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THE SPECIFICATION AND ESTIMATION OF A PRODUCTION FUNCTION FOR SMALLHOLDING RUBBER IN SRI LANKA

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SUMMARY

An attempt is made to analyse the main input/output relationships in a cross-section of smallholdings growing high yielding rubber in the Matugama and Agalawatta areas of Sri Lanka. It follows from the results reported by Barlow et al. (1975) of the 1971 survey of these holdings.

The factors found to have most impact on output were tree age, planting density, area of mature rubber and tapping frequency. Specification problems associated with these variables and with rubber, as a perennial crop, are discussed. Two main types of clones Tjir 1 and PB 86 were grown on these holdings and a comparison of their performance was made. Similarly, the sample has been divided by the number and type (family or hired) of labour employed in evaluating the performance of the various holdings in the sample. Throughout this paper the Cobb-Douglas production function approach was followed.

INTRODUCTION

This paper discusses a study made in 1971 of 289 rubber smallholdings. The main objective of this study was to get basic data on the economics of smallholder production, particularly the input/output relationships (Barlow *et al.*, 1975). An attempt to quantify these relationships in terms of a production function model is also made in order to find out the efficiency of allocation of resources by farmers.

The study was conducted by the Rubber Research Institute of Sri Lanka, in collaboration with Dr. C. Barlow from the Australian National University. The field survey was carried out in Matugama and its adjoining area of Agalawatta, which together cover some 87 square miles of the Kalutara District, the second largest rubber growing district of the island (Table 1). This area is located in the wet zone and experiences a heavy rainfall, as much as 150 in., at Agalawatta (10 yr average). The uneven distribution of rainfall together with the withdrawal of some labour for rice cultivation and harvesting are responsible for seasonal fluctuations of the monthly rubber yields. The terrain in the area is undulating, with rubber on the highland and slopes and paddy fields restricted to the valley bottoms. Fungal diseases are more prevalent in this area, compared with the drier districts such as in Galle and Kurunegala.

Selection of the sample of farms used in this study depended basically on the availability of recorded output data, since the farmers' memories on the subject were found to be grossly unreliable and that data were not worth collecting. On the other hand, it was possible to obtain reasonably accurate input data from verbal interviews of the farmers. However, this restriction of the study to farmers with recorded data introduces some bias in the sample, probably favouring well managed and bigger farms : the larger average farm size observed, *i.e.* 0·7 ha, compared to the 0·4 ha for the island, may be attributed to this.

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TABLE 1 : DISTRIBUTION OF RUBBER HOLDINGS IN SRI LANKA

District	Over 100 ac	10 — 100 ac	Smallholdings less than 10 ac
Colombo	18,042	17,360	28,532
Kalutara	57,762	25,233	42,958
Galle	26,728	11,980	17,722
Matara	7,226	8,166	7,321
Hambantota	—	128	97
Ratnapura	43,196	29,066	24,877
Kegalle	63,433	23,167	42,948
Kurunegala	9,407	3,848	1,980
Puttalam	—	98	32
Kandy	8,190	4,861	3,579
Matale	13,223	4,920	2,040
Nuwara Eliya	—	141	42
Badulla Moneragala	14,604	1,348	569

A random sample of high yielding farms with sheet production records was selected in the area of each town or village ; the share of this sub-sample in the total was approximately proportional to its share in the area of rubber covered by the study. Data were gathered by checking production records, verbally interviewing smallholders and by the direct observation of field conditions. All work was undertaken by pairs of enumerators, one of whom was an experienced rubber instructor. One questionnaire form was entered for each farmer smallholding and each pair of enumerators covered about two smallholdings per working day allowing time for travel, securing data from nearby shops or contract processors and rechecking questionable data. The questionnaires entered each day were usually scrutinized by the supervisors that same evening and any queries resolved by further visits to the holding in question. Although 300 smallholdings were originally surveyed, eleven of them were subsequently rejected due to inadequate data. Out of the 289 farms, 258 have been replanted with budgrafts or selected seedlings since 1953, while the rest were newplanted with high yielding material. High yielding farms were chosen because further guidance is needed for appropriate research and extension to be undertaken for such farms. Low yielding farms, on the other hand, should obviously be replanted first, and so existing input/output relationships are less significant. The socio-economic constraints to replanting have been dealt with by Jayasuriya & Carrad (1976) in a separate paper.

The production function and its specification

A production function, as the term is generally used, is a mathematical expression showing the transformation of a given set of inputs into a set of outputs. Although it is possible to specify those relationships in numerous mathematically functional forms (Heady & Dillon, 1961), often it is difficult to select one which will represent the exact form of the biological transformation process in Agricultural Production. On the other hand. there is no point in specifying complex and refined models if they are not amenable to easy estimation and subsequent manipulation so as to elucidate the nature of the transformation process for economic analyses employing factor product prices.

