University of New England

Graduate School of Agricultural and Resource Economics

Management strategies for Indonesian

small-holder rubber production in South Sumatra:

a bioeconomic analysis

by

Ririn Purnamasari, Oscar Cacho
and Phil Simmons

No. 99-14 – September 1999

Management strategies for Indonesian small-holder rubber production in South Sumatra: a bioeconomic analysis*

Ririn Purnamasari, Oscar Cacho and Phil Simmons**

Abstract

A simplified version of the BEAM Rubber Agroforestry Model is embedded in a dynamic economic model to examine the impact of uncertainty about prices and climate on decision variables. Solutions, in terms of optimal levels for decision variables are found using a Monte Carlo stochastic framework. These solutions were used to derive risk-efficient frontiers corresponding to different levels of the decision variables. The results underline the importance of including uncertainty in dynamic bioeconomic systems since profits under uncertainty turned out to be quite different from those obtained with prices and climate assumed to be constant.

Key Words: Bioeconomics, Stochastic analysis, Rubber, Indonesia

Management strategies for Indonesian small-holder rubber production in South Sumatra: a bioeconomic analysis

Introduction

Natural rubber is one of the most important agricultural industries in the Indonesian economy. Despite its declining contribution to total non-oil exports, natural rubber is still the second largest agricultural commodity in revenue terms after timber (CBSI 1998). The industry is dominated by smallholders who have 85 per cent of area planted and undertake 76 per cent of production (CBSI 1998).

The rubber-growing areas of Indonesia stretch across a five-thousand kilometre band, from Aceh to Irian. The most extensive plantings are in West Java, Riau, North and South Sumatra, and West Kalimantan. These regions are tropical areas, with a well distributed annual rainfall of 2000 - 2500 mm, having average temperatures of 24 - 28°C, and most of the soil is provided with adequate drainage. These are necessary conditions for successful rubber cultivation (Barlow and Muharminto 1982)

In the first half of the century estates in Indonesia were pioneers in the introduction of selected high-yielding rubber clones, they were also leaders in rubber research, producing a uniformly high-quality product through central processing factories (Lynch 1977). As a source of foreign earnings, development of natural rubber became a major concern of the Indonesian government after its independence in 1945. However, government intervention was not significant until nationalisation of the Dutch estates in 1958 and taking over British and American plantations in the early 1960s (Mubyarto & Dewanta 1991).

Since the early 1970s several government initiatives have been launched to improve the rubber sector. An important initiative which gave considerable benefits to estates was the provision of low-cost capital for rubber development and encouraging rejuvenation with high-yielding clone material (Barlow and Muharminto 1982). Smallholding rubber development was initiated through various Nucleus Estate Smallholder System (NESS) schemes in 1977. The NESS program and other integrated schemes have caused a massive increase in total area planted. In 1967, total area of rubber was 2.1 million ha, by the end of 1997, the total area planted was 3.5 million ha. (DGEC 1998, CBSI 1998).

In line with expansion of area planted, Indonesian rubber production has increased sharply. The total rubber production increased from 709 251 tonnes in 1967 to 1 568 609 tonnes in 1997. The rapid growth of total production has been due not only to increases in area planted but also to productivity improvements in both smallholdings and estates. Between 1967 and 1997 smallholdings improved yields from 462 kg per ha to 597 kg per ha; however, these yields are still low compared to estates that improved yields from 606 kg per ha to 1015 kg per ha in the same period (DGEC 1998).

Approximately 90 per cent of Indonesian natural rubber production is exported. The three main destinations are the United States, Singapore and Japan which in 1997 accounted for 42.5 per cent, 8.6 per cent, and 7.0 per cent of total Indonesian rubber

exports respectively (CBSI 1998). Indonesian natural rubber exports have suffered from fluctuations in prices. A study by Ambarawati (1995) concluded that variation in the world natural rubber price was the main factor affecting price instability on Indonesian rubber.

A rubber producer's profit depends on the quality and quantity of latex yield, the main product of the rubber tree and the costs involved in producing it. These factors largely depend on tree-management decisions such as clone used, tree density, rotation length, tapping method and other factors. Management decisions are also influenced by risks arising from unpredictable climatic changes and uncertainty about rubber prices.

In this study, Indonesian small-holder rubber production is analysed to identify optimal levels for management decision variables embedded in a dynamic bioeconomic model. The bioeconomic analysis incorporates biological and economic aspects of rubber production. The broad approach is first to construct a deterministic model which identifies the optimal management strategy in the absence of risk. In the second stage, rainfall variability and price fluctuations are incorporated into the analysis to account for risk. Comparisons between the deterministic and stochastic results show that there are important implications from ignoring production and price uncertainty in management decision-making in rubber production.

The Model

A simplified version of the Modified BEAM Rubber Agroforestry Model reported by Grist, Menz and Thomas (1998) is used as a basis for the bioeconomic model. The BEAM model was originally developed as part of the Bioeconomic Agroforestry Modelling Project which is based at the University of Wales, Bangor. Further detail on rubber production can be found in Grist and Menz (1996a), Grist and Menz (1996b) and Grist, Menz and Amarasinghe (1997). The biological model deals with the influences of a number of bioclimatic, topographic and silvicultural factors on changes in rubber outputs such as latex and wood. The physical inputs and outputs from the biological model then determine overall economic returns in the economic model (Grist et al., 1998). Although the modified BEAM model is freely available and can be run from within a spreadsheet, a simpler version had to be developed for this study to allow stochastic analysis. The introduction of stochastic variables requires the model to be run repeatedly, which could not be undertaken with the existing model due to the time requirements to solve a single life cycle of the plantation.

