PRODUCTION FUNCTION ANALYSIS OF TEA ESTATES IN SRI LANKA

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Summary: This article analyses returns to scale by fitting a Cobb-Douglas production function model to three inputs (land, labor and fertilizer) subject to management control and two environmental factors (rainfall and altitude) in tea production of Sri Lanka. State-owned estates in two tea-growing study districts of Ratnapura in the low-elevation belt and Nuwara Eliya in the high-elevation zone are taken as samples to examine the impact of management and environmental factors on yield. Other important factors are discussed in determining the level of tea productivity in the island.

Introduction

The tea sector of the Sri Lankan economy has for almost two decades been declining in terms of its world market share, world production share, and contribution to the national economy (Table 1). The **World Development Report** (1986, p. 74) points out that Sri Lanka's share of the international market has dropped from about one-third in the 1960s to not much more than one-fifth in the 1980s. De Silva (1986, p. 22) further states that "the plight of the tea industry, which accounts for a third of Sri Lanka's export earnings, has been identified as a 'crippling blow' to the island's economy by both the World Bank and International Monetary Fund." A recent World Bank report, **Sri Lanka and the World Bank** (1987, p. 33), observes that stagnant production levels among the island's tree crops (tea, rubber and coconut) have figured regularly in the Bank's discussion of Sri Lanka for almost three decades. The poor production performance is clearly a major problem.

In addition to these developments, productivity (production per hectare) has stagnated for almost two decades in Sri Lanka. Compared with other

Table 1.
Basic Indicators of the Tea Industry's Relative Performance in the National Economy and the world Tea Market 1969-86

Year	*Share of World Market (%)*	*Share of World Production (%)*	*Contribution to Economy (% of GDP)*
1969	34.1	20.7	na
1970	32.0	19.1	55
1971	29.5	19.5	59
1972	27.1	17.8	58
1973	26.5	17.1	48
1974	28.6	16.6	39
1975	28.3	16.7	49
1976	25.2	14.8	44
1977	22.8	12.1	53
1978	24.0	11.2	48
1979	22.0	11.4	37
1980	21.5	10.4	35
1981	21.5	11.2	31
1982	22.1	9.8	30
1983	18.1	8.9	33
1984	21.6	9.6	42
1985	20.7	9.5	33
1986	21.5	9.5	na

na: not available.

Sources: *ITC Annual Bulletin of Statistics, Sri Lanka Tea Board Annual Report* and *Tea Board of India Statistics* (various issues, 1970-1987).

major tea producing countries, the productivity level in Sri Lanka is low and has shown no recent improvement. Table 2 illustrates this conspicuous feature of the island's tea industry. In 1984, the productivity levels of other tea-producing nations ranged from 1,394 kilograms per hectare in Kenya, 1,468 kilograms in India, 1,500 kilograms in Indonesia to 1,684 kilograms in Japan. Sri Lanka's productivity has remained less than 1,000 kilograms for more than three decades.

Table 2

Level of Productivity in Selected Major Tea Producing Countries (kilograms per hectare)

Year	Sri Lanka	India	Kenya	Indonesia	Japan
1951	641	901	865	419	na
1961	869	1070	712	552	na
1969	910	1111	987	649	na
1970	878	1174	1020	706	1765
1972	883	1266	1072	801	1765
1974	872	1353	913	846	1631
1976	817	1405	940	1025	1680
1978	819	1527	1296	1078	1746
1980	782	1491	1174	1118	1677
1982	776	1420	1184	1174	1615
1984	918	1468	1394	1500	1684
1986	954	na	1698	na	na

na: not available.

Sources: Calculated from *ITC Annual Bulletin of Statistics* and *Tea Statistics of India* (various issues, 1955-1987).

Analysis of the foregoing indicators suggests that Sri Lanka faces the task of increasing total production and productivity to maintain its competitiveness with other tea producers and exporters. Tea specialists in Sri Lanka and in international financial agencies such as the World Bank, the International Monetary Fund, and the Asian Development Bank identify the production performance as a major cause of the declining tea industry.

The main purpose of this paper is to determine and explain returns to scale in tea production and to describe and analyse the influence of environmental factors and management factors on tea cultivation. The findings of this study will shed some light on whether the tea estates in Sri Lanka are of optimum size and why the level of productivity has remained stagnant for over two decades.