In the light of these comments, in this study, a modified form of the Cobb-Douglas equation is specified to model the production process of the rubber small holdings. Mathematically, it may be expressed as follows :

$$Q_J = b_o X_{lj}^{bl} \ldots\ldots\ldots\ldots X_{ij}^{bi} \ldots\ldots\ldots\ldots X_{wj}^{bw} + U_j \qquad \ldots\ldots\ldots\ldots (1)$$

where

Q_J is the output of farm j

X_{ij} is the ith factor input used by farm j

b_o is the constant term

bi is the parameter associated with the ith factor used by farm j

U_j is the random error term

Equation (1) can be transformed into the logarithmic form as :

$$Q_j = b_o + b_1 X_{lj} + \ldots\ldots\ldots\ldots + b_i X_{ij} + b'_w X_{wj} + U_j \qquad \ldots\ldots\ldots\ldots (2)$$

which lends itself to estimation by the least squares method. Once the parameters or the b coefficients of the model are estimated partial differentiation with respect to each imput factor, X, will yield the corresponding value of marginal productivity.

TABLE 2 : AREAS PER HOLDING OF MAIN CROPS BY AREA OF MATURE RUBBER (HECTARES)

	Mature rubber, ha per holding						
	Under 0·4 (62)[a]	0·4–0·8 (131)	0·8–1·2 (47)	1·2–1·6 (21)	1·6–2·0 (17)	2·0 or more (11)	All classes (289)
Mature rubber	0·26	0·50	0·89	1·29	1·69	2·42	0·71
Immature rubber	0·05	0·14	0·22	0·28	0·35	0·06	0·16
Paddy	0·26	0·35	0·57	1·26	0·63	0·65	0·46
Coconut	0·02	0·03	0·05	0·04	0·22	0·09	0·05
Tea	0·01	0·01	—	0·02	0·36	0·02	0·03
Abandoned	0·08	0·03	—	0·09	0·04	—	—
Totals	0·68	1·06	1·73	2·98	3·29	3·24	1·41

Note : a. Figures in brackets are total numbers of holdings in each area class (including those without areas of some crops).

Although the Cobb-Douglas production function is most commonly used, because it is amenable to mathematical manipulation as mentioned above, it has a number of drawbacks, particularly when dealing with non-experimental cross-sectional data. Its use, then, has been criticized by many researchers (Anderson & Bodha, 1973) because of constant, partial and total elasticity of production and unit elasticity of substitution. Constant partial elasticity refers to the b coefficients associated with each input variable, which would not change at all levels of the input under consideration[1]. Total elasticity of production refers to the sum of individual b coefficients, *i.e.* $\sum_{i=1}^{n} b_i$ of the respective variable. This, too, will be constant at any level of input because the partial coefficients will be constant, as mentioned earlier. However, it is observed that the model can still be operational if it is not used as a test of rather sophisticated hypotheses. This is particularly so when alternative models are hard to find.

Variables and their specification

Large number of factors, either independently or in combination with each other, are believed to affect the production process of rubber trees (Teo, 1976). They can be broadly grouped into three catagories: annual inputs controlled by the smallholder in a particular year, lagged values of the annual inputs applied in the previous years, and completely exogenous variables both current and lagged. The first category (category one) includes labour inputs in tapping rubber trees (L), supplementary inputs such as fertilizers, weeding and fungicides (P), intensity of management (M) and the type of tapping (W). Category two includes factors such as planting density (X), land input of the farm (B), age of trees (G), clone or variety of rubber (V) and the distance of the tappers house from the farm and the distance from the buying centre (D). Category three includes the topography of the farm (T), and soil types (S) and the climatic conditions (C). All these factors can be specified in a mathematical model as :

$$Q = f(L, P, M, W, X, B, G, V, D/T, S, C) \qquad \ldots\ldots\ldots\ldots \quad (3)$$

Therefore, of the 12 factors in equation (3), planting density (X), tapping frequency (L), farm size (B), tapping age of trees (G) and clone or variety of rubber (V) are considered as important variables affecting the output of rubber. The correlation coefficients of the variables X, L and B are given in Table 3, separately for the two types of clone. The other variables in equation (3) are omitted because the necessary data is unavailable.

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[1] The output elasticity n of Xi is divided by :