The Economic Model

The present value of profits (V_1) obtained from a hectare or rubber trees over a growth cycle of T years is defined as:

$$V_1 = \sum_{t=1}^{T} \left[y_t(\mathbf{X}) \cdot p_t^y - c_t^y(\mathbf{X}) \right] \cdot e^{-rt} + \left[w_T(\mathbf{X}) \cdot p_T^w - c_T^w(\mathbf{X}) \right] \cdot e^{-rT} - k_0 \qquad (1)$$

The right hand side of this function has three components; the first term is the discounted stream of profits obtained from latex yield y_t in year t, sold at price p_t^y and subject to tapping labour costs c_t^y; the second term is the discounted profit obtained from selling a harvest of wood w_T in the final time period at price p_T^w and with harvest costs c_T^w; the third term is the establishment cost (k_0). $\mathbf{X}$ is a vector of decision variables, which may be a function of time for annual decisions such as fertiliser application rates. In our case, however, $\mathbf{X}$ is static with respect to a production cycle of T years and is defined as:

$$\mathbf{X} = (B, D) \tag{2}$$

where B is the year at which tapping for latex starts and D is the stand density (stems per hectare). A short-sighted producer whose objective is to maximise profit would want to determine the values of T, B and D that maximise the value of V_1 in equation (1). But this would ignore the possibility of replanting the stand after harvest in year T to start a new cycle.

Here it is assumed that plantation land continues to be used for growing rubber trees after the end of the first rotation and hence that there are two types of costs associated with Net Present Value (NPV) of the plantation. The first of these are the actual costs of cultivating the rubber plantation. That is, the cost of planting, tapping, tree harvesting and transportation to market, as described in equation (1). The second cost is the opportunity cost of keeping the plantation in production rather than re-assigning the land to its next most valued end use, assumed to be a new rotation (Hartwick & Olewiler 1986, Neher 1990). Thus, the cumulative NPV for a rotation period of T years is:

$$V = V_1 + V_1 \frac{1}{e^{rT} - 1} \tag{3}$$

where the first term on the right hand side is the value of the first production cycle, including the value of the timber harvested. The second term is the value of the second and all subsequent harvests. The second term can also be interpreted as the opportunity cost of delaying the harvest. Our maximisation problem now becomes:

$$\max_{T,B,D} V(B,D,T) = V_1(B,D,T) + V_1(B,D,T) \frac{1}{e^{rT} - 1} \tag{4}$$

with V_1 defined as in equation (1). Annual yields of latex (y_t) and final wood harvest (w_T) are calculated through a biological model based on the BEAM model, as explained in the following section. Table 1 presents variable definitions and Table 2 presents assumptions regarding costs and prices.

Table 1. Variable definitions

Variable	Definition	Units
Economic Model		
V_1	present value of first cycle	Rp '000/ha
V	present value of infinite cycles	Rp '000/ha
y_t	latex yield	kg/ha
p_t^y	latex price	Rp '000/kg
c_t^y	latex production cost	Rp '000/kg
w_t	wood yield	m3/ha
p_t^w	price of wood	Rp '000/m3
c_t^w	cost of wood harvest	Rp '000/m3
k_0	establishment costs	Rp '000/ha
r	discount rate	%
Decision Variables		
T	Rotation length	years
B	First tapping year	years
D	Tree density	trees/ha
Biological Model		
at	tree age	years
Gt	girth diameter	cm
$\overline{G}_t$	standard girth	cm
Lt	Buttlog yield	m3
St	Smallwood Yield	m3
ℓ	buttlog length	m3
h	tree height	m
h_L	latex growth index	*
h_C	yield clonal index	*
h_S	site index	*
h_G	girth clonal index	*

* unitless indexes

4

Table 2. Price and cost assumptions

Item	Value	Units
Prices		
Latex grade1	2.48	Rp '000/kg
Latex grade2	1.65	Rp '000/kg
Wood	8.00	Rp '000/m^3
Clone seedling	0.35	Rp '000/tree
Labour Costs		Rp '000/md
Site preparation	4.75	
Planting	4.00	
Tapping	4.00	
Harvesting	5.33	
Transportation costs		Rp '000/m^3
Buttlog	2.50	
Smallwood	1.00	
Other Costs		
Harvest per tree	0.60	Rp '000/tree
Site preparation	1.72	Rp '000/ha
Requirements		
Planting labour	0.005	md/tree
Tapping labour	0.1607	md/tree
Harvest labour	0.2	md/tree

The Biological Model

The main purpose of the biological model is to predict latex yields throughout the plantation cycle and timber yield at harvest. These estimates are used by the economic model in equation (1) in the process of solving (4). For a given variety of tree, latex yield on any given year is mainly determined by tree girth, although tree age, planting density and site condition also have an effect:

$$y_t = \begin{cases} G_t \cdot 30 \cdot \dfrac{\exp(2 \cdot B)}{1 + \exp(2 \cdot B)} \cdot \boldsymbol{h}_L \cdot \boldsymbol{h}_C \left(\dfrac{D}{400} \right)^{0.7} - \boldsymbol{q}(B, a_t) & \textit{if tapping} \\ 0 & \textit{otherwise} \end{cases} \tag{5}$$

where G_t is tree girth (cm), $\boldsymbol{h}_L$ and $\boldsymbol{h}_C$ are indexes for latex growth and clonal yield respectively and $\boldsymbol{q}$ is a function of age (a_t). Tree girth in any given year is estimated through the first-order difference equation:

$$G_{t+1} = G_t + \Delta G_t (G_t, B, D, a_t) \tag{6}$$

This specification implies that calculation of total girth is based on factor input levels in the current period as well as events in preceding periods. The annual girth growth is:

$$\Delta G_t = \Delta \overline{G}_t (D, a_t) \cdot g(G_t, B) \tag{7}$$

where $\Delta \overline{G}_t$ is expected girth growth under standard conditions and g is a function of tapping and tree girth. The 'Templeton relationship' (Grist and Menz, 1995) is used to provide the relationship between rate of growth of tapped and untapped trees and is used to calculate changes in girth when tapping commences at girths other than 45 centimeters:

$$g = \begin{cases} 0.587 & \textit{if } G_t < 45 \textit{ and tapped} \\ 1.700 & \textit{if } G_t > 45 \textit{ and not tapped} \\ 1.000 & \textit{otherwise} \end{cases} \tag{8}$$

Tree girth is a central factor in the biophysical model since elementary equations such as those for latex yield, tree height and wood are functions of girth. Expected girth growth is estimated by first differences from a growth function derived from that presented by Grist et al. (1998):

$$\overline{G}_t = \frac{2.37 \cdot a_t \cdot \boldsymbol{h}_S \cdot \boldsymbol{h}_G}{22 + a_t + 3.07 \cdot 10^{-4} \left(\dfrac{a^2 \cdot D}{0.2 + 5a_t} \right)^{1.35}} \tag{9}$$

where $\boldsymbol{h}_S$ and $\boldsymbol{h}_G$ are a site index and a girth-clonal index explained later. Tapping and ground cover are two important factors influencing actual girth increment. Ground cover is not discussed further due to lack of data and information needed in incorporating ground-cover effects on the Sumatran site, such as light intensity and ground-cover control. Thus, it is assumed that the ground under the plantation is clear with no girth loss due to ground cover.

As in the Modified BEAM Model, our model predicts a natural decline in latex yield after the ninth year of tapping. The age effect in equation (5) depends on the number of years the tree has been tapped for latex:

$$\boldsymbol{q} = \begin{cases} 9 \cdot (B - 9)^{1.5} & \textit{if } (a_t - B) > 9 \\ 0 & \textit{otherwise} \end{cases} \tag{10}$$

Although not the main product of the plantation, the yield of wood is included because it provides income at the end of the plantation cycle. The yield of wood has two components, logs (L_t) and smallwood (S_t), thus we have:

$$w_t = L_t + S_t \tag{11}$$

$$L_t = D \cdot \boldsymbol{b}_t \tag{12}$$

$$S_t = (\Omega_t - b_t) \cdot D \qquad (13)$$

where b is the buttlog volume per tree and Ω is the total volume of wood produced by an individual tree. These functions are defined as:

$$b_t = \ell \cdot p \left(\frac{0.01 G_t}{2p} \right)^2 \qquad (14)$$

$$\Omega_t = 4.35 \cdot 10^2 + \left(5.031 \cdot 10^5 \cdot \left(\frac{G_t}{p} \right)^2 \right) \cdot h_t \qquad (15)$$

where ℓ is the buttlog length, assumed to be 2.5 m, p is 3.1416 and h_t is the tree height, calculated as:

$$h_t = 0.382 \cdot G_t - 5.12 \cdot 10^{-3} \cdot G_t^2 + 2.585 \cdot 10^{-5} \cdot G_t^3 \qquad (16)$$

Clonal Material

Research has shown that rubber tree clones containing improved genetic materials exhibit faster growth (Barlow and Muharminto, 1982). In this study a GT1 clone, the most common clone used in Indonesia, is included in the model. This clone is assumed to grow 30 percent faster compared to a wildling (Gouyon and Nancy, 1989). The model also considers a wildling, or unselected seedling. A wildling is grown from seed dispersed from nearby planted trees. Although these seedlings are usually of poor quality, their use is common because there is no initial cost other than the time required to collect them.

Indexes

The BEAM model contains a number of indexes to account for the quality of the site, climate, management practices and quality of genetic material contained in the rubber trees. These indexes are based on integration of a large body of scientific research.

The site index (h_S) has a value between zero and 100 and is estimated by multiplying a climate index and a soil index, both of which are calculated through complex formulae. The soil index considers seven soil characteristics, including soil depth, slope, texture and drainage. The climate index includes the effects of rainfall, air temperature and light density. We did not attempt to estimate a site index based on these factors, but rather assumed an expected value of 75 which reflects typical circumstances in plantations in Indonesia (Grist et al. 1995).

The latex growth index (h_L), which has a value between zero and one, is a composite of growing conditions at the site plus the effect of fertiliser. The effect of fertiliser was not considered in this study hence the latex growth index was calculated based on the site index as $h_L = h_S / 100$. The latex growth index was used to account for climatic variability in stochastic simulations as explained later.

The yield clonal index (h_C) and girth clonal index (h_G) account for the growth and yield potential of the given clonal material planted but they may also depend on management practices. In Indonesia the clonal index of trees produced by smallholders is smaller than for estates hence h_C was given a value of 0.6 to reflect this fact; h_G was given a value of 1.0 for wildling and 1.3 for clonal material.

