Investing in Oil Palm: An Analysis of Independent Smallholder Oil Palm Adoption in Sumatra, Indonesia

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Abstract

This papers investigates the economic profitability and incentives for independent smallholders to invest in oil palm. Profitability is calculated using the policy analysis matrix framework. A real options model of investment under uncertainty and irreversibility is then developed using monthly nominal prices of crude palm oil covering the period 1987-1999 to derive the parameters of the model. The results suggest that the returns to oil palm are potentially high relative to other smallholder activities, but that significant sunk costs and uncertainty in returns may create an option value to waiting to invest in oil palm. These modified conversion thresholds suggest that critical investment levels for the adoption of oil palm may be over 6 times higher than cost of the investment.

1. *Introduction*

Indonesia is endowed with the second largest expanse of tropical forest on the globe. Using 1997 satellite imagery, the Ministry of Forestry and Estate Crops has produced new forest cover maps for the islands of Kalimantan, Sulawesi and Sumatra which show a shocking loss of more than 17 million hectares in 12 years. This is one-fourth of the total Indonesian forest cover that existed in 1985. The ministry now estimates that the nationwide annual deforestation rate is at least 1.5 million hectares, nearly twice the estimate published by the World Bank in 1994 (Walton & Holmes, 2000). In terms of prioritizing for the conservation of "biodiversity hotspots" Indonesia is ranked at the top of global list (Myers *et al*., 2000). The leading cause of deforestation has been commercial logging, but the growth of the tree-crop sector has also been rapid, in particular for oil palm.

The government of Indonesia (GOI) has long viewed its forest resources as an asset to be converted to other uses in order to support its growth strategy. This is the primary reason that Indonesia is a world leader in the export of tropical forest products. Since the 1960's the GOI has promoted the expansion of oil palm estates to meet such strategic needs as foreign exchange, domestic cooking oil supply, and the absorption of an increasing rural labor force. Initial government support favored state-owned companies. Support for smallholders began in 1978 as the government began to initiate block schemes. The primary scheme is the Perkebunan Inti Rakyat or Nucleus Estate and Smallholder Scheme (PIR/NES).

In 1997, the GOI had plans to double the area in oil palm from 2.5 million hectares to 5 million hectares before the year 2000. Beginning with the financial crisis that started in 1997, there have been a number of changes in policy and market conditions that have slowed the rate of growth in area of oil palm estates, but the sector still expanded by 6% percent in 1999. Throughout the 1990's the land area allocated to oil palm plantations grew at an average rate of 13% to a total of about 3.5 million hectares by the end of the 1999.

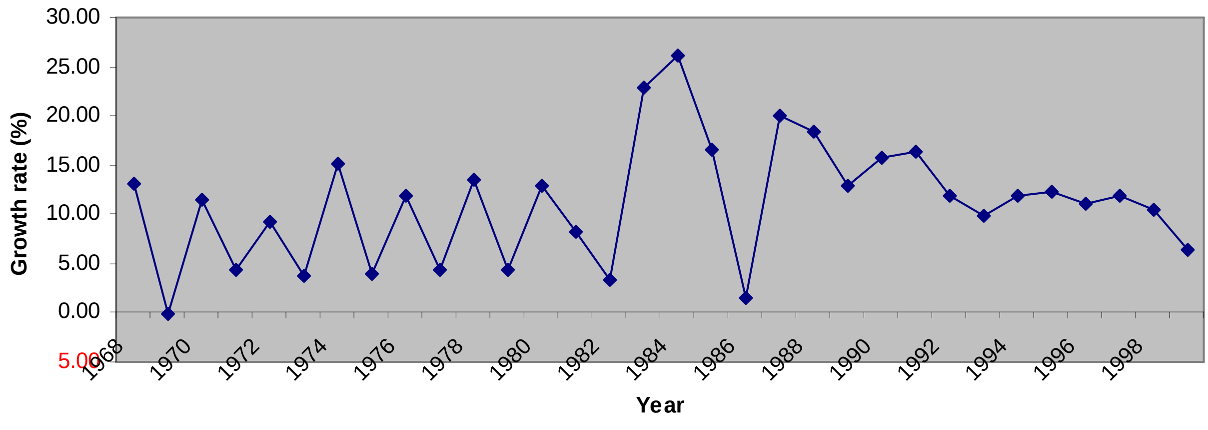


Figure 1: Growth Rate of Total Area in Oil Palm (1967-1999)

With the exception of oil palm, most tree crops in Indonesia belong to smallholders. Although smallholders involved in block schemes such as the NES/PIR schemes officially manage almost one-third of land allocated oil palm to Indonesia, severe monitoring costs and poor management have led to severe difficulty in recovering capital and interest payments. In the late 1980's, as the area allocated to oil palm continued to expand, a parallel increase in the number of processing facilities led to a situation of overcapacity in many areas, especially in the province of Northern Sumatra. Independent smallholder farmers began to cultivate informal oil palm plots to take advantage of this marketing niche. Since that time, the development of independent smallholder cultivation has continued to follow the expansion of oil palm estates in other provinces of Sumatra and Kalimantan. To date there has been no formal study of these independent farmers choosing to convert their land to oil palm.

As the agricultural frontier continues to expand, there is a premium for information relating to the crops in the vanguard of this expansion. In Indonesia, indications from investment behavior by large plantations indicate that there is transition underway from rubber to oil palm in Sumatra. If independent smallholder rubber farmers also begin to follow this pattern, this shift in landuse activities could have significant implications for the environment. Increasing fragmentation of tropical forest habitat and landscapes poses a serious threat to the biodiversity found in both primary and secondary forests and the increasing rate of conversion of secondary forests is cause for re-thinking and re-assessing strategies for tropical landscape planning and conservation. Most economic models concerned with forest conversion deal with primary forests. The conversion of secondary forests and rubber agroforests to monoculture agriculture has received no attention in the literature. Rubber agroforests have a complex ecological structure and support biodiversity similar to that found in a secondary tropical forest in its mature phase (Gouyon, *et. al.*, 1993). The primary purpose of this paper is to explore the profitability of independent smallholder oil palm using the policy analysis matrix and then to the explore the incentives to convert land to oil palm when the land conversion decision is modeled as an investment decision. In particular, a real options approach will be used to investigate the incentives to convert land to oil palm when economic returns to oil palm are uncertain .

