sharing Wage model should be established:* The other important reason for the low performance of the corporate tea sector is high labor cost. Labor cost has increased during the study period. It is widely reported that plantation sector labor wages are not tied to productivity especially in the corporate sector as well as compared with the other competing countries Sri Lanka has recorded the lowest labor productivity levels. On the other hand, it is uncertain if wages can be further increased with the current wage model, which offers a mandatory 300 days of work per year at a lower level of productivity. Further in the long run, if the estates are unable to negotiate a wage rate that is tied to productivity, estate companies may make substantive losses and become incapable of paying wages of the plantation workers or start laying off labor. Therefore, by introducing productivity based revenue sharing wage model, both the plantation company owners as well as the plantation sector workers can maximize their benefits.

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References

Abeysekara, M.G.D. and Prasada, D.V.P. (2021). Returns to Factors of Production and Total Factor Productivity in Coconut Plantations in Sri Lanka. *Tropical Agricultural Research*. *32*(1), 58-67.

Aigner, D., Lovell, C. A. and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*. *6*(1), 21–37.

Alam, M. J., Begum, I. A., Rahman, S., Buysse, J. and Huylenbroeck, G. V. (2011). Total Factor Productivity and the Efficiency of Rice Farms in Bangladesh: A Farm Level Panel Data Comparison of the Pre- and Post-Market Reform Period. 85th Annual Conference of the Agricultural Economics Society, Warwick University, UK.

Arazmuradov, A., Martini, G., Scotti, D. (2014). Determinants of total factor productivity in former Soviet Union economies: A stochastic frontier approach. *Economic Systems*. *38*(1), 115-135.

Bayarsaihan, T., Battese, G. E. and Coelli, T. J. (1997). Productivity of Mongolian Grain Farming, 1976–1989. CEPA Working Paper, Centre for Efficiency and Productivity Analysis, University of New England, Armidale, Australia.

Basnayake, B. M. J. K. and Gunaratne, L. H. P. (2002). Estimation of Technical Efficiency and Its Determinants in the Tea Small Holdings Sector in the Mid Country Wet Zone of Sri Lanka. *Sri Lankan Journal of Agricultural Economics*. 4(1), 137-150.

Baten, M. A., Kamil, A. A. and Haque, M. A. (2010). Productive efficiency of tea industry: A stochastic frontier approach. *African Journal of Biotechnology*. *9*(25), 3808-3816.

Battese, G. E. (1997). A note on the estimation of Cobb-Douglas production functions when some explanatory variables have zero values. *Journal of Agricultural Economics*. *48*(1-3), 250-252.

CBSL (Central Bank of Sri Lanka). (2018). Annual Report - 2018. Retrieved from https://www.cbsl.gov.lk/en/publications/economic-and-financial-reports/annual-reports/annual-report-2018. Accessed August 5, 2021.

CBSL (Central Bank of Sri Lanka). (2019). Annual Report – 2019. Retrieved from https://www.cbsl.gov.lk/en/publications/economic-and-financial-reports/annual-reports/annual-report-2019. Accessed August 10, 2021.

CBSL (Central Bank of Sri Lanka). (2020). Annual Report - 2020. Economic and Social Statistics of Sri Lanka. Retrieved from https://www.cbsl.gov.lk/en/publications/other-publications/statistical-publications/economic-and-social-statistics-of-sri-lanka. Accessed July 30, 2021.

Coelli, T. (1995a). Estimators and hypothesis tests for a stochastic frontier function: A Monte Carlo analysis. *Journal of Productivity Analysis*. *6*(3), 247–268.

Coelli, T. J. (1995b). Recent developments in frontier modeling and efficiency measurement. *Australian Journal of Agricultural Economics*. *39*(3), 219–245.

Coelli, T. J., Rao, D., O'Donnell, C., Battese, G. (1998). An Introduction to Efficiency and Productivity Analysis. 2nd ed. New York, NY, United States: Springer.

Coelli, T., Rahman, S. and Thirtle, C. (2003). A stochastic frontier approach to total factor productivity measurement in Bangladesh crop agriculture 1961-92. *Journal of International Development*. *15,* 321–333.

Das, K. and Das, D. (2020). Technical Efficiency in Small Tea Gardens of Assam. *Review of Development and Change*. (1), 112–130.

Economic and Social Statistics of Sri Lanka (2010). Central Bank of Sri Lanka. Retrievedfrom https://www.cbsl.gov.lk/sites/default/files/cbslweb_documents/statistics/otherpub/econ_%26_ss_2010_e-min.pdf. Accessed on September 18, 2022.

Economic and Social Statistics of Sri Lanka (2020). Central Bank of Sri Lanka. Retrieved from https://www.cbsl.gov.lk/sites/default/files/cbslweb_documents/statistics/otherpub/ess_2020_e1.pdf. Accessed on September 18, 2022.

Fare, R., Grosskopf, S. and Lovell, C. K. (1985). The measurement of efficiency of production. luwer- Nijhoff: Boston.

Ferrara, G. and Vidoli, F. (2017). Semiparametric stochastic frontier models: A generalized additive model approach. *European Journal of Operational Research*. *258*(2), 761–777.

Ganewatta, G. and Edwards, G. W. (2000). The Sri Lanka Tea Industry: Economic Issues and Government Policies. 44th Annual Conference of Australian Agricultural and Resources Economics Society, University of Sydney, Australia.

Government of Sri Lanka, (1995). Report of the President Commission on the Tea Industry and Trade 1995 (Sessional Paper No. 11-1995). Colombo: Government Publications Bureau.

Hayatullah, A. (2017). Crop diversification and technical efficiency in Afghanistan: Stochastic frontier analysis. CREDIT Research paper, No 17/04, The University of Nottingham, Center for Research in Economic Development and International Trade (CREDIT), Nottingham.

Hong, N. B. and Yabe, M. (2015). Technical Efficiency Analysis of Tea Production in the Northern Mountainous Region of Vietnam. Global Journal of Science Frontier Research: D Agriculture and Veterinary**.** 15(1), 31- 42.

Hazarika, C. and Subramanian, S.R. (1999). Estimation of Technical Efficiency in the Stochastic Frontier Production Function Model – An Application to the Tea Industry in Assam. Ind. in. of Agri. Econ. 54(2), 201-211.

Jayakody, S. and Dishanka, S. (2019). An Estimation of Technical Efficiency of Tea Smallholdings in Ratnapura District of Sri Lanka. *Journal of Social and Development Sciences*. *10*(4), 1-11.

Jayasuriya, R. T. (1998). Technological Change and Scarcity of Soil in the Tea Sector of Sri Lanka. La Trobe University, Bundoora.

Jeewanthi, D.G.M. and Shantha, A.A. (2021). The Technical Efficiency of Small-scale Tea Plantation in Sri Lanka. *Asian Journal of Management Studies***.** *1*(1), 128-149.

Katungwe, F., Elepu, G. and Dzanja, J. (2017). Technical Effi ciency of Smallholder Tea Production in South-Eastern Malawi: A Stochastic Frontier Approach. *The Journal of Agricultural Sciences*. *12*(3), 185-196.

Kelegama, S. (2010). Productivity Decline in the Tea Plantations and a Possible Way Forward. In S. Kelegama, & D. Gunawardena, Economic and Social Development under a Market Economy Regime in Sri Lanka, Buddhadasa Hewavitharana Felicitation Vol. 2. Colombo: Vijitha Yapa Publications.

Kim, S. and Han, G. (2001). A Decomposition of Total Factor Productivity Growth in Korean Manufacturing Industries: A Stochastic Frontier Approach. *Journal of Productivity Analysis*. *16*, 269–281.

Kim, S. (2010). Factor Determinants of Total Factor Productivity Growth in the Malaysian Hotel Industry: A Stochastic Frontier Approach. Cornell Hospitality Quarterly Online First.

Kodagoda, A.H., Dharmadasa, R.A.P.I.S. (2020). Technical efficiency of organic tea smallholders: Evidence from Uva Region of Sri Lanka. *Journal of Agriculture and Value Addition*. *3*(1), 43-59.

Kodde, D. A. and Palm, F. C. (1986). Wald Criteria for Jointly Testing Equality and Inequality Restrictions. Econometrica. 54(5), 1243-1248.

Li, G., You, G. and Feng, Z. (2011). The sources of total factor productivity growth in Chinese agriculture: technological progress or efficiency gain? Journal of Chinese Economic and Business Studies. 9(2), 181–203.

Madhushan, Y. W. C., Ranjan, K. R. H. M., Somarathna, A. D. K. S. S., and Edirisinghe, J. C. (2020). Variability of Technical Efficiency in High Grown Tea Estates–A Bayesian Approach In Proceedings of the

International Research Conference of Uva Wellassa University, July 29-30, 2020.

Maity, S. 2017. Reform Raises Efficiency of Tea Estates in India. Agris on-line Papers in Economics and Informatics. Volume IX: 101-116.

Meeusen, W. and Van den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review*. *18*:435–444.

Mohamed, M. T. Z. (2004). Current Trends and Future Challenges in Tea Research in Sri Lanka. In Proceedings of the First Symposium on Plantation Crop Research: Current Trends and Future Challenges. Eds. A. K. N. Zoysa and M. T. Z. Mohamed. Colombo: The Tea Research Institute of Sri Lanka, 1-7.

Nguyen-Van, P. and To-The, N. 2016.Technical efficiency and agricultural policy: evidence from the tea production in Vietnam. Rev Agric Food Environ Stud, 97(3).

Plantation Sector Statistical Pocket Book. 2012. Ministry of Plantation Industry. Retrieved from https://plantation.gov.lk/web/images/pdf/publications/plantation_sector_statistical_pocket_book_2012.pdf. Accessed on June 15, 2021.

Plantation Sector Statistical Pocket Book. 2018. Ministry of Plantation Industry. Retrieved from http://plantationindustries.gov.lk/web/images/pdf/Statistical_Information/Statistical_Information_On_Plantation_Crops_2018.pdf. Accessed June 15, 2021.

Premaratne, S.P., Priyanath, H.M.S., Yoosuf, A., Maurice, D. 2018. Technical Efficiency for Tea Smallholder Farmers under UTZ Certification System in Sri Lanka: A Stochastic Frontier Approach. *SEISENSE Journal of Management*. *1*(2).

Shahabinejad, V., Mehrjerdi, M. R. Z., Yaghoubi, M. 2013. Total Factor Productivity Growth, Technical Change and Technical Efficiency Change in Asian Economies: Decomposition Analysis. *Iranian Journal of Economic Studies*. *2*(2), 47-69.

Shiu, A. and Heshmati, A. 2006. Technical change and total factor productivity growth for Chinese provinces: A panel data analysis.

Shyamalie, H.W., Pilapitiya, H.M.C.G. Karunarathna, B.M.N.C. and Nadeeshani, K.W.N. 2020. Determinants of productivity variation and technical efficiency of tea small holders in the low country of Sri Lanka. *Sri Lanka Journal of Food and Agriculture*. *6*(2), 7-14.

Temoso, O., Hadley, D. and Villano, R. 2018. Sources of efficiency, productivity and output growth in Botswana agriculture. *Review of Development Economics. 22*(3), 1105-1124.

Wondemu, K. A. 2016. Decomposing Sources of Productivity Change in Small-Scale Farming in Ethiopia. Working Paper No 237. African Development Bank Group.

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