Study Area and Sources of Data

State-owned estates are managed by two government agencies: the Janatha Estate Development Board (JEDB) and the Sri Lanka State Plantation Corporation (SLSPC). In the early 1989, the author conducted field research to collect data from state-owned tea estates. Nuwara Eliya in the high-elevation zone (above 1200 metres) and Ratnapura in the low-elevation zone (below 600 metres) are selected as two study districts. [1] With the assistance extended by the officials of JEDB and SLSPC, the data relating to land, labor, fertilizer, rainfall, and altitude were obtained: 88 JEDB-managed estates and 27 SLSPC-managed estates in Nuwara Eliya district and 44 SLSPC-managed estates in Ratnapura district. Nuwara Eliya district has the most cultivated land in tea estates, with 36,472 hectares in high-grown tea. Ratnapura district, with 15,311 hectares in estates, accounts for the greatest area among the eight districts in the low-elevation belt. These two districts accounts for nearly 32 percent of the country's total cultivated land area in tea (Table 3).

Methodology

To investigate the level of productivity, this study selects three inputs (land, labor, and fertilizer) subject to management control and two environmental factors (rainfall and altitude). These inputs and environmental factors are generally considered the most influential in determining output. Inputs are also referred to as resources, factors of production, or variables [2] In this study, all these terms are synonymous. Output is defined as production of plucked green tea leaves per estate. Returns to scale in tea production are investigated by estimating a Cobb-Douglas production function. This model examines the collective role that the independent variables (land, labor, fertilizer, rainfall and altitude) have upon the dependent variable (output). It also provides the degree of importance of each input in determining output. The Cobb-Douglas model is expressed:

$$\text{Log}\ (Y) = \log a + b_1 \log (X) + b_2 \log (L) + b_3 \log (F) + b_4 \log (R) + b_5 \log (A)$$

where,

Y = Total output of plucked green tea leaves in kilograms in a tea estate;

X = Hectares of land area cultivated with bearing tea which has contributed to the 1988 output (Y);

L = Total number of workers employed for harvesting and field upkeeping in a tea estate;

F = Total number of NPK applied in metric tons per estate;

R = Average annual rainfall recorded in centimeters by the estate manager for the calender year 1988;

A = Mean elevation recorded in meters at the factory location. For tea estates where no factory is located, the lowest elevation is taken to stadardize the data; and

a = constant term.

Table 3

Total Number and Cultivated Tea Land Area of Estates Classified According to Administrative Districts, 1987
(Percentages are indicated in parentheses)

Elevations/ Districts	*Tea Estates Number*	*Area (ha)*	*Average size (ha)*
High-grown (above 1200 meters)			
Badulla	395 (10.74)	29,401 (17.98)	74
Nuwara Eliya	238 (6.47)	36,472 (22.31)	153
Sub-total	633 (17.21)	65,873 (40.29)	104
Mid-grown (600 meters – 1200 meters)			
Kandy	1,123 (30.53)	50,842 (31.10)	45
Matale	177 (4.81)	6,047 (3.70)	52
Sub-total	1,300 (35.34)	56,889 (34.80)	44
Low grown (below 600 meters)			
Colombo	9 (.24)	201 (.12)	22
Galle	483 (13.20)	7,278 (4.45)	15
Hambantota	1 (.03)	5 (.01)	5
Kalutara	69 (1.88)	2,595 (1.59)	38
Kegalle	214 (5.82)	6,460 (3.95)	30
Kurunegala	5 (.14)	245 (.14)	49
Matara	531 (14.44)	8,625 (5.28)	16
Ratnapura	433 (11.77)	15,311 (9.37)	35
Sub-total	1743 (43.39)	40,720 (24.91)	23
Total	3,678 (100.00)	163,482 (100.00)	44

Source: *Sri Lanka Tea Board Annual Report (1988).*

The elasticities or regression coefficients ($b_{1\text{-}5}$) idicate the percentage change in output for each one percent change in input while other factors are held constant. The sum of coefficients (excluding rainfall and altitude) indicates the returns to scale.[3]

Results and Discussion

The results of estimating the Cobb-Douglas model are presented in Table 4, where five independent variables are regressed against tea output (dependent variable) for the two study districts. The sum of coefficients is computed by adding the coefficients (elasticities) of land, labor, and fertilizer. The results suggest that land is the most important factor in tea production compared to the other inputs in both districts. The impact of altitude on output in both district is statistically insignificant when all variables interact collectively to predict tea production. Rainfall has an inverse relationship at the five percent significance level in the high-elevation district. This relationship in Ratnapura district is positive, though not significant. A noticeable influence of labor on output is evident only in Ratnapura district. The change in labor has an unexpectedly low impact on output in

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Production Function.....