$$n = \frac{Q}{Q} \times \frac{X_i}{X_i}$$

$$= \frac{Q}{X_r} \times \frac{X_i}{Q}$$

$$= \frac{bQ}{X_i} \times \frac{X_i}{Q}$$

$$n = b$$

TABLE 3 : SIMPLE CORRELATION COEFFICIENTS BETWEEN SELECTED VARIABLES FOR POOLED DATA

	Y	X_1	A_5	A_6	A_7	A_8	A_9	A_{10}	X_2	X_3	C_1	L_1	T_1
Output Y	1·000	·784	–0·094	–0·057	0·047	0·168	0·129	0·108	–0·011	0·159	0·236	–0·435	–0·639
Area X_1		1·000	–0·055	–0·055	0·038	0·101	0·156	–0·057	–0·264	–0·047	0·031	–0·482	–0·701
Age A_5			1·000	–0·158	–0·160	–0·155	–·0163	–0·134	–0·032	–0·004	0·115	0·032	–·0006
A_6				1·000	–0·175	0·169	–0·178	–0·146	–0·049	–0·041	0·001	0·036	0·140
A_7					1·000	–0·172	–0·181	–0·148	0·049	0·048	–0·125	0·171	–0·059
A_8						1·000	–0·175	–0·144	0·055	0·179	–0·033	0·150	–0·132
A_9							1·000	–0·151	0·048	–0·119	–0·001	–0·146	–0·025
A_{10}								1·000	0·095	0·075	0·151	–0·119	0·036
Planting Density X_2									1·000	–0·143	–0·277	0·109	0·082
Labour input X_3										1·000	0·109	–0·002	–0·200
Dummy C_1											1·000	–0·185	–0·162
Dummy L_1												1·000	0·306
Dummy T_1													1·000

C_1 = dummy for clone

L_1 = dummy for family farms

T_1 = dummy for one tapper farms.

Planting density

Since the number of trees in current production was collected with the original data it may be simply defined as :

$$X = \frac{P}{R}$$

where P is the total number of trees in production

R is the mature rubber area.

However it may be observed that there were a considerable number of unproductive trees on some farms, either due to undergrowth or disease. According to the above definition such trees are not taken into account in calculating the planting density. Therefore, it is possible that the per tree productivity might be slightly over-estimated. On the other hand if the total number of trees is used in the above equation then X would be under-estimated. Further, the degree of unspecification will vary according to age of trees and management practices. But no information is available concerning the relationship between management practices and tree condition or mortality, so that the limiting assumption of a uniform tree is implicit in the expression.

Labour inputs

Labour resources at the disposal of the farmers were of two main types, namely family labour and hired labour. These two types are classified in the analysis according to task. The major tasks were tapping, weeding, fertilizer and fungicide applications.

Labour input for tapping is directly related to the tapping system adopted by the farmers. The most common form of tapping system which was used on 268 of the 289 rubber farms sampled, was the S_2/d_2 system, *i.e.* tapping one half of the spiral every other day. It was observed that trees were tapped on this system from 86 days to 243 days a year with a mean of 150 days. Rain interfered with tapping in the area on an average of 76 days each year resulting in complete loss of tapping. Barlow *et al.* (1975) concluded from this, that it appears that some farms must be tapping well in excess of alternate daily.

In this analysis only labour input for tapping is considered ; because of the lack of reliable data for other activities such as weeding, disease control and fertilizer application. Labour input for tapping is computed on the basis of the following formula so as to minimize a possible bias for size of input.

$$W = \frac{D.S.T.}{P} = \text{Tapping Frequency}$$

where W = Number of times a tree is tapped per year

D = Total number of tapping days per year

S = Task size of a tapper per day, assuming that this task size is constant

T = Number of tappers per holding

P = Total number of trees in the holding

Alternatively, for reasons of simplicity, D alone could have been used. In any case this is the situation when the product of S and T will be equal to P. However, the use of D alone over-estimates the number of times each tree is tapped (W) where there is more than one task with only one tapper. Therefore D should be adjusted by the ratio of the actual task tapped on a given tapping day to the total number of tapped trees, that is by S.T/P.

Farm size, measured in acres

Data relating to land was divided in the questionnaire by function ; mature rubber land, immature rubber land, abandoned rubber land, land devoted to other crops and land occupied by housing. In the analysis, mature rubber land only, measured in acres and called mature rubber area, is used. The main advantage in dividing the land in this is to look closely at the productivity of economically active land used in current rubber production. Its disadvantage is that this land is only one part[2] of the whole farm which is being analysed. However, this partial analysis makes it possible to look in detail at the main tasks performed in actual rubber production and maintenance.

Questions of the quality of the mature rubber area are not discussed. Soil type was not available and the assumption of relative homogeneity of classification is implicitly made. This assumption is to some extent justified as the sample is drawn from an area of approximately 5 km^2, and from one ecological zone. Topographical information is available and the classification levels (gentle slope, undulating, steep slope and mixed slopes) are used. Dummy variables for topography were used initially but dropped due to their insignificant effects.

Tapping age of the trees

The present survey uses only cross-sectional data with observations for only one production year. It is, therefore, important to try to account properly for various ages of trees within that one year's observation. Summing across holdings by age allows to explain part of the variation in output by tree age, rather than to compute a function for each holding by age, which would be impossible. The method chosen was to use dummy variables for each age of tree. That is, as data was recorded, a common tree age was noted for each holding, so each has trees of a single age. Average production curve by age of trees can be computed using the coefficients for each variable in conjunction with the coefficients for the other variables with an estimating equation.

Only those farms with trees of the tapping ages[3] from 1 — 10 were chosen. This was because they were of a common age range and there was a similar number of observations for each age group (Table 4). Ages 1 and 2 were rejected because there were too few a number of observations, and ages of 3 and 4 were also eliminated after failing to contribute to the analysis significantly.