2. *The Policy Analysis Matrix*

The policy analysis matrix (PAM) is designed to analyze the pattern of incentives at the microeconomic level and to provide quantitative estimates of the impact of polices on those incentives.[1] Understanding the economic and financial incentives faced by smallholder farmers is an important aspect of the decision to convert land to oil palm cultivation. The PAM is a partial equilibrium static framework which provides a consistent framework to analyze household information regarding land use activities and relate these direct financial and economic incentives to relevant government policy which influences these incentives. The PAM is based on a comparison of household production budgets for the production of oil palm valued at private and social prices. The budget shows the benefits and costs of producing a given output with a particular technology. The private prices are the prices that households and firms actually face and provide a measure of the financial incentives for adoption and investment in oil palm by independent smallholder farmers. Social prices, calculated at economic ‘shadow prices’ remove the impact of policy regulations and market imperfections and provide an indicator of the potential profitability or comparative advantage of a particular land use activity. The basic structure of the PAM is shown in Figure 2.

[1] Monke & Pearson (1989) is the standard reference for the Policy Analysis Matrix.

Figure 2. Structure of the Policy Analysis Matrix

		Costs		
	Revenues	Tradable Inputs	Domestic factors	Profits
Private Prices	A	B	C	D
Social Prices	E	F	G	H
Divergences	I	J	K	L

D = A - B - C; H = E - F – G;

I = A – E; J= B – F; K = C – G; L = D – H = I – J - K

The first row of the matrix shows the profitability of an activity from the perspective of the individual farmer as valued by private prices. This row captures the production budget for a land use activity with the revenue and costs reflecting actual market prices paid by farmers. Private profits are given by cell D which is the difference between revenues and total costs. The second row captures the production budget for the same activity valued at social prices (shadow prices) which attempts to remove the impact of policy distortions and market imperfections on the financial incentives faced by smallholder farmers. Social profitability is given in cell H. The third row of the matrix shows the divergence between private and social profitability. This divergence shows how policies and market imperfections affect the financial incentives faced by smallholder farmers. To permit comparisons among systems producing different outputs the expression of profitability in terms of a constraining domestic factor resource can be used. In this case, the constraining domestic factor is land.

Most of the land use alternatives in Sumatra involve perennial crops such as rubber, coffee, or oil palm. Thus, an appropriate measure of profitability in the PAM for smallholder farmers is the net present value (NPV) of revenues less costs over a 25-year period. By definition, an activity in which NPV is less than zero is unprofitable by definition. This does not rule out positive cashflows, but does indicate that it would be more profitable to be engaged in alternative activities. In areas where land is scarce the NPV calculation over the 25-year period can be interpreted as the ‘returns to land’ for that land use activity. Although land abundance and labor scarcity historically prevailed in many areas of Sumatra, making it an attractive focus of government sponsored transmigration programs, this relationship seems to shifting. Much of this “excess” land has been subsequently granted to industrial plantations or has been settled by spontaneous migrants. Jambi province is currently an attractive destination for many spontaneous migrants from neighboring provinces because of cheaper land prices in Jambi. However, land prices in many areas of Jambi province which are suitable for oil palm cultivation have increased 3-4 fold in the last 2-3 years.

Adjusting the wage rate until NPV goes to zero can be used as a proxy for ‘returns to labor’ since this calculation converts the surplus to a wage rate. Returns to labor that exceed the average daily wage rate, indicate that individuals with their own land will prefer this activity to off-farm activities and it also justifies hiring non-family labor. Returns to labor valued at private prices can thus be viewed as the primary of indicator of profitability for smallholder’s production incentives.

Analysis of the PAM provides answers to important questions regarding the potential financial profitability of independent smallholder oil palm cultivation. More specifically, these indicators can be used to compare the financial incentives of different land use activities found across the Sumatran landscape. Although most conversion of land to oil palm across Indonesia has been in the form of large state and privately-owned plantations, the appearance of independent smallholders cultivating oil palm indicates its potential to become a viable crop for independent smallholders and its potential to compete with other land use activities such as rubber cultivation. Viewed as a long-term investment for smallholders, the economic profitability of oil palm cultivation is of interest to not only individual farmers, but also to policy makers and researchers involved in understand and promoting "best-bet" land use activities[2].

3. *Oil Palm Productivity*

Productivity of smallholder oil palm plots is an important factor in determining the profitability of oil palm for smallholder cultivators. Production in these smallholder developments in many cases remains suboptimal due to the following reasons:

(1) the use of uncertified seed which produces unproductive trees;

(2) planting at the wrong planting distance which results in excessively dense stands which results in good tree growth but poor yields;

(3) incorrect management such as pruning, insufficient weed control, and problems with pest management;

(4) insufficient use of the proper fertilizers due to lack of knowledge or financial capital.

Although the use of uncertified seedlings is presently a problem for independent smallholders, it is likely to become less of a problem in the future. In the past, independent farmers were unable to obtain certified seeds directly from the Indonesian Oil Palm Research Institute (IOPRI), or SOCPHINDO. However, this has recently changed and independent smallholders can directly purchases seedlings as long as they have a letter from the provincial or district office for estate crops. Like the use of uncertified seedlings, the improper design of planting distances is likely to be less of a problem as more smallholders can gain access to better extension services and diffusion of knowledge from other successful farmers in the village or district. Almost all of the smallholders interviewed had a proper understanding of proper planting dimensions. In fact, many farmers hire independent workers with proper experience for the task of lining the fields before planting. The same can be said for problems stemming from improper management. As more smallholders adopt oil palm and extension services improve, these problems will be less frequent. In many areas of Jambi & Riau, especially on plots adjacent to forested areas, the primary management concern is during the first year after planting when the trees are highly vulnerable to wild boar. Farmers who have combined using a fence in combination with poison seem to have the most success in solving this problem. These solutions are not prohibitively expensive, but are essential for successful establishment.

[2] See Tomich, T. *et-al*. (1998) for a discussion of methods to identify the impact of different land use activities on tropical landscapes based on the concerns and objectives of both smallholder farmers concerned with making a living and policy makers concerned with preserving global public goods.

Perhaps the largest establishment constraint for independent smallholder is sufficient capital for purchasing sufficient amounts of the proper fertilizers. Oil palm is an input intensive crop requiring up to 950 kg of fertilizer per year on a single hectare plot. The share of fertilizer costs in annual total costs of managing an oil palm plot after it has been established averages around 80% percent for smallholders who use the recommended amounts. This contrasts greatly with land in rubber which is a labor-intensive crop.