Table 4

The Cobb-Douglas Production Function Estimates for Nuwara Eliya and Ratnapura Districts

Model: $\text{Log}(Y) = \log a + b_1 \log(X) + b_2 \log(L) + b_3 \log(F) + b_4 \log(R) + b_5 \log(A)$

Variables	Nuwara Eliya District	Ratnapura District
Land size (X)	.80113**	.81936**
	(6.360)	(5.275)
Labor (L)	.02726	.35246
	(.282)	(1.578)
Fertilizer (F)	.06240	-.09617
	(1.626)	(-.483)
Rainfall (R)	-.21110*	.47108
	(-2.616)	(1.658)
Altitude (A)	.07779	.09670
	(.474)	(1.046)
Intercept (a)	8.48923**	3.12219
	(6.011)	(1.659)
R^2	.80938	.85164
Sum of coefficients (L+F+X)	.89079	1.07565
F-ratio	94.25949**	47.07055**
Number of observations	115	44

Notes: Figures in parentheses are t-statistics.
** Signigficance level at one percent.
* Significance level at five percent.

Nuwara Eliya district, and it is not statistically significant. The impact of fertilizer application is not discernable statistically in Nuwara Eliya district. This relationship is negative in Ratnapura district, but not significant.

Labor and fertilizer coefficient estimates are noticeably low in Nuwara Eliya district and a negative fertilizer coefficient exists in Ratnapura district. From Table 5, it appears that multicollinearity exists among land, labor, and fertilizer. Because of multicollinearity, the importance of **individual** input variables in tea production cannot be accurately determined by these results because multicollinearity produces biased coefficient estimates. More reliable input coefficients will be sought after dealing with the multicollinearity problem.

Multicollinearity arising from the least square estimation of the Cobb-Douglas production function model is not surprising. Because the estates employ about the same relative amount of inputs in tea production. The problem, therefore, inheres in the model itself. Doll (1974, p. 556) asserts that "... users of the Cobb-Douglas model who are dismayed to find multicollinearity among the 'independent' variables should be pleased because the presence of multicollinearity serves as a verification of their economic model." How does multicollinearity affect the estimates of this study? When input use is proportional, but not equal, across tea estates, the Cobb-Douglas production function model is valid even if multicollinearity exists. It is still possible to obtain reasonable estimates to determine returns to scale when inputs are highly correlated (Doll 1974, p. 557).

Analysis of Returns to Scale

The sum of coefficients of the Cobb-Douglas production function model suggests the existence of decreasing returns to scale in Nuwara Eliya district, whereas Ratnapura district demonstrates economies of scale (Table 4). Table 4 indicates that the sum of coefficients of the three management factors of production (labor, fertilizer, and land) is .89 and 1.08 for Nuwara Eliya and Ratnapura districts respectively. It is assumed that the intensive use of land, labor, and fertilizer in Nuwara Eliya district exceeds its optimal production capacity, thus resulting in diminishing returns to scale. Ratnapura district, with a smaller labor force in tea production and less fertile land, has not yet reached its saturation point but has the capacity to increase the average tea yield with each unit of added labor. The two districts demonstrate considerable variation in resource endowments and their production prospects vary commensurately (Mendis 1989).

The sums of coefficients in both districts are, however, close to unity: +.11 for Nuwara Eliya and −.08 for Ratnapura. Thus, one may ask: do these districts demonstrate, for all practical purposes, approximately constant returns to scale? To answer this question, the sums of coefficients are tested

Table 5

Correlation Matrices of Production Function Variables in Nuwara Eliya and Ratnapura Districts

A. Nuwara Eliya district

	(Y) Output	*(X) Area*	*(F) Fert.*	*(L) Labor*	*(R) Rain*	*(A) Altit.*
(Y)	1.0000	.8771*	.4057*	.8337*	-.1872	.2243
(X)		1.0000	.4213*	.9144*	-.1187	.2088
(F)			1.0000	.3886*	-.2006	.2214
(L)				1.0000	-.0716	.2124
(R)					1.0000	-.3440*
(A)						1.0000