Clone or variety of rubber

Two high yielding clones, PB 86 and Tjir 1 were found to have been adopted by the smallholders as their planting material. Although clone PB 86 is believed to be superior in its long term yield potentials yet almost an equal number of Tjir 1 farms were also found in the sample. There are three main reasons for this : the greater resilence of the Tjir 1 clone, high yields, as much as those from PB 86 during the first five years of tapping and, lastly, the fact that Tjir 1 planting material would have been relatively easier to purchase at the time of planting.

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[2] In most cases, see Table 2

[3] Tapping age : Usually it takes about seven years to bring up a tree to tapping.

TABLE 4 : NUMBER OF OBSERVATIONS BY AGE

Tapping Age in years	No. of observations (Farms)
1	4
2	8
3	23
4	20
5	31
6	36
7	37
8	35
9	39
10	27
11	17
12	7
13	1
14	1
15	2
16	1

a Years from commencement of tapping on 6th year.

There are two ways to include the type of clone in this analysis. Firstly, it is possible, if there are enough observations for each variety, to distinguish between those holdings with each type of clone and to explain the output of each variety in terms of other explanatory variables. This involves splitting the data by clonal type and analysing each section separately. A second possibility is to use the clonal type as a dummy variable in the pooled data and to test its significance, as is often done with other classificatory variables such as topography or location. Depending upon which clonal type is left out of the analysis a negative or positive coefficient should be expected if there is an unequal contribution to total output by each variety. Both of these methods are used in this analysis.

Output

Output of only the sheet weight, measured in pounds, was used as the dependant variable because no records were obtained for the amount of scrap collected by individual farmers. Although this anomaly could have been corrected by adding 10 — 15% more to the sheet weight such a constant addition to the total would have introduced a substantial bias to the measure of correlation, particularly when the LSE technique is used. The recorded data was thus left uncorrected.

It is intended that the variation in the total output of sheet rubber will be explained by the variables listed above, namely : planting density (X_1), tapping frequency (X_2); farm size measured in acres (X_3), clone or variety of rubber (C), and age of the trees (A). The following algebraic models may thus be specified in order to estimate the variable parameters by the least squared estimation technique.

Model 1. For pooled data with a dummy for clone.

$$Q_P = bo.X_1^{bl} . X_2^{b2} . X_3^{b3} . A_t^{bt} + \ldots\ldots\ldots A_{t+5}^{bt+5} + C^{k} + U_j \ldots\ldots\ldots\ldots \quad (1)$$

or in log form :

$$Q_P = bo + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_t A_t + \ldots\ldots + b_{t+3} A_{t+5} + KC + U_j \quad (2)$$

Model 2. For split data — two equations for PB 86 and TJ 1 farms separately.

a. $$Q_{PB\ 86} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_tA_t + \ldots\ldots\ldots + b_{t+5}A_{t+5} + U_j\ldots\ldots\ldots \quad (3)$$

b. $$Q_{TJ\ 1} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_tA_t + b_{t+5}A_{t+5} + U_j\ldots\ldots\ldots \quad (4)$$

Model 3. For split data — two equations for those farms tapped by a single tapper, and those tapped by more than one tapper.

a. $Q_T = bo + b_1X_1 + b_2X_2 + b_3X_3 + b_tA_t + \ldots\ldots\ldots + b_{t+5}A_{t+5} + U_j$

where Q_T is the output of those farms operated by a single tapper and Q_{Tn} is the output of those farms operated by more than one tapper.

b. $Q_{Tn} = bo + b_1X_1 + b_2X_2 + b_3X_3 + b_tA_t + \ldots\ldots\ldots + b_{t+5}A_{t+5} + U_j$

Model 4. For split data on the basis of family labour and hired labour, where Q_F is the output of those farms operated by family labour and Q_H is the output of those farms operated by the hired labour inputs.

a. $Q_F = bo + b_1X_1 + b_2X_2 + b_3X_3 + b_tA_t + \ldots\ldots\ldots + b_{t+5}A_{t+5} + U_j$

b. $Q_H = bo + b_1X_1 + b_2X_2 + b_3X_3 + b_tA_t + \ldots\ldots\ldots + b_{t+5}A_{t+5} + U_j$

wherever variable C is used it takes a value of 1 for TJ 1 farms and zero for PB 86 farms.

RESULTS AND DISCUSSION

A summary of estimated coefficients and their statistical parameters is given in Table 5 for all the models listed above. One striking feature of the table is the fact that all the models specified have increasing returns to scale with sums of regression coefficients varying from 1·66 for model 2b to 2·38 for model 2a. This means that if the input levels of all the variables could be doubled, total output would be increased 3·32 times, and 4·76 times for models 2b and 2a, respectively. However, such high rates of returns to scale are rather too high to be acceptable without qualification. One possible reason for this may be the management bias, where management skills and output levels are positively correlated, particularly in the case of relatively larger holdings.

Seventy-five per cent of the variation in output is explained by the independent variables in model 2a, and 74 per cent and 71 per cent for models 2b and 1, respectively ; whereas in the case of models 3a and 3b, the comparable figures are only about 52 per cent and 60 per cent, respectively. The lowest R^2 values are for models 4b and 4a, respectively (Table 5).