The fresh fruit bunches (FFB) yield estimates used in the PAM analysis are conservative estimates based on field observations and discussions with district level estate crop officers. This analysis assumes proper fertilizer usage for the given soil type and can be considered a lower bound for FFB productivity and an upper bound for fertilizer usage.

4. Construction and Assumptions of the PAM Parameters

Static, partial-equilibrium household budgets were constructed using data from field surveys conducted in Jambi and Riau provinces between October and December of 1999. The farm budget valued at private prices uses the data collected in the field during this period. Inputs requirements for the farm budget valued at social prices use annual average prices over a 12-year period from 1987 to 1999. Social prices have been converted to constant real prices using 1997 as the base year. Social prices or economic shadow prices have been modified from world prices in order to remove the impacts of policy distortions and market imperfections. Although it is unreasonable to assume that all policy distortions and market imperfections are captured in the calculations, policies such as export taxes and direct fertilizer subsidies clearly alter the economic incentives for a given land use activity and thus should be taken into account. For several of the inputs and capital, it was not possible to obtain historical prices or world prices so 1999 market prices are used as the social prices. In addition, the 1999 wage rate is used both social and private prices. Although this will clearly result in underestimating the effects of policy distortions and market imperfections it does not obscure the calculations of the private profitability which is the primary indicator of the incentives faced by smallholder farmers. The following table summarizes a few of the most important parameters used to calculate the results.

Table 1.	**Parameters used in PAM**
Wage Labor	6,000 Rp/day
Nominal Interest Rate	20%
Social Interest Rate	15%
Range of farmgate output prices (depends on age of trees)	185-271 Rp/kg

5. Costs of Establishing Oil Palm

Total cost of converting an existing hectare of jungle rubber to oil palm is Rp 6,746,000 for the first four years until there is positive cashflow. These establishment costs include expenditures for all labor and purchased inputs. Table 1.1 shows the composition of these initial sunk costs.

Table 2 Sunk Costs for the Establishment of Oil Palm (from jungle rubber)

		Rp '000 / ha	%
Total Cost		**6,746,033**	**100**
Purchased inputs		**5,908,700**	**87.6**
	Tools	500,000	7.4
	Seedlings	1,200,000	17.8
	Fertilizer, Herbicide, & Pesticide	4,208,700	62.4
Labor		**780,000**	**11.6**
	Land clearing	312,000	4.6
	Field Preparation & Planting	144,000	2.1
	Field Management	324,000	4.8
Capital Expenditures		**57,333**	**0.8**

The purchase of fertilizer, herbicide, and pesticides represents the largest share of these initial establishment costs with 62.4 % of the total. These costs do not include the purchase of land that would be a significant additional cost for migrant farmers. During the period of fieldwork in 1999, the cost of land in Jambi province ranged from 500,000 to 1,000,000 Rp per hectare depending on the distance from the main road.

During this establishment stage, the biggest demand for labor occurs in the first year as the land is cleared, prepared, and planted with oil palm. Some smallholders rely completely on household labor whereas other farmers hire off-farm labor for these conversion activities. Table 2 shows labor requirements for various land use activities in Sumatra. The labor requirement for establishing independent smallholder oil palm is 130 person-days/hectare.

This is substantially less than other activities such as rubber or large estate oil palm. The average labor requirement for the operational phase (years after positive cashflow) in smallholder oil palm at 51 person-days/hectare/year is substantially less than the other land use activities. The total average labor requirement per year is also substantially less for independent oil palm smallholders. Many smallholder farmers indicated during interviews that one of the primary reasons for wanting to grow oil palm is that far less labor is required to maintain and harvest a plot of land in oil palm relative to rubber which requires over two to three times more person-days per year for tapping a single hectare of rubber.

Table 3. Labor Requirement for Various Land Use Activities in Sumatra

Land Use System	Establishment Period (Person-days/ha)	Operation Phase (Person-days/ha/yr)	Total Labor (Person-days/ha/yr)
Oil Palm (independent smallholder)	130	51	48
Oil Palm (large estate)	532	83	133
Rubber Agroforest	271	157	111
Rubber Monoculture	444	166	150

Source: modified from Table IV.4 in Tomich, *et al*. 1998.

6. Returns in Oil Palm

The NPV of returns to a single hectare of land in oil palm over a 25 year span is 2,908,115 Rp valued at private prices and a discount rate of 20 percent. Returns in this study exclude a profits from selling timber harvested during the conversion of land to oil palm. In the case of converting land from jungle rubber to oil palm, these returns would not be significant as the timber from old rubber trees has little market value. However, if land is being converted from secondary or primary forest, the profits from illegally selling marketable timber could cover a large portion, if not all, of the establishment costs during the first four years.

Returns in oil palm have positive signs using both private and social prices. Smallholders begin to realize positive cashflow in the fifth year after planting. However, returns to land as measured by the NPV over the 25-year period and returns to labor are highly sensitive to the discount rate used in these calculations. Estimates of returns to land and to labor, each evaluated at both private and social prices are presented in Table 3[3]. The results are shown for different values of both the private and social rates of interest.

Table 4. Profitability of Independent Smallholder Oil Palm (Sensitivity to Interest Rate)

Interest rate Private	Interest rate Social	Returns to Land (NPV) Rp '000 per ha: NPV at Private Prices	NPV at Social Prices	Divergences	Returns to Labor (wage to set NPV to zero) Rp per person-day: At Private Prices	At Social Prices
20%	15%	2,908	10,975	(8,067)	19,635	44,465
15%	15%	6,636	10,975	(4,340)	29,256	44,465
15%	10%	6,636	19,604	(12,968)	29,256	53,478
10%	10%	13,786	19,604	(5,817)	39,389	53,478

[3] 1999 market prices are used to evaluate profitability at private prices. This includes prices on all input costs.

Returns to land and returns to labor vary greatly depending on the discount rate used. A private discount rate of 20% and a social rate of 15% were chosen as the initials values to facilitate comparison with PAM results of different land use activities already analyzed by the ASB program. It is argued that a private discount rate of 20% is a lower bound for the actual cost of capital for smallholders due to imperfections in Indonesian capital markets (Tomich *et al*., 1998). In this analysis, private discount rates over 28% would result in negative returns to land. The sensitivity of returns to land and labor to changes in the discount rate suggest that the high cost of capital to smallholders may play an important role in deterring smallholders from adopting oil palm. However, at a private interest rate of 20%, the returns to labor at 19,635 are significantly higher than the range of alternative labor opportunities that exist in Sumatra which ranges from Rp 5,000 to 10,000. The difference between the private and social interest rates is also the main cause of divergences between NPV at private and social prices. Roughly 50 % of this divergence is due to differences in private and social discount rates and thus cannot be attributed to any particular government policy. The rest of the divergence is primarily a result of government subsidies of fertilizer and export taxes on crude palm oil. The export tax is implemented by the GOI to control domestic prices for cooking oil. However, the burden of the export tax falls primarily on the producers of oil palm fruits. Government subsidies for fertilizers ranged from 21 to 59 percent between 1987 and 1997. However, the GOI ended fertilizer subsidies in 1998 during the monetary crisis. Because prices for smallholder fresh fruit bunch output are calculated directly from monthly crude palm oil prices any export tax levied by the government is partially passed on to smallholders. During the economic crisis, the government of Indonesia in a failed attempt to control the domestic price of crude palm oil, temporarily imposed a ban on exports and then replaced it with a higher export rate of 40 % and eventually 60%. Unfortunately, these high taxes, by discouraging exports, didn't allow all smallholders to benefit from the favorable conditions of a devalued currency rate and high international prices for crude palm oil. Instead many smallholders saw a decline in output price in combination with rising fertilizer input costs. These high export taxes have subsequently been lowered to rates similar to pre-crisis levels of around 10 %.

The high returns to land and labor for smallholder oil palm compare favorably with returns to land and labor in other land use activities. Table 4 compares these returns across several optional land use activities.

Table 5. Comparison of Returns in Different Land Use Activities

Land Use Activity	Returns to Land (NPV) Rp '000 per ha			Returns to Labor (wage to set NPV to zero) Rp per person-day	
	NPV at Private Prices	NPV at Social Prices	Divergences	At Private Prices	At Social Prices
Oil Palm (independent smallholder)	2,908	10,975	-8,067	19,635	44,465
Oil Palm (large estate)	275	1,480	-1,205	5,797	9,981
Rubber Agroforest (Old Jungle Rubber)	207	466	-259	4,703	5,080
Rubber Agroforest (Clones)	(-95) to 2202	234 to 3,623	(-330) to 1,420	3,900 to 6,900	4,200 to 7,700

These results indicate that independent smallholder oil palm offers the largest returns to land and returns to labor. In oil palm, returns to oil palm for independent smallholders are significantly higher than large estates in part because they do not have the high infrastructure and management costs required to run a large-scale plantation. Results in Table 4 also indicate that there are substantial financial incentives for smallholders to convert land from rubber to oil palm. The high returns in oil palm combined with the relatively lower labor requirements for establishing oil palm (see Table 2) make it an attractive land use option for smallholders. Perhaps the largest constraint facing smallholders who are interested in cultivating oil palm are the large sunk costs involved in establishing oil palm, in particular the large financial costs required for the purchase of mineral fertilizer inputs.

The PAM analysis indicates that independent smallholder oil palm cultivation is financially viable. The returns to land and labor in oil palm compare favorably with other land use activities including rubber which is the primary smallholder crop in the peneplains of Sumatra. These results indicate that independent smallholders face positive economic incentives encouraging them to convert their land to monoculture oil palm. The question naturally arises as to what constrains smallholders from converting their land to oil palm given the large potential returns in this activity?

7. Barriers to converting land to oil palm

There are four primary factors which may constrain smallholder farmers from converting land to oil palm. The first set of constraints facing smallholders interested in converting land to oil palm is the uncertainty over institutional barriers to output markets. Because oil palm has long been considered a plantation or estate crop, independent smallholders were discouraged from planting oil palm and the plantations would not buy fresh fruits from independent sources. However, with the overcapacity in existing processing facilities and the establishment of independent processing mills, a market niche was created for independent cultivators living in regions with excess processing capacity[4]. Independent smallholders are free to seek the highest prices for their fresh fruit bunches, but they are dependent on agents to market their output to the processing mills. These agents buy directly from independent smallholders and sell directly to the processing mills. Many processing mills and plantations currently have large problems with plantation smallholders selling their fresh fruits to independent agents rather than to the plantation processing mills and this has created some problems for independent smallholders who are subsequently barred from selling their sell their output to those plantations.

The second constraint inhibiting smallholders from successfully adopting oil palm is a lack of knowledge in technical issues. These are productivity-related issues such as use of proper seeds and sufficient use of the proper fertilizers which were described above. Most the independent smallholders interviewed had expertise in oil palm management from previous experience working for a plantation or they actively obtained information from neighbors and others with successful oil palm plots. At present, there are no official extension programs available to independent smallholders who would like to crop oil palm. However, several extension officers working at district level Estate Crops offices in Jambi province indicated that they would like to begin extension programs for oil palm, but did have the mandate or resources to do so.

The third constraint is the issue of large sunk costs involved in establishing oil palm. The large sunk costs of establishing oil palm constitute an important barrier to entry for many smallholders interested in converting some or all of their land to oil palm. Most smallholders cultivating rubber are typically poor with few off-farm income sources. Positive cashflows in oil palm do not occur until the fifth year so it would be necessary to have an alternative source of income to meet the financial demands of establishing oil palm in addition to providing basic necessities and food for family members[5]. Most of the smallholders involved in oil palm that were interviewed for this study had alternative sources of income ranging from other agricultural crops to small stores and other non-farm activities.

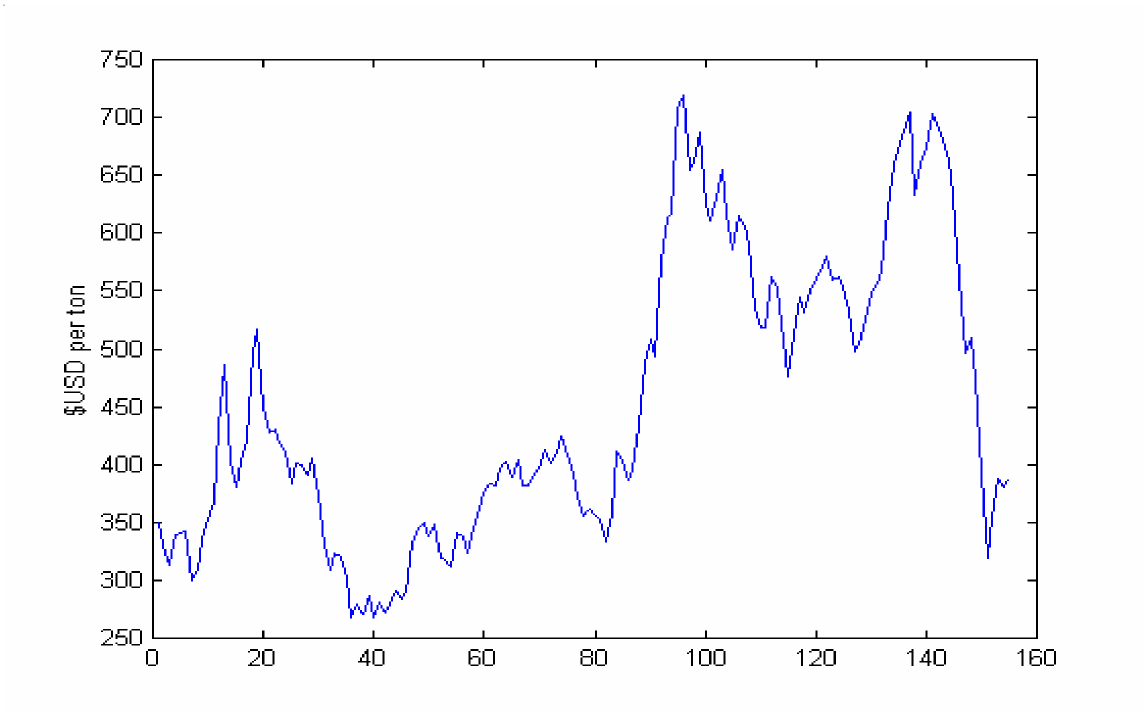
The fourth constraint stems from the effects of uncertainty on the incentives to invest in oil palm. The standard measure for judging whether or not an investment opportunity is economically sound is the net present value (NPV). This decision criterion is generally sound when estimated costs and revenues from an investment opportunity are certain. However, in the presence of significant sunk costs which are difficult to recover, or uncertainty in prices or revenue, there are elements of uncertainty and irreversibility in the investment decision which fail to account for the value of the flexibility to postpone or delay the decision. The NPV investment criterion does not account for this option value to waiting. Most agricultural activities, including oil palm and rubber are subject to considerable risk and uncertainty in both prices and yields. In the case of independent smallholder oil palm cultivation, the NPV measures generated from the static PAM model indicate that that there are positive economic incentives which may influence the decision to convert land from one

[4] Fresh fruit bunches need to be processed within 24-48 hours after harvesting limiting areas suitable to oil palm cultivation to areas which are within a 24 hour drive from the closest mill. It is not common for smallholders to sell to independent middlemen who have contracts with certain processing mills.

[5] In the PAM analysis, only costs directly related to the crop were considered. Food and basic necessities were not considered. Here it is assumed that smallholders have alternative income sources to cover these costs. It should be noted that many smallholders attempting to establish oil palm were also growing fruit and vegetables either for own consumption or to be sold as a source of cash income.

land use activity (eg. rubber agroforestry) to oil palm. However, it is also clear from the analysis that there are significant sunk costs required to convert land from rubber to oil palm (see Table 2). The presence of uncertainty in prices for CPO may also contribute to the existence of an option value to waiting to convert land to oil palm. Figure 3 shows the monthly world prices for CPO over the period 1987-1999.

Figure 3. – Nominal CPO Price (1987-1999)



The following section of the paper will investigate the incentives to invest in oil palm using a real options approach. The considerable uncertainty in agricultural activities clearly suggests that these investment decisions be more appropriately analyzed using a dynamic model of investment rather than the static NPV indicator used in the PAM analysis.

8. *The real options approach*

An appropriate way to view land conversion activities is to view them as investment decisions analogous to investment in other types of productive capital. Many features of oil palm and many other agricultural crops suggest that investments in these activities require sunk costs that are not easily recovered. In addition, uncertainty stemming from stochastic processes in both yields and prices requires a framework of analysis which can account for both uncertainty and irreversibility.

The traditional approach to valuing an investment is calculate the level of investment at which the discounted expected returns from an investment are equal to the present value of the investment cost. This point is referred to as the 'Marshallian trigger' and can be written as:

$$M = rC$$

where M is the expected return from the investment, r is the discount rate, and C is the sunk cost of the investment. Following Shively (1996) the risk modified hurdle rate or Marshallian trigger can be written as:

$$M = \delta C = \frac{\beta}{\beta - 1}\delta C > \delta C \qquad (1)$$

where the parameter β is greater than 1 and depends on the level of uncertainty in the investment. When investments are analyzed in this framework, investments that would be made using the standard Marshallian trigger rule would be rejected under this modified framework. Purvis et al. (1995) and Fousekis & Shortle (1995) provide examples in agriculture in which investments that would have normally been made are rejected using the modified framework.

9. A Stochastic Model of Land Conversion with Price Uncertainty

Returns in oil palm are uncertain in both yields and out put prices. Oil palm yields can vary from month to month depending on weather and previous use of inputs. Prices for fresh fruit bunches are also uncertain and depend on the movement of the price for crude palm oil (CPO) on the world market. In this simplified analysis, I will assume that both price and yield uncertainty are captured in overall returns to oil palm.

The decision to convert land from rubber to oil palm is characterized by a relatively large sunk cost for establishing oil palm and significant uncertainty in future returns. This uncertainty influences the timing of conversion to oil palm by risk-neutral smallholders who have the financial capital to convert land from rubber to oil palm. Smallholders with land in rubber face the continuous decision of whether to continue the land in rubber or whether to convert to the alternative use, oil palm. Converting land from rubber to oil palm is not an irreversible decision in the long run. However, due to the large sunk costs, both financial and temporal, of converting from one perennial tree crop to another, I will treat this decision as an irreversible decision over the time period of interest. If the smallholder decides to convert land from rubber to oil palm, the returns are equal to the future returns in oil palm less the conversion costs. If the smallholder decides to continue to keep the land in rubber, the value of the land includes the next periods profits, but also the value of a future option to convert the land to oil palm. This choice can be represented by:

$$V = \max\left\{ E\left(R_t\right) + E(V_{t+1}^R)\left(\frac{1}{1+rdt}\right)^{-1}, E(V_{t+1}^P) - C_t^P\left(\frac{1}{1+rdt}\right)^{-1} \right\} \qquad (2)$$

where: V – value of the investment option;
$E(R_t)$ - the expected returns to rubber;
$E(V_{t+1}^P) - C_t^P$ - the expected returns in oil palm less sunk costs for establishment;
r – smallholder discount rate.

The first term in the brackets represents the expected returns from keeping land in rubber and the second term represents the expected returns once the smallholder has converted to oil palm. When smallholders with rubber convert land to oil palm this is equivalent to buying an asset for the exercise price of foregone rubber returns plus the cost of conversion. The smallholder earns the rights to returns in oil palm after the conversion time, T. The value of this investment opportunity can be written as:

$$F(V) = \max E\left\{\left(\frac{P}{r-\theta}\right)e^{(\theta-r)T} - \left(\frac{R}{r-\mu}e^{(\mu-r)T} + C^P\right)\right\} \qquad (3)$$

where: P – returns in oil palm
θ - the growth rate in returns to oil palm
u – growth rate in returns to rubber

By assumption, $r > \theta > \mu$. If the growth in returns to oil palm θ, were not greater than the returns in rubber μ, then no farmer would ever make the transition from rubber to oil palm.

Now to derive the value of the option under price uncertainty, model the incremental value of the investment in oil palm *dP* so that the returns to oil palm are approximated by a geometric Brownian motion process (random walk). The returns (ie. the value of the investment in oil palm) thus evolve stochastically according to:

$$dP = \alpha P dt + \sigma P dz \qquad (4)$$

where *dz* is the increment of a Wiener process and *dt* is the time increment. The term, α, has the interpretation of a fixed proportional growth rate and the term, σ, is a fixed variance rate. This Wiener process (Brownian motion) is a continuous time stochastic process with three important properties. First, it is a Markov process which is important because it means that only the current value is needed in order to predict its future value. Secondly, the Wiener process has independent increments so that a change in the process over any time interval is independent of any nonoverlapping interval. Finally, the change in the process over any time interval is normally distributed with a variance that increases linearly with time (Dixit & Pindyck, 1994, pg 63).

Over the time interval when land remains in rubber, the value of the land is equivalent to the continuous returns in rubber plus the value of the investment opportunity to convert the land to oil palm. This land value can be determined by using the equilibrium condition which states that the rate of return on the asset must be equal to the market return the asset would yield if were sold (ibid, pg. 140). That is, the asset's value times the market interest rate, *r*, such that:

$$rFdt = \varepsilon(dF) \qquad (5)$$

In order to expand dF use Ito's Lemma to get:

$$dF = F'(V)dV + 0.5F(V)''(dV)^2 dt \qquad (6)$$

Now substitute (18) into (20) and note that $(dz)^2 = dt$:

$$E(dF) = \alpha V F'(V)dt + 0.5\sigma^2 V^2 F''(V)dt \qquad (7)$$

Now substitute this back into the equilibrium condition (19) and divide by *dt*:

$$\alpha V F'(V) + 0.5\sigma^2 V F''(V) - rF = 0 \qquad (8)$$

This Bellman equation must satisfy three boundary conditions: (1) $F(0)=0$ which says that the option to invest in oil palm is worth zero if the value of investing in oil palm is zero; (2) $F(V^*)=V^{*P}-C^P$ which says that at the optimum, the smallholder will receive the payoff (V^*-C^P) which is also known as the value matching condition; (3) $F'(V)=1$ which is the smooth pasting condition which requires that the value matching condition be continuously differentiable. To solve for *F(V)*, the solution takes the general form:

$$F(V) = A_1 V^{B_1} + A_2 V^{B_2} \qquad (9)$$

The two roots to this general solution, B_1, and B_2, can be solved and shown to be $B_1 > 1$ and $B_2 < 0$ (Dixit & Pindyck, pg. 142). Since the first boundary condition of the Bellman equation states that the value of the investement opportunity must go to zero when the value of the investment is zero, this implies that $A_2 = 0$. Now the general solution can be used to solve for the optimal V^*. At the time of conversion, the value of the land is equivalent to the returns in rubber plus the option value of waiting to convert and this is equal to the value of the land in oil palm less the costs of conversion which leads to:

$$A_1 V^B + \frac{R}{\mu - r} = V^* - C^P \qquad (10)$$

where $B_1 = B$. Now the second and the third boundary conditions can be substituted into (24) to solve for V^*. This lead to:

$$\frac{V^* - \left(C^P - \frac{R}{\mu - r}\right)}{V^B} = \frac{V^{1-B}}{B} \qquad (11)$$

which can be re-arranged to solve for the critical value which is the optimal conversion threshhold:

$$V^* = \left(\frac{R}{\mu - r} + C^P\right)\left(\frac{B}{B-1}\right) \qquad (12)$$

where the root of the solution is:

$$B = 0.5 - \frac{\alpha}{\sigma^2} + \sqrt{\frac{\alpha}{\sigma^2} - 0.5 + \frac{2r}{\sigma^2}} \qquad (13)$$

Because B1 > 1, the term $\left(\frac{B}{B-1}\right)$ > 1 which implies that $V^* > \left(\frac{R}{\mu - r} + C^P\right)$. Thus one can see that land is not converted when the value of land in oil palm is equal the the foregone returns in rubber plus the conversion costs. Because of the uncertainty in oil palm returns which is captured in the term, $\left(\frac{B}{B-1}\right)$, smallholders optimally wait to convert until the value of the investment in oil palm exceeds the opportunity costs of foregone revenue in rubber and the cost of conversion. This is equivalent to an option value to waiting to convert land from rubber to oil palm. The factor, $\left(\frac{B}{B-1}\right)$, depends on the parameters of the Ito process and the smallholder's discount rate, *r*. The option value to waiting delays the conversion decision and allows the smallholder to avoid downside losses due to uncertainty while still retaining the opportunity to have access to future outcomes that are more favorable. In this case, uncertainty in the returns to oil palm give rise to a value of waiting to convert land from rubber to oil palm.

It can also be shown that as the degree of uncertainty increases, $\sigma \rightarrow \infty$, $B \rightarrow 1$. More intuitively, the threshold of conversion will increase as the uncertainty parameter increases, or as $B \rightarrow 1$ land is less likely to be converted to oil palm as the uncertainty in returns to oil palm becomes exceedingly large. This is related to the result $\frac{dB}{d\sigma} < 0$ which implies that as uncertainty increases, the risk factor, $\left(\frac{B}{B-1}\right)$, increases which thus increases the critical conversion value.

This rise in the critical conversion value is best understood by viewing the decision to delay conversion to oil palm as a decision to gain more information over the parameters responsible for the uncertainty in oil palm returns. This uncertainty could be due to uncertainty in variability in yields or variability and uncertainty in the prices that smallholders recieve for selling their fresh fruit bunches. When more information is gained during this interval, the option value to waiting becomes larger.

Equation (12) can viewed as the risk-modified hurdle rate, where the level of the risk factor, $\left(\frac{B}{B-1}\right)$ depends on the parameters of the Wiener process represented in equation (4).

10. Empirical Analysis of the Risk-Modified Hurdle Rate

To explore the impact of price uncertainty on the investment decision, it is necessary to generate estimates of the risk factor which is based on equation (13). This analysis uses the price series represented in Figure (3) which charts monthly nominal crude palm oil prices over the period 1987-1999. Month smallholder prices for fresh fruits is not available, but because the prices which smallholders receive is calculated directly from these crude oil palm prices and it is assumed that smallholder prices would follow a similar pattern of the same time-frame. Equation (4) assumes Brownian motion in returns. In order to test whether this is a valid assumption, the price process should be tested for a unit root.

11. Testing for the Unit Root and Markov Properties of the Price Process

The theoretical model developed above makes the assumption of pure Brownian motion to describe the diffusion process of oil palm prices. Are CPO prices best modeled as geometric Brownian motion or as a mean-reverting process? If the price generating process can be characterized by a Brownian motion diffusion process, it is also a Markov process. This

$$\Delta P_t = \alpha_0 + \alpha_1 t + \lambda P_t + \sum_{j=1}^{p} \gamma_j \Delta P + \varepsilon_t$$

implies that the probability distribution for all future values of the process depends only on its current value. Brownian motion diffusion processes are equivalent to the limit of a random walk. To test whether oil palm prices can be characterized as having as a Markov process, the augmented Dickey-Fuller test is used to test for a unit root in the time series data. The augmented Dickey-Fuller test compares the restricted process:

Against the unrestricted process:

$$\Delta P_t = \alpha_0 + \sum_{j=1}^{p} \gamma_j \Delta P + \varepsilon_t$$

The number of observations T = 153. The augmented Dickey-Fuller test statistic is (-2.05) which exceeds the 5% critical value of (-3.4398). Thus, the assumption that oil palm prices can be characterized by a random walk is valid.
Estimating the Risk Factor

Without any loss of generality, it is possible to set $\left(\frac{R}{\mu - r} + C^P\right)$ from equation (12) equal to zero in order to investigate the impact of the risk factor, $\left(\frac{B}{B-1}\right)$, on the optimal level of investment or conversion thereshold *V**. First, it is necessary to estimate the parameters, α and σ from equation (4). The first parameter, α, is interpreted as the fixed growth rate, and σ is the fixed variance rate. For an estimate of the growth rate parameter, the difference in the internal rate of return between oil palm (28%) and rubber revenues (25%) is used so that $\alpha = 0.03$. For an estimate of the fixed variance rate, the coefficient of variation for the price data charted in Figure (3) is used and set to $\sigma = 0.276$. With a discount rate $r = 0.20$, these parameter values give a risk factor to 6.13. This means that the optimal conversion threshold, *V**, in equation (12) should be over 6 times larger than the critical value of investment that would be given from a standard NPV calculation. The PAM analysis indicated that there are strong economic incentives to convert land to oil palm. However, when this decision is viewed as an investment decision which both irreversible and uncertain, we see that the critical threshold for investment is significantly higher than standard calculations may suggest.

The most important implication of this analysis is the smallholders will convert land to oil palm which has a relatively large risk factor at a lower rate than the standard NPV calculations might suggest. To look further at the implications of uncertainty on the investment decision to convert land to oil palm, the value of the risk factor is plotted for a range of values for α and σ. The plot in Figure (4) suggests that the incentives to convert land to oil palm decrease with a combination of high fixed variance rates, σ, and low expected returns, α. With high expected returns, the conversion threshold would increases with high variance rates.

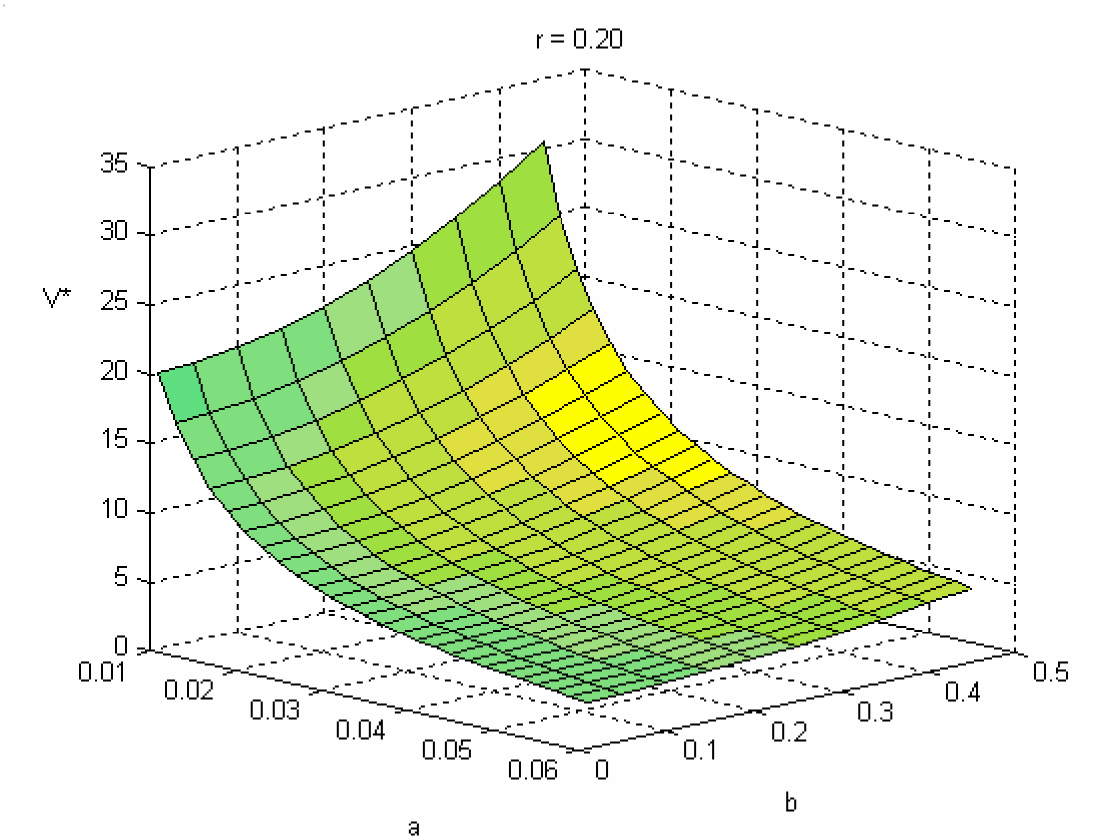


Figure 4. Critical Investment Threshold as a function of expected returns (α = a) and variance rates (σ = b) with a discount value of r = 0.20.

The critical threshold of conversion is also sensitive to the discount rate r. Figure 5 indicates the critical level of investment increases linearly with increases in the discount rate.

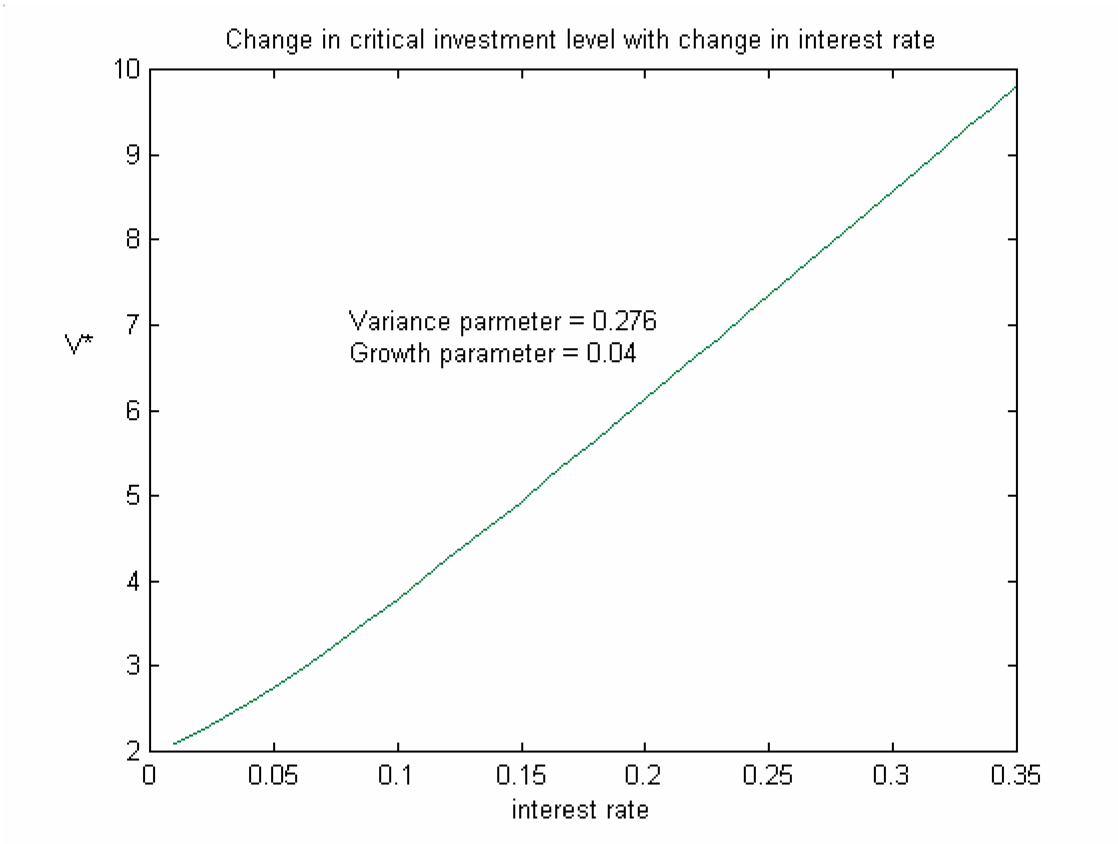


Figure 5. Critical Conversion Threshold with Changes to Interest Rate

12. Conclusions

What implications can be drawn from these results. First, if policy makers are interested in promoting particular agricultural activities, focusing only on improving rates of return to that activity may be inappropriate. Rates of return are just one aspect of investment decisions, and as indicated above, the threshold level for investment in activities even with relatively high rates of return can be dampened by uncertainty in other market factors. In terms of independent smallholder oil palm, using the standard NPV measure to guide investment decisions fails to account for the inherent levels of uncertainty and irreversibility in this activity. Oil palm requires significant sunk costs, and the volatility in oil palm prices suggest that the critical investment threshold may be out of reach for many smallholders who are interested in converting their land to oil palm. Secondly, these results suggest that policymakers need to seriously consider the economic and agricultural policies which create uncertainty for smallholders. This suggests an important linkage between broader regional and national macroeconomic policy and local land use decisions. For example, trade and exchange rate policies may have considerable impact on investment decisions for oil palm.

As indicated in the introduction, the expansion of agricultural in Indonesia has broad implications for natural resource development and conservation. The conversion of land from one use to another should be viewed as an investment decision and embodied in most investment decisions are elements of risk and uncertainty. With large tracts of primary forest being converted to agriculture uses, the role of secondary forests and agroforestry systems activities becomes increasingly important in terms of lessening the biological impacts of habitat fragmentation. In the case of Sumatra, land in rubber forests covers a large area. Whether this land will remain in rubber or be converted to alternative land uses such as monoculture oil palm is uncertain. However, this investigation suggests that if researchers and policymakers hope to understand the dynamics of land conversion activities, the role of risk and uncertainty should play an important role in the analysis.

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