Number of observations: 115

B. Ratnapura District:

	(Y) Output	*(X) Area*	*(F) Fert.*	*(L) Labor*	*(R) Rain*	*(A) Altit.*
(Y)	1.0000	.7858*	.8970*	.8951*	.2241	.0905
(X)		1.0000	.8846*	.9451*	.0331	.0918
(F)			1.0000	.9383*	.1360	.1330
(L)				1.0000	.1282	.1003
(R)					1.0000	.2907
(A)						1.0000

Number of observations: 44

Notes: *Significance level at one percent.
Only half of the matrix is presented because the lower half is obviously a mirror image of the upper half.

statistiacally to determine whether they are significantly different from unity.4 The sums of coefficients could exceed 1.41 with the significance level at five percent in Nuwara Eliya district. Similarly, the land, labor, and fertilizer coefficients minus twice the sum of the relevant standard error of estimates indicate that the sum of coefficients could decrease to .72 at the five percent significance level in Ratnapura district. Hence, these two tests suggest that the sum of coefficients between the two districts, which measures returns to scale, may not significantly differ from one district to another.

Similar to Sri Lanka, Japan's tea production has constant returns to scale (Heady and Dillan 1961, p. 630). The land and labor coefficients, .29 and .30 respectively, on the island of Honshu suggest that these two factors are equally important in tea cultivation. "Other" inputs reported by relatively large coefficient of .46 may possibly result from the high intensity of fertilizer use and mechanization in Japanese tea production. The nature of tea cultivation in Japan is that relatively small-size, family-owned tea gardens are more land-intensive than those of large land-extensive but labor-intensive estates found in Sri Lanka. It is possible that tea estates could gain economies of scale as size increases in Sri Lanka if they optimize the use of inputs, improve managerial skills, and maintain a better employer-employee relationship.

With regard to the multicollinearity problem, other empirical studies which applied the Cobb-Douglas model have dealt with the problem in two ways: (1) Aggregating variables when they are perfectly complementary or perfectly substitutable (Wong 1986), and (2) Dropping or deleting a principal variable (Hayami and Ruttan 1985, pp. 141-142). Hayami and Ruttan, who employed the Cobb-Douglas production function model in international agricultural productivity comparisons, attempted to avoid multicollinearity by using various alternatives. They tried deleting principal component(s) to explain the remaining components. This study, where independent variables are neither perfectly complementary nor perfectly substitutable, applies a similar approach by omitting one variable (i.e., land) from the model to give better estimates of the remaining input variables.

Since land area is highly correlated in the two districts, the factor is dropped from the original model to obtain new estimates. These estimates are presented in Table 6. After excluding the land area factor, labor and fertilizer coefficients improved significantly in Nuwara Eliya and Ratnapura districts. More reliable coefficient estimates in the high-elevation district suggest that a one percent increase in labor and fertilizer would increase output by .55 percent and .17 percent respectively, *ceteris paribus*. These input coefficients are highly significant. The results suggest that labor becomes a more important source of variation than fertilizer in tea production. When land area is dropped from the model, returns to scale cannot be tested because one of the most essential factors of tea cultivation is excluded. The impact of rainfall, similar to the coefficient estimate of the original model, shows a negative influence on tea cultivation. In Ratnapura district, rainfall becomes more important (coefficient .72) than other inputs. The increase of fertilizer use by one percent would increase output by .62 percent, whereas the increase of labor force by one percent would raise output only .42%. These results suggest that rainfall and the use of fertilizer have greater impact on output in the low-elevation district than at higher elevations. Altitude becomes less significant than all other variables in tea production in both districts.

Table 6

The Cobb-Douglas Production Function Estimates for Nuwara Eliya and Ratnapura Districts

Model: $\text{Log}(Y) = \log a + b_1 \log(L) + b_2 \log(F) + b_3 \log(R) + b_4 \log(A)$

Variables	*Nuwara Eliya District*	*Ratnapura District*
Labor (L)	.54687** (10.535)	.41687 (1.460)
Fertilizer (F)	.16569** (3.934)	.61544** (3.289)
Rainfall (R)	(-.23273)* (-2. 432)	.71954 (2.006)
Altitude (A)	.02578 (.132)	.08084 (.684)
Intercept (a)	9.54235** (5.713)	2.30283 (.954)
R^2	.72795	.75096
F-ratio	74.92396**	31.66138**
Number of observations	115	44**

Notes: In this model,returns to scale cannot be measured because land area is excluded.
Figures in parentheses are t-statistics.
** Significance level at one percent.
* Significance level at five percent.