TABLE 5 : SUMMARY OF ESTIMATED COEFFICIENTS AND THEIR STATISTICAL PARAMETERS

Model No.	Estimated B Coefficients										Constant term	R^2	F.Ratio
	X_1	X_2	X_3	A_5	A_6	A_7	A_8	A_9	A_{10}	C			
1	*** ·70776 (·09171)	*** ·28994 (·06603)	*** ·91654 (·04195)	·10445 (·09837)	*** ·23521 (·09409)	*** ·25350 (·09370)	*** ·32700 (·31262)	*** ·31262 (·09368)	*** ·35049 (·10337)	*** –0·29295 (·05715)	1·50557	·71532	60·08
2a	*** ·80293 (·12017)	*** ·65252 (·10386)	*** ·93434 (·05055)	·02648 (·12429)	·11829 (·12737)	*** ·32756 (·13747)	·14968 (·13254)	* ·17474 (·12584)	*** ·38515 (·12607)		–0·64036	·75236	44·20858
2b	*** ·49343 (·13311)	** ·22140 (·10658)	*** ·95252 (·06146)	·08726 (·13701)	·11411 (·11813)	–·00475 (·11077)	** ·21504 (·12170)	** ·22453 (·12432)	* –·22544 (·16572)		2·81675	·74593	36·23029
3a	*** ·64379 (·09612)	*** ·42260 (·09677)	*** ·88027 (·06692)	·16510 (·10893)	·19972 (·10109)	·08707 (·10572)	** ·24696 (·11246)	** ·29188 (·10630)	*** ·35531 (·111341)		1·10526	·51766	24·61128
3b	·32694 (·29545)	·39270 (·20277)	*** 1·23218 (·17273)	–0·17746 (·23171)	·47758 (·36835)	** ·44116 (·21644)	·27921 (·21293)	·11870 (·21447)	·37456 (·25840)		2·57936	·60179	8·55631
4a	*** ·55283 (·13181)	*** ·36107 (·14416)	*** ·72172 (·11367)	·10292 (·15193)	·23062 (·14860)	·10636 (·13627)	* ·38389 (·20456)	·02839 (19790)	* ·33734 (·21755)		1·86047	·38978	7·31668
4b	*** ·73671 (·14962)	*** ·49952 (·13547)	*** 1·01108 (·09503)	·06857 (·15398)	·14081 (·13986)	·06347 (·17978)	·15236 (·14552)	* ·33809 (·13728)	·29786 (·14604)		·27896	·50738	14·16088

X_1 = Planting Density X_2 = Tapping frequency X_3 = Farm size in acres A = Age (s) C = Clone.

*** 1 per cent
** 5 per cent
* 10 per cent

It is observed that almost all the estimated coefficients were significantly different from zero at 1 per cent for pooled data. The negative coefficient obtained for the clone dummy variable confirms to the *a priori* expectations that Tjir 1 holdings yield significantly less than PB 86 holdings. Almost all age dummy variables, expecting coefficients for the three variables, planting density, tapping frequency and farm size, are significantly different from zero at 1 per cent for the PB 86 farms equation (model 2a). However, of the age dummies, only A_7 and A_{10} seem to be significant at the 1 per cent level. On the other hand none of the age dummies in Tjir 1 equation are significantly different from zero at the 1 per cent level, whereas the first three coefficients for variables X_1, X_2, X_3 are significantly different from zero at the 1 per cent level. The levels of significants of coefficients for the rest of the models are indicated in the Table 6.

TABLE 6 : COMPUTED GEOMETRIC MEANS

	Geometric means			
	Output	Planting density	Size	Tapping frequency
Pooled data	1,053·74	187·00	1·38	111·1
Tjir 1	837·15	209·00	1·20	110·5
PB 86	1,255·01	172·00	1·51	113·3
One tapper farms	833·14	189·00	1·11	107·7
Multiple tapper farms	2,956·32	177·00	3·68	129·0
Family labour farms	665·14	190·80	0·862	109·9
Hired labour farms	1,339·43	181·27	1·65	110·6

Although the pooled model seems to be more attractive as an analytical tool because of the greater statistical significance of its estimated coefficients, yet it would be unreliable to use it for two reasons. Firstly, almost all the coefficients estimated with split data for the two clones have a considerable variation except for land area. Secondly, the application of Chow's tests show (see Appendix 1) that the two models, *i.e.* for PB 86 and Tjir 1, are significantly different from each other. Hence it is imperative that the data be treated separately rather than pooled for further analysis in the search for an explanation of the variation in output in the two types of farms.

Implication of the Production Function

As discussed above the models specified for PB 86 and Tjir 1 farms explained about 75% and 74% of the variation in output of PB 86 and Tjir 1 farms, respectively. The unexplained variation(s) in the total product(s) can be partly attributed to variations in farms in respect to management, soil differences, climatic and weather conditions and also due to the errors in reporting the original data.