Model Implementation and Solution

The biological model (5) to (16) was implemented in a speadsheet format that allowed for easy modification of the decision variables *B*, *D* and *T* to calculate the resulting stream of yields (y_t) and final wood harvest (w_T). The biological model was then linked to the economic model by introducing prices and costs (as detailed in Table 2) and solving equation (1) for any given set of decision variables {*B, D, T*}. Maximisation of (4) was accomplished through a simple search algorithm that treats decision variables as integers. This simplifying assumption causes no problems, as *B* and *T* are essentially discrete variables measured in years, and *D* represents number of trees per hectare, which is an integer. The decision variables were constrained to the following values:

$$5 \leq B \leq 9; \ \ 400 \leq D \leq 600; \ \ 20 \leq T \leq 40$$

These bounds were based on previous studies (Grist et al. 1998, Mubyarto & Dewanta 1991, Barlow et al. 1994) and were required to limit the search space. In the case of density the upper bound prevents the use of very high densities that would cause root and disease problems.

The model was run for both the GT1 clone and the wildling and results compared. Most rubber producers in Indonesia are supported by government-sponsored schemes which provide credit with long payback periods (12 to 15 years) at interest rates of 10 to 15 percent (Grist and Menz 1995; Dereinda et al. 1989). Thus the model was solved for discount rates of 10, 12 and 15 per cent.

In the deterministic model prices were held constant at their expected values (Table 2), while time series data on rainfall and rubber prices were used to enable stochastic analysis. Annual observations from 1967 to 1988 on average rainfall for South Sumatra were obtained from the Agency of Meteorology and Geophysics and annual observations of rubber prices came from the Central Board of Statistics of Indonesia (various issues) for 1967-1997. Other data were from the South Sumatra region where smallholder rubber plantations are predominant. The data were fitted to a lognormal distribution which has the desirable property of being bounded below at zero. The lognormal distribution has two parameters, mean (*m*) and standard deviation (*s*), and is denoted as $LN(m,s)$. The estimated distributions to represent rainfall and prices were $LN(2792.85, 918.41)$ and $LN(2.48, 0.622)$ respectively.

The rainfall distribution was linked to the latex growth index by assuming that the optimal level of rainfall for rubber trees in South Sumatra is 2500 mm/year. It was further assumed that rainfall levels above and below this value cause reduced yields as described by the function:

$$h_L = \left[0.16875 - 0.0006.65 \cdot 10^{-4} \cdot R_t - 1.33 \cdot 10^{-7} \cdot R_t^2 \right] \cdot 0.75$$

where R_t is rainfall (mm/year) in year t. Although this approach ignores the fact that the timing and duration of rainfall events are as important as the total amount of rain received, it is considered an acceptable first approximation given data limitations.

The stochastic version of the model was solved through Monte carlo analysis for different sets of values of the decision variables, based on deterministic results. The @RISK software package (Palisade 1996) was used for this purpose. The uncertainty specified in the price and rainfall distributions was used as a base to produce numerical results as probability distributions of yield and NPV. One thousand iterations were used for each stochastic run.

Each stochastic simulation yields a different set of NPV results that, collectively, can be represented as a risk efficient frontier in expected value-variance (E-VAR) space. Hence, the stochastic model is used to identify dominant combinations of expected net present value and risk, as measured by the variance of profit, where each point on the frontier represents a different management strategy.

Deciding that something is risky requires personal judgments by individuals who may differ in the amount of risk they are willing to accept. Different management strategies may be undertaken because of differences in both preferences and circumstances. Hence, the results report the whole NPV-VAR frontier with the implication that the user, in applying the model, would subjectively choose his or her own E-V point and its associated management strategy.

Results

Deterministic Results

Given values of interest rates and prices, the optimal management strategy is defined in terms of the values for tapping commencement year (B), stand density (D) and rotation period (T) which maximise NPV. These strategies and the corresponding latex yields and NPV are described in Table 3 for both planting materials.

Table 3. Optimal results for clone and wilding, deterministic model.

Discount rate (%)	B^* (year)	D^* (stems/ha)	T^* (years)	Yield (kg/ha)	NPV (Rp '000/ha)
Clone					
10	7	600	38	41 338	12 027
12	6	600	37	38 368	8 566
15	5	600	36	34 858	5 471
Wilding					
10	6	600	32	21 471	7 037
12	5	600	30	19 195	5 071
15	5	600	31	19 671	3 251
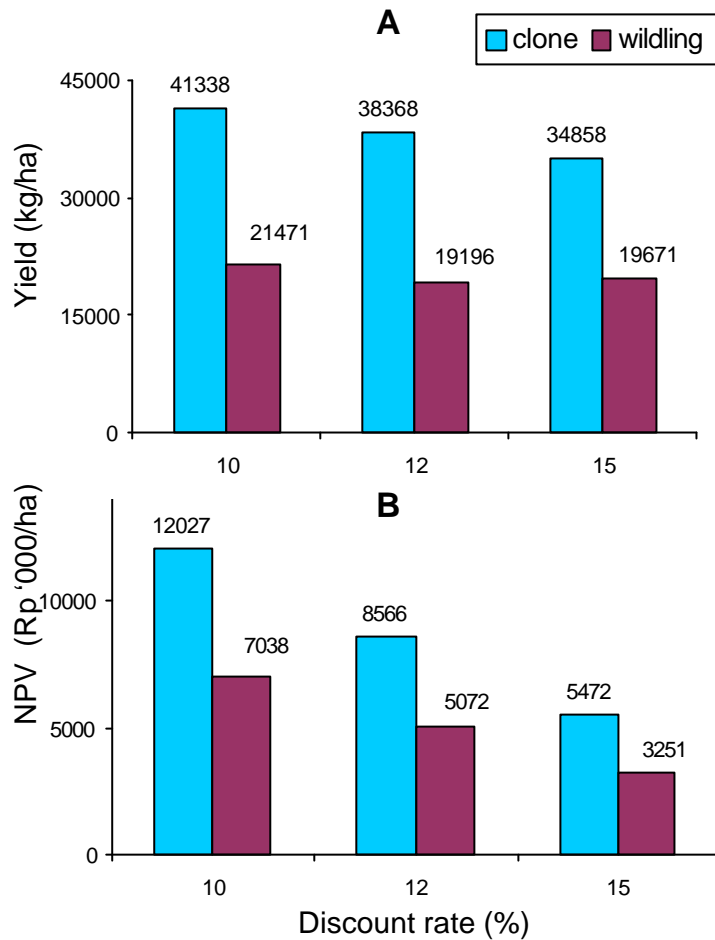
Figure 1. Yield (A) and NPV (B) under optimal management, comparison between clone and wildling.

The optimal tapping commencement year for both planting materials ranged from 5 to 7. For the same interest rates, the optimal tapping commencement years for the GT1 clone is one year later than for the wildling, except at an interest rate of 15 per cent where the optimal tapping years are the same. Generally, tapping commenced in an earlier year when interest rates were higher and an increase in interest rates from 10 to 12 per cent reduced tapping commencement year by one. When interest rates increased from 12 to 15 per cent, tapping commencement years for the GT1 clone declined by one year but remained the same for the wildling.

Optimal density for the clone and wildling has only one value of 600 suggesting that density is not significantly affected by interest rates (Table 3). Also, the optimal rotation is shorter for the wildling than for the clone. The minimum optimal rotation for the clone is 36 years and the maximum is 38 years. For the wildling, optimal rotation ranges from 30 years to 32 years.

The optimal rotation period for the clone decreases by one year with an increase in interest rates from 10 to 12 per cent or from 12 to 15 per cent. On the other hand, optimal rotation for the wildling is different. Rotation years decrease by two as interest increases from 10 to 12 per cent while increasing interest rates from 12 to 15 per cent increases rotation length by one year.

10

Average latex yield is quite different between the clone and wildling. The clonal material has an average yield about 90 per cent higher than the wildling. Latex yield from the clone ranges from 35 to 41 tonnes per hectare, while maximum yield from the wildling is only 21 tonnes per hectare with a minimum of 19 tonnes (Figure 1A).

As with results for average latex yield, NPV from the clonal material is about 70 per cent higher than for the wildling. NPV from the clone reaches a maximum of 12 million rupiah per hectare with a minimum of 5 million. From the wildling, NPV ranges from 3 million rupiah per hectare to 7 million (Figure 1B). As expected from the way it is calculated, NPV decreases as interest rates increase. Increasing interest rates from 10 to 12 per cent decreases NPV about 40 per cent, while increasing interest rates from 12 to 15 per cent decreases NPV by 56 per cent.

Stochastic Results

As explained earlier, the model was solved using @RISK for a set of values of decision variables obtained from the deterministic results. Production and price risks were incorporated by applying probability distributions for rainfall and prices simultaneously. The model was run for 36 combinations of the decision variables for the clone and 45 combinations for the wildling with 1000 iterations, or 'draws', from the two distributions. This gave results for means and variances of yield and NPV for each combination of decision variables.

Results for the highest NPV with the corresponding coefficient of variation (CV), yield and management strategy from the stochastic simulations are presented in Table 4 for each interest rate.

<div align="center">

Table 4. Optimal risk-neutral results for clone and wilding, stochastic model.

</div>

Discount rate (%)	B^* (year)	D^* (stems/ha)	T^* (years)	Yield (kg/ha)	NPV (Rp '000/ha)	CV (%)
Clone						
10	7	600	36	33 700	10 070	12.20
12	6	600	35	31 189	7 156	13.19
15	5	600	35	28 835	4 460	14.06
Wilding						
10	7	600	32	19 274	5 754	13.93
12	6	600	31	17 777	4 104	15.12
15	5	600	30	16 246	2 594	16.54

The results for the decision variables from the stochastic model are different from those obtained from the deterministic model. For the clone, rotation length in the stochastic run is shorter while tapping commencement years and densities are the same. For the wildling, only density has the same value while the other decision variables are different.

Following a similar pattern to the deterministic results, average yield and NPV from the stochastic model with the clone are about 76 and 74 per cent respectively higher than those with the wildling.

The wildling has a larger coefficient of variation for NPV with the variability of NPV increasing with interest rates. A comparison of results for yield and NPV between the deterministic and stochastic models is presented in Table 5.
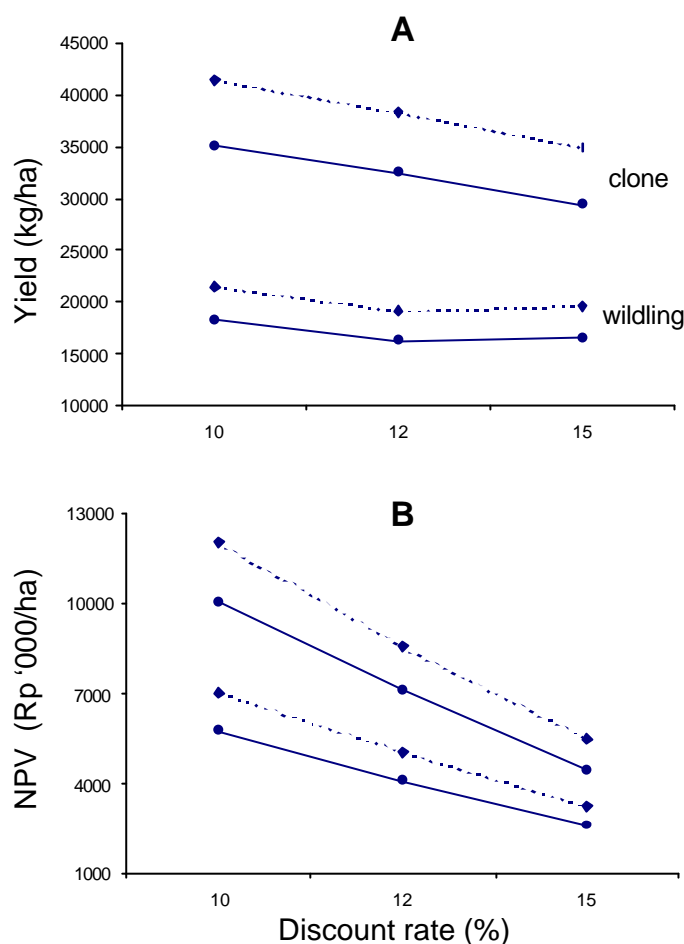

Figure 2. Optimal Yield (A) and NPV (B) results for clone and wildling materials and from deterministic (dotted line) and stochastic (solid line) simulations.

Table 5. Yield and NPV comparisons between deterministic and stochastic simulations

r	Clone			Wilding		
(%)	Deterministic	Stochastic	Difference (%)	Deterministic	Stochastic	Difference (%)
	Yield (kg/ha)					
10	41 388	35 072	-15.26	21 471	18 165	-15.40
12	38 368	32 432	-15.47	19 195	16 250	-15.35
15	34 858	29 353	-15.79	19 671	16 580	-15.71
	NPV (Rp '000/ha)					
10	12 027	10 064	-16.32	7 037	5 731	-18.57
12	8 566	7 153	-16.49	5 071	4 102	-19.13
15	5 472	4 459	-18.50	3 250	2 593	-20.24

For both clone and wildling, the stochastic simulations give lower yields compared to the deterministic mode. On average, the stochastic results for yield are about 15 per cent lower than the deterministic results at all levels of interest rates (Figure 2A).

As with yield results, stochastic NPV has a lower average value than deterministic NPV. In contrast to the yield results that have similar percentage differences, the differences between stochastic and deterministic NPV are higher for the wildling than for the clone (Table 5). The difference between the stochastic and deterministic NPV ranges from 16 to 18 per cent for the clone while for the wildling it ranges from 18 to 20 per cent with both differences increasing with interest rates. A graph of the NPV comparison between the deterministic and stochastic simulations is presented in Figure 2B.
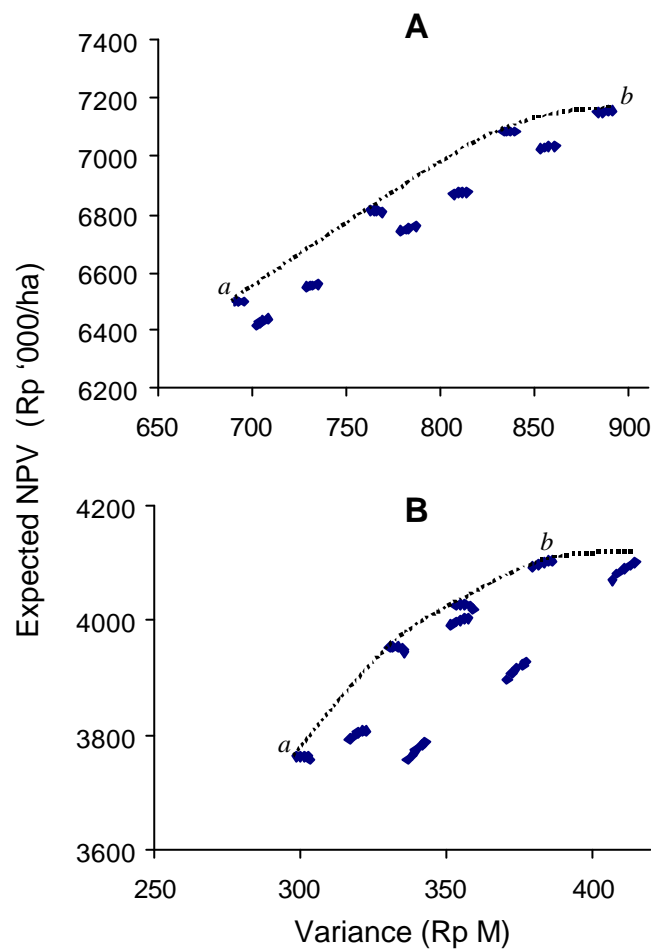
Figure 3. Risk efficient frontier for clone (A) and wildling (B).

Risk Efficient Frontier

The risk efficient frontier represents the efficient combinations of NPV and risk (measured as variance of NPV) and their associated management strategies. Combinations of means and variances of NPV at different interest rates yield different

risk efficient frontiers however, to facilitate discussion in this section, the discussion of the risk efficient frontier assumes an interest rate of 12 per cent.

The risk efficient frontier for the clone is shown in Figure 3A and, for the wildling, in Figure 3B. Each point on the frontiers represents a different management strategy whose outcome is in terms of risk and expected NPV and any point not on the frontier (approximated by the dotted line) is either inefficient or not physically possible. For the clone, the efficient combinations of NPV and risk range from (691, 6498) to (891, 7157), indicated by points *a* and *b* in Figure 3A. These are from the (*B, D, T*) management strategies of (7, 500, 38) and (6, 600, 35) representing tapping commencement year, density and rotation length respectively. For the wildling, the efficient combinations of risk and NPV range from (299, 3761) to (385, 4104) with management strategies of (7, 500, 34) and (6, 600, 31), indicated by points *a* and *b* respectively (Figure 3B).

Discussion

Optimal Management Strategy

Optimal tapping age ranges between 5 and 7 years for both planting materials. For the clone, tree girth of 45 cm, around where tapping begins, is normally reached in year 5 or 6. The wildling, on the other hand, usually reaches a girth of 45 cm between 8 and 9 years. This means the wildling rubber tree is tapped before it reaches a girth of 45 cm. Commencing tapping before a tree reaches girth of 45 cm not only reduces girth increment every year until the tree reaches a girth of 45 cm, but also reduces total latex production every year over the rotation period (Grist et al. 1998).

In contrast, the clone has a tree girth of approximately 45 cm in the fifth year after establishment. Thus, the clone does not have much reduction in girth increment or in latex yield as a result of early tapping.

The optimal density of 600 trees per hectare is the same for all modes and is a corner solution, as it is the maximum density allowed in the model. When the density constraint was relaxed, the density producing the highest NPV was up to 800 trees per hectare, reflecting that lower individual tree yields are more than offset by a greater number of trees. However, in practice, the recommended density is 400-600 trees per hectare to avoid losses due to wind damage, root diseases and permanent drying up of latex (Barlow et al 1994, Mubyarto and Dewanta 1991). Obviously, density constraints would not be required if the model took explicit account of these factors.

The results for length of rotation indicate that the optimal rotation length for the clone is longer than for the wildling. As discussed previously, the clonal material is expected to have 30 per cent higher growth than the wildling where growth, represented by tree girth increment, contributes directly to latex yield. With its slower growth rate once tapping has begun, the wildling has lower quality and less virgin and renewal of accessible bark. This decreases production from the wildling tree and reduces latex yield year to year. Hence, there are no financial benefits from keeping the wildling tree for as long as the clone.

The cost of purchasing clone seedlings (at Rp350 per tree) increases establishment costs and was expected to contribute to the longer optimal cycle length observed. To test whether this cost has an effect on the optimal solution, the clone seedling price was set to zero and the maximisation problem solved. This change resulted in larger NPV values, with increases of 1.79, 2.48 and 3.86 percent at discount rates of 10, 12 and 15 percent respectively; however the optimal level of the decision variables were not affected.

Yield and NPV

For any set of decision variables, yields and NPVs from the clone are higher than from the wildling reflecting that the clonal rubber tree has a higher growth rate than the wildling. The faster growth of the clonal material means tapping commences earlier without causing significant loss of girth increment. This enables the clonal tree to have more accessible bark and hence a higher latex yield and, consequently, NPV over the rotation.

The optimal management strategies from the stochastic runs are different from the deterministic ones. With climatic risk, the variability of rainfall affects rubber tree growth which, in turn, influences NPV. In a dynamic model, current year growth influences growth in following years and hence influences latex yield over the whole rotation. Hence, a 'bad year' early in the rotation flows on as reduced yields to later years. The variability in latex yield also influences variability in NPV. As a result of these dynamic effects average yields and NPVs are lower in the stochastic simulations, similar results were found by Cacho et al. (1999) for a grazing system. By contrast, price variability affects NPV only in individual years and hence its effects do not flow on to future years.
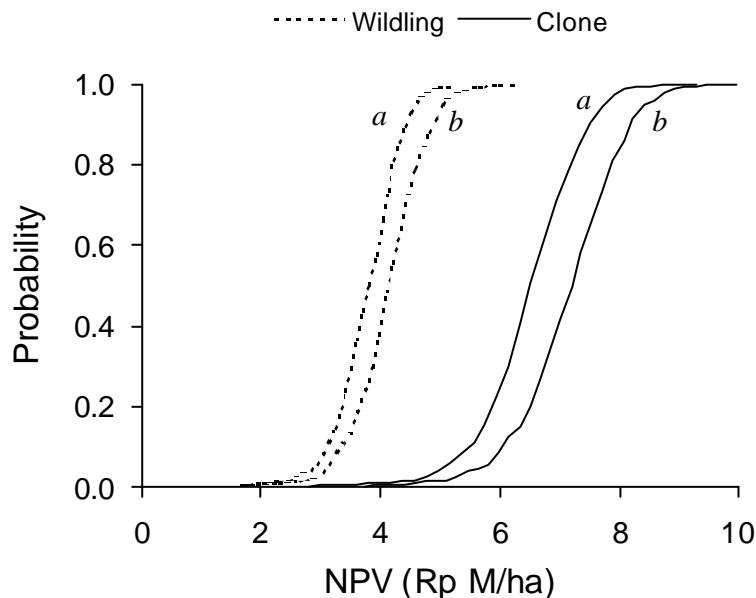
Figure 4. Cumulative density functions for selected points on the risk efficient frontier. Distributions labeled *a* and *b* correspond to extreme points in figure 3.

15

Risk Efficient Frontier

The stochastic results were used to determine risk efficient frontiers providing potential users of the model with the opportunity of choosing their own subjectively optimal management strategies. Thus, no unique optimal solution was found but, rather, a range of optimal solutions for individuals with either different attitudes towards risk or different circumstances. The extreme points on the risk efficient frontiers (labelled *a* and *b* in figure 3) represent the optimal solutions for an extremely risk-averse individual (*a*) and a risk-neutral individual (*b*). At these two extremes the clone dominates the wildling based on the first-order stochastic dominance criterion (Whitmore & Findlay, 1978), as illustrated in figure 4 by the fact that the cumulative density functions for the clone lay completely to the right of those for the wildling.

At the lowest and highest points on the frontiers, the efficient combinations of risk and expected profit for both planting materials come from the same tapping commencement years and densities. However, due to the differences between productivity of the planting materials the profitable cultivation period of the clonal tree is longer than for the wildling. Thus, the efficient rotation length for the clone is longer than for the wildling and expected NPV is higher. Movement along the frontier from the risk-averse to the risk-neutral solution results in earlier commencement of tapping (from year 7 to year 6), higher density (from 500 to 600 trees per hectare) and shorter cycles (from 38 to 35 years for the clone and from 34 to 31 years for the wildling).

Summary and Conclusions

In this study the farm management systems in Indonesian smallholder rubber production were examined to obtain optimal results for decision variables using a bioeconomic framework. Risk analysis was undertaken by incorporating dynamic and stochastic characteristics of the system and it was found that the bioeconomic approach was useful for solving this sort of production decision problems.

In the stochastic simulations, variability in rainfall affects latex yield year by year and flows on for the whole rotation while price variability only affects NPV in individual years. Hence, decision variables from the stochastic simulations that yield the highest NPV differ from the decision variables obtained from the deterministic simulations. This is an important consideration since, generally, management decisions are based on deterministic analysis.

Given additional information on the variance of NPV, the stochastic simulation results can be used to determine risk efficient frontiers where each point on the frontier represents an efficient management strategy. Hence, the risk efficient frontier can be used as a decision tool that can be used by individuals to understand, in a technical sense, trade-offs between profit and risk.

Finally, due to lack of data and information, fertiliser and ground cover effects have not been included in the model. If information on fertiliser practices and ground cover interaction becomes available, the model could be easily amended so that it could be applied to a broader range of sites.

References

Ambarawati, I.G.A.A. 1995, 'The contribution of supply and demand components to the instability of Indonesian natural rubber price', MEc dissertation, University of New England, Armidale.

Barlow, C., Jayasuriya, S. and Tan, C.S. 1994, The World Rubber Industry, Routledge, London.

Barlow, C. & Muharminto 1982, 'The rubber smallholder economy', *Bulletin of Indonesian Economic Studies*, vol. 18, pp. 86-119.

Cacho, O.J., Bywater, A.C. & Dillon, J.L. 1999, 'Assessment of production risk in grazing models', *Agricultural Systems*, vol. 60, no. 2, pp. 87-98.

Central Board of Statistics of Indonesia (CBSI) 1998, *Plantation Estates Statistics 1997*, Jakarta.

_____ various issues, *Statistical Pocketbook of Indonesia: Annual Statistics*, Jakarta.

Dereinda, R., Asmar-Arsjad & Sadarudin 1989, 'Nucleus estate and smallholder rubber development in Indonesia: Socio-economic issues for research', *Proceedings of RRIM Rubber Growers' Conference*, Rubber Research Institute of Malaysia, Malacca, Malaysia, 21-23 August 1989, pp. 636-46.

Directorate General of Estate Crops (DGEC) 1998, *Statistical Estate Crops of Indonesia: Rubber 1995-1997*, Jakarta.

Gouyon, A. and Nancy, C. 1989, 'Increasing the productivity of rubber smallholders in Indonesia: agro-economic constraints and proposals', *Proceedings of the RRIM Rubber Growers' Conference*, Rubber Research Institute of Malaysia, Malacca, malaysia, 21-23 August, pp. 587-613.

Grist, P.G. & Menz, K.M. 1995, 'Modelling the economic of *Imperata* control in smallholder rubber plantations', Canberra, CRESS, ANU: *Imperata* Project Paper, 1995/5.

Grist, P.G. & Menz, K.M. 1996a, 'An economic analysis of the commencement of tapping by smallholders in Indonesia' *Journal of Natural Rubber*, 1996, vol. 10, no. 4, pp. 276-82.

_____ 1996b, 'The economics of *Imperata* control in Indonesian smallholder rubber (*Hevea* spp.) plantations using bioeconomic modelling', *Tropical Agriculture*, vol. 73, no. 4, pp. 320-24.

Grist, P.G., Menz, K.M. & Amarasinghe A. 1997, 'Private and social benefits from the use of clonal rubber', Canberra, CRESS, ANU: *Imperata* Project Paper, 1997/10.

Grist, P.G., Menz, K.M. & Thomas 1998, 'Modified BEAM Rubber Agroforestry Models: RRYIELD and RRECON', *ACIAR Technical Reports Series*, no. 42.

Hartwick, J.M. & Olewiler, N.D. 1986, *The Economics of Natural Resource Use*, Harper & Row Inc., New York.

Lynch, B. 1977, *Indonesia: Problems & Prospects*, Sorrett Publishing Pty Limited, Victoria.

Mubyarto & Dewanta, A.S. 1991, *Karet: Kajian Sosial-Ekonomi*, Aditya Media, Yogyakarta.

Neher, P.A. 1990, *Natural Resource Economics: Conservation and Exploitation*, Cambridge University Press, Cambridge.

Palisade 1996, *A User's Guide to @RISK: Risk Analysis & Modelling*, Palisade Corporation, New York.

Whitmore, G.A. & Findlay, M.C. 1978, *Stochastic Dominance: An Approach to Decision-Making Under Risk*, D.C. Heath and Company, Lexington.