Analysis of Returns to Scale in JEDB — and SLSPC-managed Estates

Table 7 shows the results of the Cobb-Douglas production function model for the two agencies in Nuwara Eliya district. Although the sum of coefficients (.98 for JEDB and .91 for SLSPC) are slightly less than one, the results of the test reportedly suggest that the sum of the coefficients are not significantly different from one [5] The negative coefficient of land size in the two agencies suggests the existence of multicollinearity between independent variables. High collinearity seems to exist between fertilizer and land for JEDB-owned estates, whereas in SLSPC-owned estates it appears to exist between labor and land. As discussed earlier, however, multicolinearity does not prohibit one from making reasonable estimates in measuring returns to scale.

Conclusion

The results of the Cobb-Douglas production function model, which provide statistical evidence to test returns to scale, suggest that Sri Lanka's tea production, on the average, experiences constant returns to scale. Even though this study does not specify an optimum size of a tea estate, it suggests that large estates do not necessarily obtain maximum efficiency in production. The results further imply that the smaller estates are operating at a relatively higher efficiency level than larger tea estates.

The **individual** estimates of the models generally indicate that land, labor, fertilizer, and rainfall are the significant influencing factors in tea production. For Nuwara Eliya district, in addition to land the other influencing factors of tea cultivation are labor and fertilizer. In Ratnapura district, however, rainfall and fertilizer become more important determinants in tea cultivation. The impact of altitude is not significant statistically; tea can grow from a few meters above sea level to altitudes over 2,500 metres. Rainfall appears to have a negative influence in the high-elevation, but not in the low-elevation. The reasons for this are complex because the impact of southwest and northeast monsoons, the water-holding capacity of soil, and the unique topographical characteristics in the study area vary considerably, and cannot be discussed within the scope of this paper.

In this study, the reader's attention is, however, brought to notice that the age of tea bushes, managerial skills, locational characteristics of tea-growing areas, capital investment, research, and training are also important, but not included for practical reasons, in determining the level of tea productivity in Sri Lanka. The stagnated tea productivity can be overcome by replacing the aging tea bushes with high-yield varieties, motivating managerial staff with minimum or no political influences, maintaining beter labor relations, providing better husbandary practices, and increasing research, training, and extension services. Further studies are encouraged to evaluate the importance of such variables as they change over the years. The reported constant returns to scale may also change as population increases, advances in technology, innovations in institutions and policies, and development in agricultural research and development.

Table 7

The Cobb-Douglas Production Function Estimates for JEDB – and SLSPC-owned Tea Estates in Nuwara Eliya District

Model: $\text{Log}(Y) = \log a + b_1 \log(X) + b_2 \log(L) + b_3 \log(F) + b_4 \log(R) + b_5 \log(A)$

Variables	*JEDB*	*SLSPC*
Land size (X)	-.1379 (-1.596)	-.1462 (-.467)
Labor (L)	.1343** (2.043)	.8654** (2.615)
Fertilizer (F)	.9786** (14.970)	.1910** (1.870)**
Rainfall (R)	.1142** (-2.461)	.0221 (.206)
Altitude (A)	.0849 (.894)	-.5535** (-.2.198)
Intercept (a)	8.9718** (10.998)	10.7076** (5.351)
R^2	.9578	.8930
Sum of coefficients (L+F+X)	.9750	.9102
F-ratio	363.518**	35.060**
Number of obvservations	88	27

Notes: Figures in parentheses are t-statistics.
** Significance level at one percent.
* significance level at five percent.

NOTES

1 Tea is grown in three elevation zones: high, mid, and low. Although actual elevation is traditionally taken as a parameter to describe the quality of tea, for an analysis of policy implications, estate management, and political and budgetary administration, district boundaries are deemed to be more practical and important than actual altitude zonation.

2 In a production function analysis, the relationship between inputs and output is measured in physical terms. Also see Peterson (1989, pp. 86-92).

3 A sum equal to unity indicates constant returns to scale because the total percentage increase in all factors of production (land, labor and fertilizer) willincrease the output by the same percentage. A sum less than one indicates diminishing returns to scale. A sum greater than one indicates economies of scale. See Heady (1946, pp. 989-1004).

4 To test whether the sum of the coefficients differ from one: add the coefficients plus twice the standard errors of three variables of land, labor and fertilizer. Then obtain the standard deviation of this number and divided it into the difference between the sum of the coefficient and one.

5 A calculation similar to footnote 4 is used to test the significance of deviation of the sum of coefficients from unity●

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