1. Production elasticity of planting density :

The production elasticity of the planting density indicates that if the planting density were increased by one per cent, PB 86 farms could be expected to increase output by about 0·8% (or 80% if the density were doubled) while the output on

Tjir 1 farms would increase by about 49% if the density were doubled. In accordance with the RRISL findings between 140 to 160 trees per ac are recommended for optimal results. The survey indicates that, on an average, there were 172 trees per acre for PB 86 farms and 210 trees per acre for Tjir 1 farms. The density then, for PB 86 farms is notably closer to the RRISL recommendations. However, a more important observation is the high positive production elasticity obtained for both types of trees. This implies that the case for still higher densities needs to be examined both by further experimental work at the RRISL and with respect to the very low opportunity costs of family labour which were found on most of the smaller farms.

2. *Production elasticities for tapping :*

Production elasticity for tapping frequency for PB 86 farms is significantly different from zero at 1 per cent. On the other hand, the coefficient for Tjir 1 farms is only significant at the 5 per cent level. Thus, if the tapping frequency of PB 86 farms were increased by 100% then the output would increase by 65 per cent; whereas, in the case of the Tjir 1 farms, a doubling of the tapping frequency would yield only a 22% increase in the total output. This implies that PB 86 farms are less exploited than Tjir 1 farms as far as their tapping is concerned. In actual fact, the analysis shows that (Table 7) about 3·5 lb more of rubber could be obtained from additional tapping on the average PB 86 farm. In value terms this amount of rubber works out to about Rs. 3.50, *i.e.* the marginal value product, at a price of one rupee per pound of rubber. The marginal cost of a "tapping" works out to about Rs. 2.90 on the assumption that a single tapper could tap about 300 trees on a normal working day[4] at a cost of Rs. 5.00 per day. It is then profitable to increase the number of tappings on PB 86 farms such that the marginal cost of tapping equals that of the marginal value product. In the case of those farms operated by the family labour, the actual cost of tapping 300 trees on a normal tapping day may not cost as much as Rs. 5.00 because of the lower opportunity cost of labour. In that case it is still advantageous to increase the number of tappings, limited by the biological endurance of the trees, so as to maximise the total income rather than the return on labour. This, however, is limited by the interference of rainy days, unless low cost rainguards are made available to the farmers. The marginal value product of a tapping on an average Tjir 1 farm is only Rs. 2.10 and therefore it does not warrant an increase in number of tappings for maximising profit, because of the high marginal cost of tapping.[5]

3. *Production elasticity of farm size :*

Production elasticities of farm size for both PB 86 and Tjir 1 are not significantly different from unity indicating a constant marginal return that is, output could be expected to increase by 100% if the farm size could be doubled. From the social point of view this implies that under smallholder conditions there is no advantage in increasing the existing farm size, because the social cost of supplying such land would be extremely high.

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[4] Three hundred trees/tapper costs Rs. 5·00 day, but on the average PB 86 farm we have 172 trees. Therefore, an additional tapping would cost $\frac{5\cdot 00}{3\cdot 00} \times 172 = \text{Rs. } 2\cdot 8666$

[5] Three hundred trees/tapper/day costs Rs. 5·00, so for 210 trees/tapper/day cost = $\frac{5}{300} \times 210 =$ Rs. 3·49 for Tjir 1 farms.

On the other hand, if the policy objective is to increase smallholders' incomes, then that can be evaluated by estimating the marginal productivities for the variable land area. Table 7 gives the value of the marginal productivities of land for the average PB 86 and Tjir 1 farm at different ages of trees. It is observed that on the average farm there is no considerable difference between the two values for the two types of farm, but the difference between them is that maturing PB 86 trees give greater yields, far more than those of Tjir 1 trees, over time. Since the field data are limited to trees of ten years of tapping age, only the behaviour of trees beyond this limit, cannot be projected further. However, it is very likely that the high marginal value product of around Rs. 1,100.00 (at Rs. 1.00/lb of RSS.) would continue to obtain particularly for PB 86 holdings (Table 8).

TABLE 7 : MARGINAL PRODUCTIVITIES OF PLANTING DENSITY LAND AREA AND TAPPING FREQUENCY

	Marginal Products		
	Planting density	Land area*	Tapping frequency
Pooled data	3·98	699·85	2·75
Tjir 1	1·89	651·79	1·05
PB 86	5·36	749·07	3·54
One tapper farms	3·17	600·45	1·39
More than one tapper	6·35	988·92	12·95
Family labour	1·92	780·00	3·61
Hired labour	5·44	820·5	6·43

* Marginal value products will be the same values if RSS 1 is priced at Rs. 1.00 per pound.

