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Financial potential of rubber plantations considering rubberwood production: Wood and crop production nexus

Akira Shigematsu [a,*], Nobuya Mizoue [a], Khun Kakada [a,b], Pheng Muthavy [b], Tsuyoshi Kajisa [a], Shigejiro Yoshida [a]

[a] Faculty of Agriculture, Kyushu University, 6-10-1 Hakozaki, Fukuoka 812-8581, Japan

[b] Rubber Development Department, Directorate Rubber, No. 48, Vithei Neary Khlahan St. Sras Chak Quarter, Khan Daun Penh, Phnom Penh, Cambodia

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ABSTRACT

Globalization and urbanization have significantly increased the food and non-food commodity demand for the last century, and it is vital to consider a business strategy with economical and ecological sustainability. The objective of this study was to project the contribution of wood to the financial performance of rubber plantations. We adopted cost and revenue data of rubber plantations in Cambodia and utilized land expectation value (LEV) as the criterion for profitability analysis. Among the top-ten rubber-producing countries in pan-tropics, the areas of rubber plantation were equivalent to from 1% to 90% of forest plantations and 0.3%–10.2% of total forest areas. Rubberwood revenue accounts for about 4%–10% of the 30th year LEV in rubber plantations at discount rates of 2% y^{-1}–10% y^{-1}, and this was sufficient to cover the cost of re-establishing the plantations. The proportion of the 30th year LEV contributed by wood revenue increased under conditions normally associated with a more difficult business environment, i.e., at higher wage costs, and lower latex revenue. We found that the wood revenue can improve the profitability of rubber plantations by up to 40% depending on the price of the rubberwood. We assert that timber from wood producing commodity plantations should be encouragingly utilized as industrial timber by linking the wood production in the management strategy of the plantations.

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1. Introduction

Globalization and concentration of population in urban areas in concomitant with the modernization of lifestyle have driven the deforestation and degradation of natural forests globally [1–9]. Tremendous efforts have been made to alleviate the development pressure to tropical woody biomes, such as protected areas for conserving ecological services [10,11] and implementation of reduced impact logging [12,13]. Another stream of alleviating further conversion of natural forests is to improve yields of the existing crop and tree areas through technological advance [14–18], because the improvement of efficiency would theoretically decrease the necessity of additional production areas. Nevertheless, these two steams of alleviating forest loss would be insufficient as long as we also effectively utilize the affluent yet untapped

* Corresponding author. Tel./fax: +81 92 642 2867.
E-mail address: aki.shigematsu@gmail.com (A. Shigematsu).

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resources such as the residuals in production, processing and supply fields of plantations.

Industrial forest plantations satisfy one-third of global wood demand [17], but it is not widely known that timber from non-forest plantations has gradually become an important wood resource in recent years [19,20]. The emergence of non-forest wood resources could be aligned with both the strict logging control of natural forests and continuous improvements of processing technology for wood from non-forest plantations [19]. The areas of forest plantations of *Eucalyptus* spp. and *Pinus* spp. make up some 42% of global tree plantations; by comparison, non-forest plantations cover an area equal to about 23% of that of forest plantations [19]. Non-forest plantations have the main objective of producing agricultural cash crops such as cacao, coconuts, or rubber resin, not wood [21]. There are about 15 million hectares of non-forest plantations, located mainly in Asia [19], and this land use type has great potential to be utilized as a source of wood to meet growing wood demand [22]. However, there have been few analyses to compare how non-forest plantations would be equivalent to the forest plantations and total forest areas in a global scale. The residuals from non-forest plantations could provide additional wood resources to timber industries, which would be of great importance in countries undergoing deforestation and degradation of natural forests.

A number of studies on economic valuation has been increasing [7,23,24], and the Faustmann formula [25–27] is one of the most commonly applied techniques in economic studies [28–34]. Faustmann formula enables different types of land management options to be compared [35–37] and optimal rotation periods to be identified [38–40]. However, past financial analyses of non-forest plantations have not considered the effect of wood revenue because the main focus has been the risk assessment of different price levels of the main cash crops [32,41–45]. A research gap exists concerning the financial projection of the wood production function in non-forest plantations. Such information would be beneficial for non-forest plantation owners to realize the quantitative benefit of producing wood more sustainably.

Rubber tree (*Hevea brasiliensis*) plantations have become an important source of wood in recent years [46–49]. Shigematsu et al. [50] presented that more than 30% and 50% of wood export market in Malaysia and Thailand consists of wood from rubber plantations. The large contribution of rubberwood in wood industry is also confirmed in Cambodia [51]. However, the benefit to plantation owners of supplying wood from the plantations over and above the main rubber crop is still obscure. Effective management of the plantations is pivotal for meeting the growing wood demand. Studies of rubber plantations have demonstrated the sensitivity of economic analyses to revenue, cost and discount rate [43], but they have not demonstrated or even explicitly examined the extent to which wood revenue could contribute to the profitability of rubber plantations. Therefore, the effect of changing wood revenue in the financial analysis of rubber plantations has not previously been examined.

Cambodia embraces one of the fastest-growing rubber production industries in Southeast Asia, though the production area is small compared to those of the traditional rubber-producing countries of Indonesia, Thailand and Malaysia [50,52]. Because of continuing deforestation and degradation of natural forests in Cambodia [21], greater wood production is needed from plantations of various types. Our objective in conducting this study was to clarify the contribution of wood revenue to the financial performance of rubber plantations by applying the Faustmann formula. More specifically, we aimed to: (1) identify composition of rubber plantations in both forest plantations and forest areas in top-ten countries based on the rubber productive areas; (2) clarify the contribution of wood in rubber plantation revenue; and (3) present the sensitivity of financial performance to latex revenue, wood revenue and cost of labor.

2. Study area

Cambodia has a population of 14.6 million people, an annual population growth rate of 1.6% (compared with an average of 0.8% for East Asia and the Pacific) and urban population of 20% of total population (compared with an average of 44% for East Asia and the Pacific [53]). Forest resources in Cambodia have been depleted by deforestation and degradation of natural forests [54]. Although there are some 113,000 ha of industrial forest plantations (*Eucalyptus* spp. and *Acacia* spp.), production from them has mainly been used for woodchip and pulp production [55]. Some 50,000 ha of chestnut plantations (*Castanea dentata*) also exist, but utilization of the wood from the trees has not been reported [56]. In contrast, rubber plantations have been widely utilized as wood resources [52] and have been increasing in area [57].

The area under rubber has been expanding on the Indo-Chinese Peninsula [58,59], and in Cambodia the area planted to rubber has doubled over the last two decades, from 43,000 ha in 1993 [60] to 82,000 ha in 2007 [57]. Estate plantations used to dominate the plantings, but recent ownership is mostly in smallholdings as a result of government efforts to encourage family-scale plantations [60]. Estate ownership in 1993 accounted for 67% of the total rubber plantations, but this percentage had declined to 48% in 2007 [57]. On the other hand, smallholdings rose from 5% of the total rubber plantations in 1993 to 44 % in 2007 [57].

More than 80% of the rubber plantations in Cambodia are located in Kampong Cham Province in southwestern Cambodia. This province contains large areas of fertile red soil suitable for rubber production. The province consists of 16 districts, 173 communes and 1748 villages [61]. Its climate can be characterized as tropical monsoonal: the wet season is from May to October and the dry season from November to April. Average annual rainfall and temperature for the 5 years to 2008 were 1700 mm and 28 °C, respectively [52]. As in Cambodia as a whole, ownership of rubber plantations has shifted from estate-dominated to smallholdings-dominated. The planting density in both estates and smallholdings is 555 ha^{-1}, and the standard schedule for replanting (final felling) is in year 33 for estates [62] and year 30 for smallholdings [56]. No thinning is performed between initial planting and the final harvest, and most of the wood resources are sold to local contractors who are responsible for logging, yarding, and transporting the harvested timber.

3. Methods

3.1. Data sources

The data adopted here are mainly based on secondary data sources. To clarify the percentage of rubber plantations against forest plantations and total forest areas, we adopted the database of the Food and Agriculture Organizations of the United Nations based on the Forest Resource Assessment (FRA) survey 2010 [18]. To explore the potential contribution of wood revenue in rubber plantations, we collected secondary data during a field survey in July 2007. Time-series data of cost and revenue for the standard rubber plantation in Cambodia were obtained from statistics collected by the Economic Institute of Cambodia (EIC) and United Nations Development Program [56]. The length of production was considered to be 30 years following the current practice, and the first latex tapping was assumed to occur in year 5. The expense before planting rubber plants (overhead) is the labor cost for the land preparation [32,43], and it is included in the planting cost in the first year. Intercropping of soybean was assumed during years 1–3 of the production cycle, and the impact of this on the cash flow was considered. We assumed that proper management and maintenance practices to maintain trees in healthy condition were applied.

3.2. Data analysis

3.2.1. Proportion of rubber plantations in forest plantations and total forest areas

The proportion of productive rubber plantations in forest plantations or total forest areas was calculated for each country producing natural rubber in 2010. In the definition of FRA since 2000, countries are to report rubber plantations in forest areas [63]. However, in some countries in Africa, the area of rubber plantations exceeded the area of forest plantations, suggesting that these countries are not reporting the rubber plantations in forest areas. Nevertheless, as the aim of this analysis is not to present how much rubber plantations account for forest areas, but to show the scale of rubber plantations in comparison to the forest plantations and forest areas. Whether rubber plantations are counted in forest plantations or not would therefore not influence on the analysis. We presented the percentage of rubber plantation areas in forest plantations or total forest areas for the top-ten countries producing rubber in the year 2010.

3.2.2. Faustmann formula

The Faustmann model is a standard economic model for estimating land expectation values in forestry [25], and it can also be utilized to evaluate land management options for agriculture crops [64]. The formula calculates the land expectation value (LEV) under the case of perpetual land use, and this enables us to directly compare the values even when the management cycles have differed. