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THE ECONOMICS OF RUBBER REPLANTING CYCLES: AN INTERPRETIVE ESSAY

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" Crow's feathers at home are worth more than the feathers of the peacock in the forest." — *Sinhalese proverb*

INTRODUCTION

The timeless Sri Lanka proverb that heads this article has its parallel in all languages. It can be paraphrased in less poetic terms for a farmer by noting that few farmers will be equally happy with the gift of the hundred rupees today as against the guarantee of the same amount in one year's time or ten years hence. The money would be most welcome now, if only to be deposited in a bank and withdrawn with the accumulated interest at some future date. Conversely, the guarantee of a hundred rupees in ten years ' time will have a discounted present value.

A number of economic studies of rubber production in Malaysia and Sri Lanka have emphasised the importance of the timing of costs and returns. Consider for example Barlow & Ng (1966), Lim (1972), Lim, Ho & Yoon (1973), Ng (1972), and Lim & Chong (1974) for Malaysia ; or Barlow (1970) and Jayasuriya (1973) for Sri Lanka. In many instances in these studies the ranking of alternative cultural practices was reversed when time in the form of a discount rate was introduced.[1] Such studies have shown that economic analysis of agricultural research has an important role to play in ensuring that research results are translated into action on farms and plantations (Anderson, 1975).[2] Agricultural research is primarily a service to the country rather than specifically to farmers. While farmers are particularly interested to know whether research results will enhance the returns from their farms, research stations should be interested in the care and good management of the ' national estate'. At either level the questions raised are rarely trivial. This is particularly true in perennial crop agriculture where extra care has to be taken in economic analysis because investment, production and returns take place over a long period of time ; the element of time cannot be ignored (*in a different context see* Etherington, 1973). While underplaying many of the complexities of rubber production, this paper examines the importance of the time dimension by setting out the economic principles of optimal replacement and by applying them to the commercial production of latex and wood from *Hevea brasiliensis*.

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[1] For example, Barlow (1970, p. 5) shows that while normal tapping on smallholders is " better " than intensive tapping if net returns are simply added up, the reverse is true at a discount rate of 6 per cent. Similarly Lim *et al.* (1973, p. 3) show how a precious clone after 20 years outyields 30 years of RRIM 600 when yields are discounted at 10 per cent but such is not the case where straight addition of yields is employed.

[2] An increasing number of agricultural research institutes are employing agricultural economists or are having some of their personnel given additional training in agricultural economics It is an interesting historic note to add that the Australian National University was prompted to initiate a training programme for such agricultural research personnel by a request from Sri Lanka. The A.N.U.'s Masters Degree in Agricultural Development Economics has trained some 50 graduates from S.E. Asia, the Pacific and Africa.

The paper starts with an examination of the rules for the optimal sequencing of rubber trees without time preference. We then consider time preference and the effects of certain forms of technological change on replanting decisions. Lessons for research priorities are derived from the exercise. The paper uses one particular set of data because it represents a recent attempt to grapple with the problem in Sri Lanka (Abeyesekera, 1974). Additional or alternative sets of data could have been used (Jayasuriya, 1973) but their use would cloud the didactic intent of this interpretive essay.

Replacement without time preference

In his recent article, Abeyesekera aimed to stimulate inquiry and discussion on 'rubber replanting cycles' and to provide a simple yet rational basis of evaluating three straightforward alternative(s) 'rubber replanting strategies.'[3] The three alternative which a rubber planter might consider were given as :—

Case X — a 33 year replanting cycle with intensified tapping over the years 27 to 33.[4]

Case Y — a 30 year cycle with Ethrel stimulation during years 24 to 30, and finally,

Case Z — a 25 year cycle with Ethrel stimulation during years 19 to 25.

The basis for judgement as to which of the alternatives was best was taken as the net profit over a period of 100 years and the ranking was in favour of the shortest exploitation cycle. In other words, Case Z had a higher profit than Case Y which, in turn, was more profitable than Case X. Unfortunately the ranking of arbitrarily chosen cycle lengths only told us which of these specific selections was better than the others, it did not tell us which was the best of all possible selections. That is, Abeysekera did not give the planter any decision rule by which to make his selection of an appropriate cycle length. By providing such a decision rule the planter will be able to apply it to his particular circumstances and come to his own answers.

From the substantial literature on optimal replacement theory[5] Abeyesekera considers only the case of replacement without positive time preference. This means that income earned in any future time period is as highly regarded by the decision maker as income earned in the current period. Given this assumption and the set of alternative profit streams over time the profit maximiser will try to maximise his average profits over the specified period (100 years). This is equivalent to maximising the average profit *per year* for 100 years — or for any other period. Thus, by expressing profits on a per year basis the length of the time period can be ignored.[6] In actuarial terms the maximisation of profits per unit of time (one year) means seeking that replanting sequence that will generate the highest possible annuity (but with a zero rate of discount). The mathematical expression for this is given by equation (1) :

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[3] For the sake of completeness Abeyesekera's tables are reproduced in full in the Appendix.

[4] In all Cases the years date from the year of planting which is taken as year 1.

[5] See, for example, Baumol (1965), Chisholm (1966), Ng (1972), Perrin (1972) and Jayasuriya (1973). The theory and the mathematical derivation of the rules are most clearly presented in the last two references.

[6] This avoids the awkwardness of the partial cycles evident in Abeyesekera's analysis.

$$(1) \qquad R(T) = \frac{1}{T}\sum_{0}^{T} R(t)$$

where R is the net return in any year t, including the current year under consideration T, numbering from the year of planting (t = 0).

The date (T) at which the profit per unit of time will be greatest will be when the average and marginal profits are equal.[7] On the left hand side of (1) is the " marginal " profit, that is, the (annual) profit earned in the year under consideration. On the right hand side is the cumulative profit to date divided by the number of years since the rubber was planted (*i.e.* the annual average profit). Equation (1) requires the planter to accumulate an account of his annual profits and as long as the average is increasing (which will be when each successive year's profit is higher than the previous average) he retains his trees but cuts them down when the annual profit goes below the long run average.

Fig 1(a) illustrates the fundamentals of the decision rule ; the annual profits are shown as a continuous curve with the annuities rising to meet that curve and then falling away. The intersection of the curves gives the maximum annuity (vertical axis) and the optimal date to replant.

For practical decisions it may be easier to rewrite equation (1) in the form of inequalities because it is unlikely that the equality condition of (1) will be met. It is more likely that two successive annual profits will straddle the annuity, as in the following expression.

$$(2) \qquad R(T) > \frac{1}{T}\sum_{0}^{T} R(t) > R(T+1)$$

where the notation is the same as in (1).

Table 1 presents the data from Abeyesekera's article in a form to which the rule in (2) can be applied. The data presented only refer to the *Basic* yields without intensification or stimulation in the later years. For calculating the profits, a constant price of Rs. 1·50 per lb of latex is assumed. It is seen that average annual profits are maximised on a 26 year cycle when the annuity is Rs. 594·23 whereas if the cycle were continued to year 33 the annuity would only be Rs. 491 per annum.

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[7] Consider for the moment that the stream of profits from rubber is continuous. Since we seek to maximise profits per unit of time, then the objective function is :

$$R^*(T) = \int_O^T \frac{R(t)\,dt}{T}$$

where R (t) = profits in each year t and T is the terminal date.
R* (T) = profit per unit of time.

Then from the first order conditions for maximisation

$$\frac{dR^*}{dT} = \frac{T.\,R(T) - \int_O^T R(t)\,dt}{T^2} = 0$$

or $$R(T) = \frac{1}{T}\int_O^T (t)\,dt$$

the discrete analogue is given at equation (1) in the text.

In other words the loss in revenue from adopting a 33 rather than a 26 year cycle would be in excess of Rs. 100 per ac per annum.[8] Note the manner in which the decision rule (2) is applied :

$$600\,(26) > \frac{15{,}450}{26} > 500\,(27)$$

where the figures in brackets are T and T + 1 and the middle term $\frac{15{,}450}{26}$ = annuity of 594·23.

TABLE 1 : YIELDS PER ACRE AND ACCUMULATED AND AVERAGE PROFITS (YEARS 16 TO 33)

Year[a] (1)	Basic Yield[b] lb (2)	Basic Costs[c] Rs./ac (3)	Annual Profit[d] Rs. (4)	Accumulated Profits Rs. (5)	Average Profit Rs. (6) (5) ÷ (1)
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16	1,800	1,530	1,170	5,240	
17	1,900	1,615	1,235	6,475	
18	2,000	1,500	1,500	7,975	
19	1,900	1,615	1,235	9,210	
20	1,800	1.530	1,170	10,380	519·00
21	1,700	1,445	1,105	11,485	546·90
22	1,600	1,360	1,040	12,525	569·32
23	1,500	1,275	975	13,500	586·96
24	1,400	1,400	700	14,200	591·67
25	1,300	1,300	650	14,850	594·00
26	1,200	1,200	600	15,450	594·23
27	1,000	1,000	500	15,950	590·74
28	800	960	240	16,190	578·21
29	600	720	180	16,370	564·48
30	500	600	150	16,520	550·67
31	400	720	- 120	16,400	529·03
32	300	540	- 90	16,310	509·69
33	300	540	- 90	16,220	491·52

a For the date on the earlier years see the original article

b Yields without intensification or stimulation.

c Average costs per pound vary from Rs. 1·80 per lb for yields up to 500 lb to 1·20, 1·00, 0·85 and 0·75 Rs. per lb for yields between successive increments of 500 lb (*e.g.* Rs. 1·00/lb for yields in the range 1,000 — 1,500 lb). During the immature years (1 to 5) establishment costs are taken as the fixed costs of Rs. 360 per year.

d (2) x Price (Rs. 1·50/lb) — (3).

Source : Adapted from data presented in ABEYESEKERA (1974).

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[8] If no replacement were being considered then the objective function would be total profits rather, than profits per unit of time. In this case the trees would be cut down at the end of year 30 before annual profits become negative and bring down the total profits (Rs. 16,520).

A planter would clearly have to do some interpolating from his trend in yields and take into account current rubber prices in order to judge the right hand term and proceed with cutting at the end of year 26.

Table 2 presents the annuities for the Basic case and for the three cases (X, Y and Z) considered by Abeyesekera. In no case is the proposed cropping cycle length (of 33, 20 and 25 years) the optimal one and the losses from adopting these arbitrary cycles can be considerable as the ranking of the alternatives in Table 3 shows. In particular it should be noted that the basic technology with an optimal replanting cycle (of 26 years) has a higher value than the improved technology X with the arbitrary cycle length of 33 years. In this case the potential loss is 9 per cent.

TABLE 2 : AVERAGE ANNUAL PROFITS FOR THREE RUBBER REPLACEMENT SEQUENCES

Year	Average Annual Profits[a]		
	Case X (Rs.)	Case Y (Rs.)	Case Z (Rs.)
•			
•			
•			
23	586·96	586·96	698·59
24	591·67	611·79	718·77
25	594·00	631·26	733·96*
26	594·23	645·98	744·73
27	598·15	646·13	741·22
28	596·43	641·63	
29	593·10	627·57	
30	581·33	613·15*	
31	569·35		
32	557·19		
33	545·76*		

[a] The average annual profits are annuities calculated with no interest.

The underlined figures are the maximum annuity values. The year in which these occur is the optimal length of the cycle.

* Annuity values at replacement dates arbitrarily chosen in the article from which the data came (ABEYESEKERA, 1974).

TABLE 3 : RANKING OF ALTERNATIVE CYCLES

Technology	Decision Rule	Cycle length (yr)	Annuity Value (Rs.)	Rank	% loss[a]
Basic	Given	33	492	8	21
	Optimal	26	594	6	
X	Given	33	546	7	10
	Optimal	27	598	5	
Y	Given	30	613	4	5
	Optimal	27	646	3	
Z	Given	25	734	2	1
	Optimal	26	745	1	

[a] The difference between the values at the given and the optimal dates expressed as a percentage of the value on the given date.

An alternative way of looking at the logic of this decision rule is that there is always an opportunity cost of maintaining production from the existing stands of trees : that opportunity cost is the income which the land could be earning if replanting took place. As soon as the potential earnings exceed the current earnings then it would pay to replant.

Generating annuities

The above discussion may sound too abstract and may not satisfy those who argue that longer cycles are beneficial because they mean that a greater proportion of a given estate is mature at any given time and, hence, there is not an undue burden of immature trees. Such reasoning usually relates to the possibility of a period of years during which there will be too few mature acres to maintain a minimal cash flow. The answer to this problem is not to alter the replanting cycle *per se* but to continue the practice of replanting 3 per cent of the holding per year if one is operating on a 33 year cycle or 4 per cent per year if it is a 25 year cycle. It should be recognised that this normal estate management practice is generating precisely the annuities discussed in terms of the optimal rule. Thus, although the analysis has been done with an acre of rubber as a useful and conventional unit of account, there is no reason why the arguments could not have been advanced with single trees as the units of account. It now becomes more obvious that one can stagger one's planting (replanting) at sufficiently short intervals to generate a continuous annuity, although the *optimal decision rule remains the same* irrespective of whether one is dealing with an acre, a hundred acres or a single tree. In effect one is moving from the situation depicted in Fig. 1 (a) where a total estate is planted at one time and where the perpetual annuity might be viewed as a figment of an accountant's imagination, to Fig. 1 (b) where the staggering of the replanting, but with the same cycle length, has generated an actual *de facto* annuity.

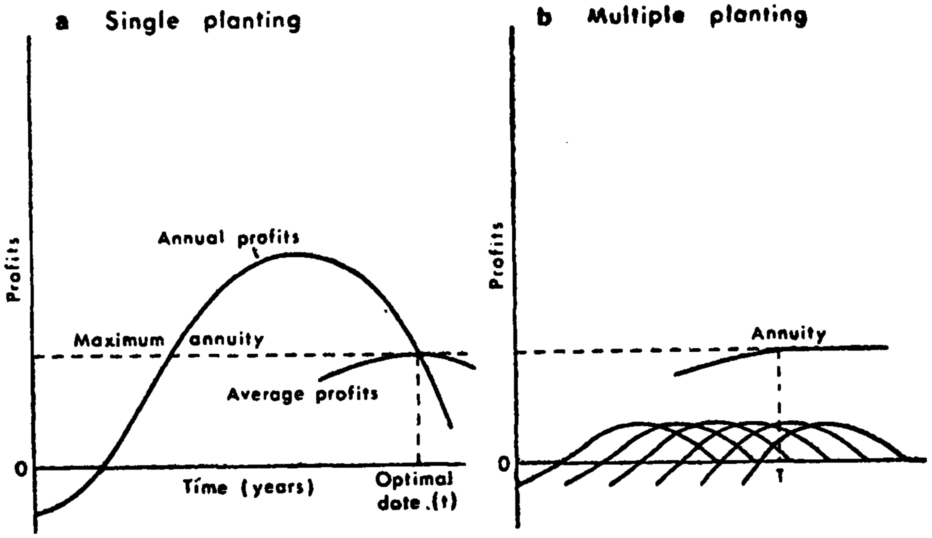

Fig. 1 Creating annuities by phased replanting

Time preference

The question now arises as to what happens to the optimal replacement decision rule where there is positive time preference, that is to say, where there is a positive rate of interest. Following on from this, what effect does the introduction of positive interest rates have on the annuity values and the optimal replanting dates ?

The objective function is now to maximise the present value of a series of production cycles continuing through time. Through appropriate mathematical manipulation this complex series collapses to maximising the following expression :

$$(3) \qquad \hat{R}\,(T) = \frac{(1+r)^{T}}{(1+r)^{T} - 1} \sum_{O}^{T} R\,(t)\,(1+r)^{-t}$$

where the notation is as before but where $\hat{R}$ is the present value of the profit of an infinite sequence of production cycles of the form R and where r is the annual rate of interest. The conditions for this to be a maximum is an equation that parallels equation (1)

$$(4) \qquad R\,(T) = \frac{r\,(1+r)^{T}}{(1+r)^{T} - 1} \left[\sum_{O}^{T} R\,(t)\,(1+r)^{-t}\right]$$

The left hand side of (4) is again simply the annual profit in the year under consideration. The right hand side is made up of a form of annuity expression together with the present value of the profits of one cycle up to date T. Since the only difference between equations (3) and (4) is in the extra r in the numerator of the annuity expression one can easily move from considering the perpetual annuity (4) to the present value of the perpetual sequence of replacements (3). The expression outside the square brackets in (4) tends to the value $\frac{1}{T}$ as the rate of interest tends towards zero so that the whole equation tends towards (1) as r tends to zero. Since the term outside the brackets in (4) increases while the term inside the bracket falls as r increases, it may not be immediately obvious as to the net effect of the change in the interest rate. In fact the discount term in the brackets has a much greater effect so that not only is the present value of the income stream reduced by also the annuity.[9] The reduced annuity will thus ' slide ' further into the future, extending the length of the cycle, as the interest rate is increased. This is illustrated in Fig. 2.

Table 4 gives the relevant annuities for the four technologies using two different interest rates (10% and 15%). The highest amortised values (annuities) are underlined. Table 5 summarises the results pertaining to the optimal date and interest rates. Here the extension of the cycle length with the increase in interest rate is clearly seen.

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[9] Although it can be proved mathematically an example will best illustrate this point. The discount factor giving the present value of Rs. 1 to be earned in ten years' time shifts from 0·386 at 10 per cent to 0·247 at 15 per cent, a decrease of 36 percent while the increase in the annuity is :

$$\frac{\cdot 15\,(1\cdot 15)^{10}}{(1\cdot 15) - 1} = \cdot 20 > \cdot 16 = \frac{\cdot 10\,(1\cdot 0)}{(1\cdot 1)^{10} - 1}$$

an increase of only 22 per cent.

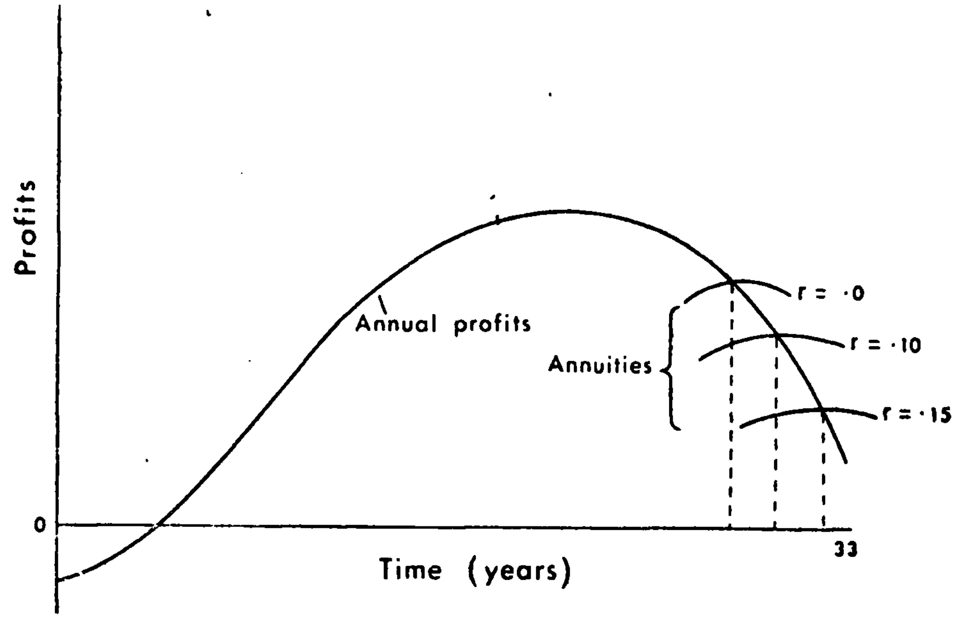

Fig. 2. Schematic representation of net revenue and annuities for rubber at three interest rates.

Tables 4 and 5 indicate the degree of sensitivity of the optimal replanting date to changes in the interest rate. In only one case is the maximum possible cycle length optimal. Concentration on the optimal date however diverts attention from another important feature of the annuities in Table 4, this is relatively ' flat ' region of the annuity values around the maximum. In other words, as the interest rate is raised not only are annuity values lowered but the curve is flattened as is illustrated in Fig. 2. This implies that the loss from choosing an arbitrary, suboptimal, date a couple of years on either side of the optimal has little effect on the long run average profits.

TABLE 4 : AMORTISED PROFITS IN RUPEES FOR FOUR YIELD SEQUENCES WITH INTEREST RATES OF 10 AND 15 PERCENT

Year	Technology							
	Basic		X		Y		Z	
	10%	15%	10%	15%	10%	15%	10%	15%
⋮								
25	236·71	92·68	236·71	92·68	246·68	97·41	286·24	119·72
26	240·03	94·75	240·03	94·75	258·72	101·14	292·91	123·36
27	242·18	96·17	243·83	96·88	256·99	103·07	295·86	125·22
28	242·16	96·61	246·11	98·26	258·95	104·35	297·53	126·43
29	241·75	96·84	247·82	99·33	258·78	104·69	297·10	126·71
30	241·19	96·96	247·77	99·65	258·39	104·90	296·48	126·87
31	289·20	96·52	247·57	99·87	257·83	105·00	295·71	126·93
32	237·57	96·20	247·23	100·01	255·97	104·62	293·73	126·53
33	236·09	95·92	246·93	100·13	254·29	104·28	291·95	126·19

TABLE 5 : OPTIMAL DATES OF REPLANTING BY TECHNOLOGY AND INTEREST RATES

Technology	Interest Rate (%)		
	0	10	15
Basic	26	27	30
X	27	29	33
Y	27	28	31
Z	26	28	31

From an examination of equation (4) and Fig. 2 one can gather additional important clues as to the main reason for the sensitivity, or lack of it, in optimal replacement dates — and the importance of those dates. If yields in the later years fall very suddenly then the annuity will be relatively 'peaked' but changes in the discount rate will move the annuity function over a very small range of dates as illustrated in Fig. 3(a). If, on the other hand, yields are stretched into the future and decline gradually then the annuity function will be similarly flat about the optimal date. Thus, in these circumstances, although the *optimal* date is more sensitive to interest rate changes, the cost of selecting the wrong date will be less because of the flatness of this annuity function (Fig. 3 (b)).

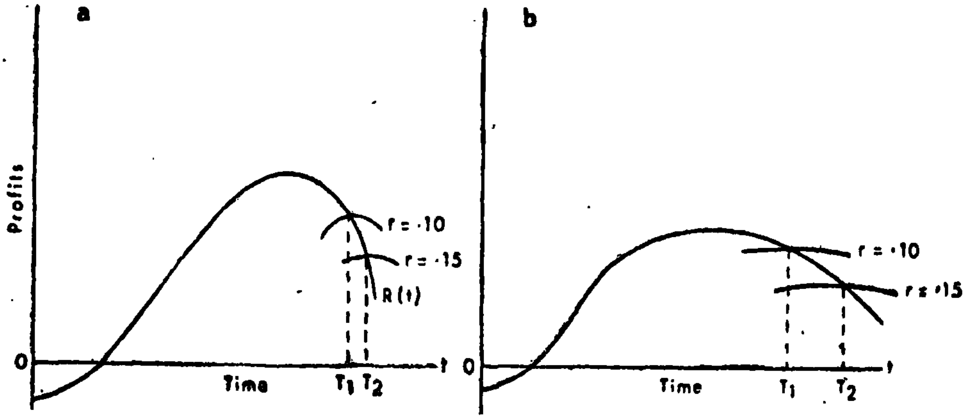

Fig. 3 (a) Fig. 3 (b)

Effects of varying yield patterns and Prices on optimal replacement dates

The economic analysis thus far has made the highly unrealistic assumption that the rubber price (Rs. 1·50/lb) is constant. Interestingly enough this is not a serious omission as far as optimal dates are concerned because the two sides of equation (4) move together with increases or falls in product or factor prices — which are of course reflected in the profit function. This proposition is illustrated in Fig. 3 (c) where R (t) at the higher price (P_2) and the associated annuity curve move up together with very little impact on the optimal date (T)[10].

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[10] This is comparing the effect on the optimal date of two static situations and the question arises as to what happens with fluctuating prices and yields. The authors are currently working on a simulation model of the problem using Malaysian data, in which prices and yields do vary in a stochastic manner over time. The results (Etherington & Jayasuriya, 1976) complement and expand rather than change comparative static conclusions.

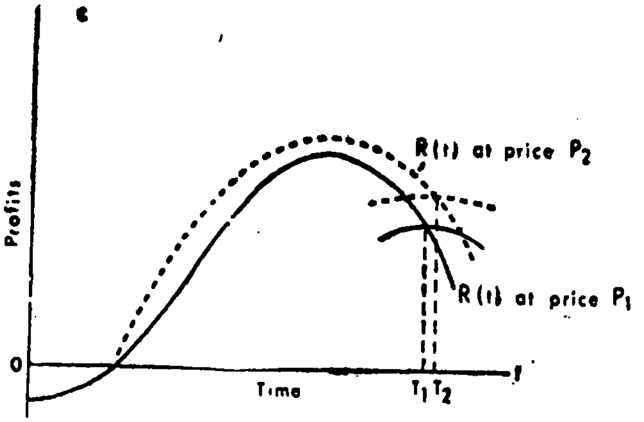

Fig. 3 (c)

From a research institute and extension viewpoint these results are most satisfactory since the replanting advice to planters can be fairly specific for a particular clone being exploited under a particular tapping system. Variations in individual planters time preferences, as reflected in their rates of discount, or fluctuations in prices do not cause similar fluctuations in the optimal replanting dates. Furthermore, the loss associated with making a wrong decision *i.e.* a couple of years either side of the optimal solution is likely to be very low. Thus planters can be advised to adopt a particular replanting cycle in the form of a range of years (say 24 to 28 years) for the purpose of forward planning but that the actual date chosen within this range will depend on other management considerations, for example the availability of labour for replanting and the temporary fluctuation in the rubber price.

Technological change

It is generally acknowledged that the rapid rate of technological change in the natural rubber industry has enabled the industry to not merely survive but even thrive in the face of strong competition from synthetic substitutes. It is highly unlikely that changes in technology will suddenly cease : yields that have risen from some 500 lb/ac before World War II five fold to 2,500 lb/ac on new clones, have a long way to go to their theoretical limit of around 9,000 lb/ac. (Sekhar, 1973 ; 1974). Technological change must thus be introduced explicitly into the replacement problem.

That four different yield curves have been considered in the present analysis implies a concern with technological change and a useful distinction can be drawn from these examples between 'embodied' and 'disembodied' technical change.[11] Disembodied technical change is a change that can be adopted at any stage in the production process. With rubber this is likely to be in the form of alternative management practices on an existing stand of trees. Intensification of tapping and Ethrel stimulation would fall under this category since they represent changes in technology that can be adopted in 'mid stream' and do not necessarily have to await the planting of a new clone. For these cases both the annual profit function (R (t)) and the annuity curves are raised. Thus one moves from considering the replacement problem on the Basic function to either X, Y, or Z (depending on the technology adopted) and forget the original practice. Since the effect is not only to raise the curves but change their shapes (*e.g.* possibly making the annual profit

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[11] A certain poetic licence has been taken with the definitions of these forms of technical change as normally used in economic literature, see for example Allen, 1967, chapter 13.

function more, or less, steep in the final years) the direction of change in the optimal date cannot be predicted. For example, the move from Basic to Case X extends the cycle, the move from X to technology Y retracts the cycle and moving from Y to Z makes no difference to the cycle length. Our suspicion is that although such mid-stream changes have a welcome influence on profitability because they are usually applied to mature trees the effects on the optimal replanting date can be ignored for all practical purposes.

Embodied technical change is a typical characteristic of the rubber industry. The national (or private) cost of not replanting is more evident when the replacement plant is of a new ' high yielding variety '. This is to say that the high yielding characteristics of the clone are 'inbuilt' or embodied in the genetics of the specific clone and cannot be transfered to existing-stands of trees. In such cases it is the estimate of the maximum annuity from the new clone which must be compared to the annual returns from the outgoing trees. For example, assume that technology Z is embodied (*i.e.* forget that it is due to stimulation and assume it to be genetically determined) and that this ' new clone ' is to replace the Basic trees. In this particular case the appropriate replanting date (at 10 per cent) would not be changed because the annuity value for the Basic technique (Rs. 242) and for Z (Rs. 297) both fall into the annual profit range of the basic technology between years 27 and 28. Numerically we have

$$500^{BR}_{27} > 297^{Z} > 242^{B} > 240^{BR}_{28} \tag{5}$$

where the superscript B and Z refer to the technologies generating the respective maximum annuities and BR refers to the annual profit of the Basic technology in the year indicated by the subscript.

The reason for the insensitivity to this form of technological change in this particular case is due to the fact that the new technology only effects profits late in the life cycle of the rubber and hence has a low present value. That this is the reason can be ascertained by re-examining this case with a zero discount rate. Here we have

$$975^{BR}_{23} > 745^{Z} > 600^{BR}_{26} > 594^{B} > 500^{BR}_{27} \tag{6}$$

This expression says that if the new technology (Z) is ' built in ' and cannot be used by the basic technology then, if there is no time preference, B should be replaced by Z at the end of year 23.

Such analysis highlights the economic importance of the time phasing of technological change. Where the technology reduces the immature period or raises yields in the early years, the impact on optimal replanting dates and annuity values — and hence profitability — is very marked indeed.

This is a very important point. It is sometimes argued by scientists concerned with breeding perennial crops that longevity is important ' for economic reasons '. This would only be true if time did not count or if longevity imposes no penalty in terms of the period of immaturity or higher early yields. That some of the smallholders in Sri Lanka understand this is seem in their choice of Tjir 1, ' owing to its greater resilience, its shorter period of immaturity and the fact that its early yields, over the first 5 – 6 years of tapping, were as high as those of most budgrafts . . . The relative popularity of Tjir 1 with smallfarmers illustrates the importance ascribed by them both to lowered risk and to a flow of income commencing as soon after replanting as possible.' (Barlow *et al.*, 1975).

These lessons can be illustrated from our present data set by considering a radical change in embodied technology that reduces the immature period from 5 to 3 years.[12] To avoid confusion this change in technology is only applied to the Basic and Z yield or profit curves and the new curves will be called B_2 and Z_2. Table 6 sets out the relevant annuities and optimal replanting dates for the three interest rates considered :

TABLE 6 : EFFECT OF REDUCED IMMATURE PERIOD ON ANNUITIES AND REPLACEMENT DATES

Technology**		Maximum Annuities at	
	0%	10%	15%
B	594·23 (26)*	242·18 (27)	96·96 (30)
B_2	645·65 (23)	381·50 (25)	247·90 (25)
Z	744·73 (24)	297·53 (28)	126·93 (31)
Z_2	836·79 (24)	448·26 (26)	297·55 (26)

* The figures in parentheses are the optimal replacement dates.

** B_2 and Z_2 refer to technology B (Basic) and Z (stimulation from year 20) but with three rather than 5 years immature period.

The sensitivity of the optimal date to the reduction of the immature period depends on the interest rate and how fast yields in later years fall off. The impact on the data used here is to reduce the cycle by the amount of the reduction in the immature period (2 years) at the lower interest rates (0 and 10%) but at 15% there is the more typical situation where the reduction in the cycle length (5 years) is substantially greater than the reduction of the immature period. The reason for this latter situation to be more typical is seen in Fig. 4 which shows that when the immature period is reduced there is also the effect of the resultant increase in the annuity curve.

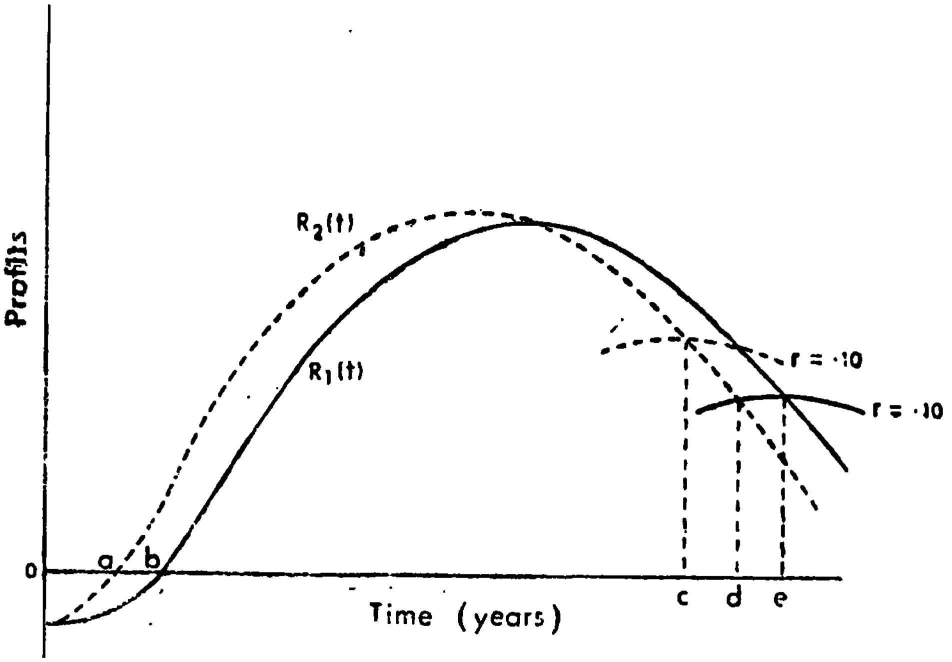

Fig. 4. Effect of reduced immature period.

Note : ab=de, simple effect of reduced immature period. cd, effect of increased annuity.

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[12] Exactly the same principles apply to the precocious yields referred to earlier. This case is examined in detail in Lim *et al.*, 1973.

Table 6 also enables us to check the relative importance of the two forms of technological change and here we see the change in ranking with and without time preference. It will be noticed that at a 0 per cent rate of discount stimulation is the preferred technological change ($Z^{\cdot 0} — B^{\cdot 0} =$ Rs. 150·50 ; $B_2^{\cdot 0} — B^{\cdot 0} =$ Rs. 51·42) at 10% the reverse is true ($B_2^{\cdot 10} — B^{\cdot 10} =$ Rs. 139·32 ; $Z^{\cdot 10} — B^{\cdot 10} =$ Rs. 55·35) because of the critical importance of the timing of the technological change. This becomes even more clear at the 15 per cent discount rate : ($B_2^{\cdot 15} — B^{\cdot 15} =$ 150·94 ; $Z^{\cdot 15} — B^{\cdot 15} =$ Rs. 29·97), but there is the added effect of a substantial reduction in the cycle lengths from 30 — 31 years to 25 — 26 years (5 — 6 years).

Fortunately it is not necessary to choose between these types of technology, thus while stimulation is ' less profitable ' than reducing the immature period it has the over-riding advantage of being able to be applied to all existing trees and not having to await the new planting cycle. Thus Z_2 is the best of both worlds where stimulation adds 31% to the Basic profitability but where the reduction in the immature period adds a further 166% to the Basic profitability (of Rs. 96·96) at the 15% discount rate. Such percentage changes in profits may be more meaningful to planters than the perpetual annuity figures in Table 6.

We conclude our discussion of technological change by considering the actual timber of the rubber trees which could become an increasingly important by-product of latex production.

'The efficiency of sunlight energy conversion through photsoynthesis can be utilised not only for rubber production, but also for vegetative growth. Rubber wood has been shown to produce very satisfactory timber for a variety of applications including furniture and panelling. The pulp also can be converted into packaging materials.' (Sekhar, 1974).

It is an obvious question to ask how this by-product enters the decision rule and, further, what effect will it have on deciding the length of the optimum cycle.

The introduction of the timber of the rubber trees into the problem is referred to in the literature as the ' salvage value ' problem. Clearly forestry economics is generally concerned with the extreme case where the salvage value is the only value — there being no intermediate products while the trees are growing. In the forestry case the decision rule is given by

$$(6) \qquad \Delta S(T) = S(T) \frac{r(1 \times r)^T}{(1 \times r)^T - 1}$$

where S (T) is the net salvage value of the timber in the terminal year T and ΔS (T) is the change in the value from the previous year. This expression again has a marginal value on the left hand side and an average, annuity, on the right. The annuity expression is the same as that used earlier but there is a critical difference between equations (4) and (6). In the latter, S (T) has no discount term directly attached to it as is true of the *flow* of income in (4). This means that since the annuity expression *increases* with increases in interest rates. *The effect is to reduce the cycle length as interest rates increase.* This is the opposite direction of response to interest rate changes in the case of the continuous flow of income and is illustrated in Fig. 5(a). Hence the impact of positive salvage values is to further stabilise the optimal date with respect to interest rate changes. Furthermore the relatively slow rate of growth of rubber *trees* in the period 20 to 35 years would suggest the fairly flat annuity curves drawn in Fig. 5(a) indicating again the small cost of suboptimal decisions.

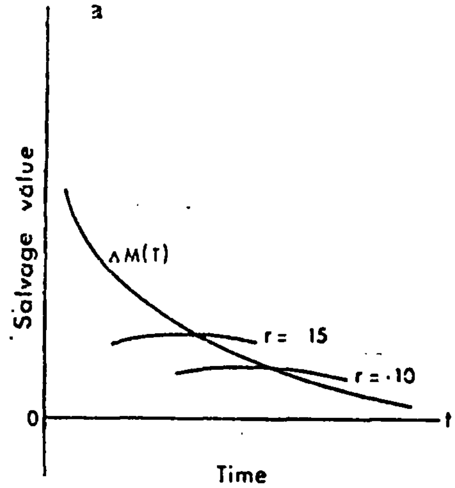

Fig. 5 (a)

The equations or the annual flow of income (4) and for the lump sum salvage value (6) are combined in equation 7.

$$(7)\quad R(T) + \Delta S(T) = [\Sigma_{o}^{T}\, R\,(t)\,(1+r)^{-T} + S(T)\,]\;\frac{r(1+r)^{T}}{(1+r)^{T}-1}$$

It will now be appreciated that the overall optimal cycle length will be a compromise between the two amnuities which are added together in equation 7 and in Fig. 5(b). Clearly the direction of change in the optimal date with respect to interest rate changes will depend on the relative importance, in terms of profits, of the two expressions in the square brackets. Similarly if the optimal cutting date obtained from (4) and from (6) are very different then the key determinant of sensitivity in the optimal date will be the relative weights, and the changes in weights of the revenue from the latex and the wood.

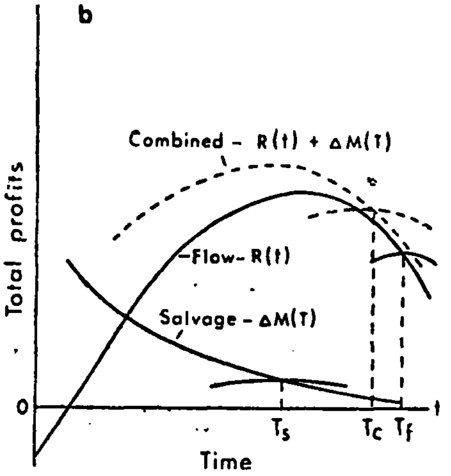

Fig. 5 (b)

Figs. 5 (a) & (b). Response of salvage value annuities to interest rate changes.

Empirical tests will be necessary to establish the effects of latex becoming a by-product of wood production rather than the current situation. Sekhar may have been joking when he noted that

> "An acre of rubber can give as much as 15 tons of timber at the end of 20 years from planting. *Hevea* trees can therefore be cultivated as a source of timber and pulp, in a 20-year replanting cycle, with rubber being extracted for 16 years as a by-product!" (*ibid*)

This is one extreme possibility; certainly the current work on the subject in Sri Lanka, Malaysia and Indonesia is of very great importance.

Because timber is so bulky transport is often the major cost element in its exploitation. It would therefore be reasonable to expect that even if new uses of *Hevea* trees are proven, the ability of individual planters to take full advantage of the fact will largely depend on the distance of their trees from the timber or pulp mill. Thus in any one country at any one time it is quite possible that there will exist a full range of situations from latex being the by-product of *Hevea* wood production to the reverse situation in which wood is of negligible importance. It is consequently possible that far from introducing increased stability in the optimal replanting date (as is true with respect to interest rate changes) wood production may result in a range of optimal dates being needed depending on location.

Replanting subsidies and intercropping

Replanting subsidies and intercropping can be considered together because of the similarity of their effects on the replanting cycle. The subsidy considered here is a full one covering the complete costs of replanting and maintenance during the immature years. For the earlier analysis the establishment costs had been assumed to be Rs. 360·00 per ac per year for the first five years. The intercropping assumption is that there are actual net returns in the immature period : Rs. 300 in the first year and declining to Rs. 200 : 100 ; 50 ; and 25 in the next four years.

The results for technologies B and Z are given in Table 7. Profitability, as measured by the annuities, is enhanced greatly by subsidies and intercropping because these occur in the early years. In general this would encourage earlier replanting (the effect usually intended) as is shown in the situations with a 15% discount rate. At 10% the lack of sensitivity is due to the large fall in the annual income stream between year 27 and 28 in B and between 28 and 29 in Z.

TABLE 7 : EFFECT OF SUBSIDIES AND INTERCROPPING ON ANNUITIES AND REPLACEMENT DATES

Technology	Maximum Annuities at	
	10%	15%
B	242·18 (27)	96·96 (30)
B with full subsidy	389·92 (27)	281·45 (27)
B with intercropping	450·85 (27)	361·11 (27)
Z	297·53 (28)	126·93 (31)
Z with full subsidy	444·17 (28)	311·13 (28)
Z with intercropping	504·64 (28)	390·55 (28)

In comparing Tables 6 and 7 it is seen that the moderate income from intercropping increases the annuity by more than the reduction in the length of the immature period from 5 to 3 years. intercropping is also more important in its effects on profitability than the introduction of stimulation. Again the reason for this result is the timing of these two changes in technology. The implications for research are important.

CONCLUSION

This paper has applied the economic principles of optimal replacement to the case of rubber trees. The principles were illustrated using a recent set of data from Sri Lanka. Various forms of embodied and disembodied technological change were investigated using a range of interest rates. The timing of the effects of the technological change was shown to be of critical importance. The main conclusion was that innovations which allow rubber to be tapped earlier and raise yields in the early (virgin bark) years are much more important to the long run viability of the rubber industry than effort to raise yields during the tapping of second renewal bark. A similar conclusion relates to the effects of intercropping. While the influence and importance of changes in prices and interest rates on the optimal replacement of *Hevea* trees producing latex is certain, the introduction of wood as an important by-product is likely to have confounding effects on optimal replacement dates.

APPENDIX

Rubber Yield and Cost of Production Data from "An Evaluation of Rubber Replanting Cycles in Relation to Productivity and Profitability" by C. M. Abeyesekera.[1]

TABLE I

	X			Y			Z		
Years	Yield/ac Normal	With Intensification	COP Rating	Yield/ac Normal	With Ehrel*	COP Rating	Yield/ac Normal	With Ethrel*	COP Rating
1 - 4	NIL		A	NIL		A	NIL		A
5	NIL		A	NIL		A	250		A
6	400		A	400		A	500		B
7	600		B	600		B	700		B
8	800		B	800		B	800		B
9	1000		C	1000		C	1000		C
10	1200		C	1200		C	1200		C
11	1300		C	1300		C	1300		C
12	1400		C	1400		C	1400		C
13	1500		D	1500		D	1500		D
14	1600		D	1600		D	1600		D
15	1700		D	1700		D	1700		D
16	1800		D	1800		D	1800		D
17	1900		D	1900		D	1900		D
18	2000		E	2000		E	2000		E
19	1900		D	1900		D	1900	570	E
20	1800		D	1800		D	1800	540	E
21	1700		D	1700		D	1700	510	E
22	1600		D	1600		D	1600	480	E
23	1500		D	1500		D	1500	450	D
24	1400		C	1400	420	D	1400	420	D
25	1300		C	1300	390	D	1300	390	D
26	1200		C	1200	360	D			
27	1000	400	C	1000	300	C	28850	3360	32210
28	800	300	C	800	240	C			
29	600	400	C	600	180	B	A	5	
30	500	300	B	500	150	B	B	3	
31	400	300	B				C	4	
32	300	300	B	32500	2040	34540	D	8	
33	300	300	B	A	6		E	5	
	33500	2300	35800	B	4		A–E	25	
				C	6				
A	6	D	10	D	13				
B	6	E	1	E	1				
C	10	A–E	33	A–E	30				

* 3 Applications of Ethrel giving a 30% increase in Crop.

[1] *Ceylon Management Accountant* Vol. 2, No. 3 June, 1974.

APPENDIX

TABLE II

			COST											
COP Rating	Yield		Fixed		Variable		Total		COP Rating into yr	X	Into yr	Y	Into yr	Z
	Range lb	Average lb	lb cts.	ac Rs.	lb cts.	ac Rs.	lb cts.	ac Rs.						
A	— 500	300	120	360	60	180	180	540	6	3240	6	3240	5	2700
B	501 — 1000	800	63	504	57	456	120	1080	6	6480	4	4320	3	3240
C	1001 — 1500	1300	45	585	55	715	100	1300	10	13000	6	7800	4	5200
D	1501 — 2000	1800	33	594	52	936	85	1530	10	15300	13	19890	8	12240
E	2001 —	2300	27	621	48	1104	75	1725	1	1725	1	1725	5	8625
									33	39745	30	36975	25	32005

TABLE III

	Years	Total crop	Total expenditure	COP	OVER 100 YEAR PERIOD						
					Crop		COP	Nsa	Net Profit		
		lb	Rs.	cts.		lb	cts.	cts.	cts.	Rs.	%
X	33	35800	39745	111	3 Cycles	104,000	111	150	39	40560	100
Y	30	34540	36975	107	3 Cycles + 10 Yrs.	108,000	107	150	43	46440	115
Z	25	32210.	32005	100	4 Cycles	129,000	100	150	50	64500	160

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