TABLE 8 : PROJECTED YIELD IN THE PER ACRE OF RSS

Clone	Years in tapping					
	5	6	7	8	9	10
PB 86	772	846	1,041	869	891	1,116
Tjir 1	710	730	652	808	815	335

4. *Tapping age of trees and elasticity of production*

The results have been presented with the assumption that there was no difference in age among the mature trees of a given farm. This assumption seems to be plausible for those farms below two acres in size. But it is doubtful whether each of the larger farms had uniform age stands. However, about 86 per cent of the farms were below two acres in size. Further, since almost all of those holdings have been replanted under the subsidy scheme it was most probable that the farmers had planted their whole area at once, rather than in stages. Tapping was assumed to commence at six years after planting.

Dummy variables have been employed to represent age in this study. The effects on yield by trees of ages 3 and 4 have been incorporated in the constant terms of the equation. The effect of other ages, *i.e.* ages from 5 to 10, will appear as deviations of the age intercept from its base, assuming that the age of trees is not related to other factors which may include farm efficiency.

Of the six dummy variables employed, *i.e.* A_5 to A_{10}, only A_7 and A_{10} are significantly different from zero at the 1 per cent level of confidence, while A_9 is significant at the 10 per cent level for PB 86 farms. Dummies A_8 and A_9 of Tjir 1 farms are significantly different from zero at the 5% level and A_{10} at the 10% level of confidence.

Using the coefficients estimated and the values of geometric means of each of the variables, the predicted yields per acre for different ages for each clone are calculated and presented in Table 9 (a).

TABLE 9 (a) : MEAN OF PLANTING DENSITY AND TAPPING FREQUENCY ACCORDING TO TAPPING AGE FOR CLONE PB 86

Tapping age (Years)	Planting density		Tapping frequency		Number of observations
	Mean	Coefficient of variation	Mean	Coefficient of variation	
3	167 (45)	27	138 (29)	21	16
4	177 (34)	19	139 (29)	21	5
5	174 (50)	29	133 (33)	25	21
6	173 (55)	32	136 (37)	27	20
7	172 (49)	28	146 (40)	27	17
8	188 (41)	22	153 (32)	21	18
9	182 (30)	16	146 (22)	15	22
10	187 (40)	21	142 (21)	15	20
TOTAL	178 (43)	24	142 (31)	22	139
	F Value 0·514		F Value 0·832		

According to Table 9 the yield of PB 86 first rises sharply to reach a peak of about 1,050 lb of RSS after six years of tapping. Thereafter, the yield declines to about 890 lb at about the ninth year, but rises again after this decline. The yield of Tjir 1 rises until about the sixth year of tapping and then drops to about 650 lb. in the seventh year before reaching a peak yield in the ninth year of tapping. Thereafter the yield drops sharply to about 533 lb of rubber.

The changes in yield between six and ten years may be due to changes in the tapping panel, or to tapping on the renewed bark, or even to a change in the tapping system. However, the available data do not warrant such conclusions. Other alternatives are possible.

Declining yields for the comparatively older trees could possibly be due to the accumulated effects of plant mortality, incidence of Brown Bast disease, or a reduction in tapping frequency. However, Table 9 (B) reveals that in this sample, the mean of planting density and tapping frequency for both clones does not differ significantly for different ages (F values were not significant). Alternatively, it might be that the younger stands have been managed better than those planted earlier because of the time lag in the diffusion of agronomic information through the extension service. Consequently, it is possible that for every farm or group of farms for every year or group of years a separate yield curve can be pivoted with respect to the effects of age. The younger trees have an higher yield curve than the older ones. Thus, instead of a single production function, there exists a family of production functions depicting various efficiency levels.

TABLE 9(B) : MEAN OF PLANTING DENSITY AND TAPPING FREQUENCY ACCORDING TO TAPPING AGE FOR CLONE TJIR 1

Tapping age (years)	Planting density		Tapping frequency		Number of observations
	Mean	Coefficient of variables	Mean	Coefficient of variables	
3	279 (96)	34	152 (31)	20	7
4	246 (82)	33	137 (23)	17	15
5	222 (50)	26	146 (17)	11	10
6	211 (41)	19	141 (25)	18	16
7	232 (68)	29	134 (22)	16	21
8	212 (40)	19	149 (29)	19	17
9	188 (58)	31	133 (28)	21	17
10	190 (43)	23	148 (23)	16	7
TOTAL	218 (66)	30	141 (25)	18	110
		F Value 2·458		F Value 1·274	

Conclusions and some policy implications

This study not only identifies some of the more important factors of production in the smallholders' sector of Sri Lanka's rubber industry, but also postulates a mathematical model embodying those factors of production. Despite the inherent drawback in using a single year's production data and specifying here only a Cobb-Douglas model, this study partly fulfills the need for econometric studies dealing with smallholder rubber cultivation in Sri Lanka.

Of the various factors believed to affect the output of rubber only four, namely ; planting density, farm size, tapping frequency, and tapping age of the trees, have been retained in the final estimation equations. Zero-one dummy variables are used to represent the different ages of rubber stands. Due to limitations in the data, farms between tapping ages of 3 to 10 years only have been considered. Two separate functions have been estimated for the two clones, PB 86 and Tjir 1. Specification of models on the basis of single tapper and multiple tappers and family labour and hired labour do not improve the overall fit of the equation (Table 5) and therefore are not dealt with in greater detail in the analysis.

In the specification of variables, various possible sources of error have been encountered. There were no data on the total output of dry rubber thus only the weight of RSS was considered. No adjustment was included for the differences between the total number of mature rubber trees and the number of trees currently in production. Labour input for tapping was specified as the frequency of tapping per year and included in the regression. This might lead to the under-estimation of this variable because smallholdings often have a larger number of trees than on the average farm. Quality differences in labour such as age, sex, educational level or experience could not be considered due to lack of data. Management bias could not be overcome because information relating to management ability over a period of years was not available.

Within the framework of the multiple regression analysis the production coefficients of the estimated average functions are statistically significant, except for some age dummies, for both clones, thus the R^2 values are high and the F ratios are significant at conventional levels of significance.

The production elasticity of tapping frequency for PB 86 farms indicates decreasing but high marginal returns, and that for Tjir 1 farms indicates diminishing returns. The production elasticity for planting density indicates decreasing marginal returns for both rubber clones. On the other hand, production elasticity for farm size for both clones exhibited constant returns to scale. When the data was split on the basis of the number of tappers (Table 5, models 3a and 3b) the production elasticity for farm size exhibits increasing returns to scale. Similarly when the data is split on the basis of family labour and hired labour, increasing returns to scale for farm size are observed. One reason for this may be that the management bias is positively correlated with the bigger farms. In other words bigger farms are better managed.

The estimated coefficients are used to predict the output for each clone. For both clones, the results strongly suggest that for every farm or group of farms and for every year or group of years there is a separate yield curve. Thus, instead of a single production function, there exists a family of functions showing various efficiency levels.

Since the farms in the sample also had other crops such as paddy, tea and coconut, besides rubber, there was a possibility that the presence of these non-rubber crops affected the measured technical efficiency levels. Without information on soil differences, management and inputs to non-rubber crops, it was not possible to conclude if the differences in technical efficiency were due to those factors or due to errors of measurement in the variables used in the production function analysis.

Because of the inherent weaknesses in the whole analysis, it is difficult to make concrete policy proposals. Nevertheless, it is hoped that the following broad remarks may be of some use not only to the policy maker but also to future researchers in this area.

- In view of the higher marginal returns per tree per ac for PB 86, the case for still higher densities for this clone should not be rejected.
- Slightly higher marginal returns to land for PB 86 farms were observed during the first nine years of tapping. It is possible that this gap could be further widened after the tenth year of tapping. This implies that PB 86 is better suited to smallholdings as a planting material.
- Tapping labour inputs on PB 86 farms appear to be under utilised. This may be attributed to the lower number of tapping days and possibly to the conservative approach to the exploitation of rubber trees as reported by Barlow (1970).

- It seems that there is no "economic" justification for increasing the existing average land area in view of the constant returns to scale as far as the land area is concerned. However, because of the high marginal productivities observed for the land variable, land area may still be increased if the policy objective is to increase the smallholders' incomes.

- Teo (1976) working with the same data and postulating a frontier production function, estimated by a linear programming package, has concluded that the best Tjir 1 farm could produce 69% higher output of rubber than the average farm while the worst farm could produce only 43% of the output of the average farm. For PB 86 farms the best farm could produce 62% higher output than an average farm while the worst farm was producing 70% less output than an average farm.

APPENDIX 1

CHOW'S TEST

Supposing the regression equations obtained for PB 86 and Tjir 1 clones are as follows :

PB 86 $Qp = bq + b_{1p} X_1 + b_{2p} X_2 + b_{3p} X_3 + a_{fp} d_{fp} + U_p$

Tjir 1 $OP = bo_x + b_{1t} X_1 + b_{2t} X_2 + b_{3t} X_3 + a_{ft} d_{ft} + U_t$

it may be necessary to find out,

(a) Do the efficiency parameters differ between clones ?

(b) Does the coefficient for each factor input differ between clones ?

(c) Does the coefficient of the age effect differ or is the different not significant, so that it may be attributed to change ? In which case we may conclude that output from these two clones does not differ significantly in this sample of smallholders.

Chow's test (1960) could be applied to answer the above questions by computing an F ratio as below :

$$F^* = \frac{R_p - (R_a + R_b) / K}{(R_a + R_b) / (N_a + N_b - 2K)}$$

where

R_p is the Error sum Squares (E.S.S.) of the pooled equation.

R_a is the E.S.S. of PB 86 equation.

R_b is the E.S.S. of Tjir 1 equation.

K is the total number of yield variables, including the intercept.

N_a is the number of observations for PB 86.

N_b is the number of observations for Tjir 1.

The null hypothesis in $b_{2p} = b_{2t}$ and a_{ft} that is, there is no difference in the coefficients obtained from two samples.

We then compare the observed F* ratio with the tabulated value of $F_{0 \cdot 05}$ with $V_1 = K$ and $V_2 = (N_a + N_b - 2K)$ degrees of freedom, which is the expected value for F if the null hypothesis were true.

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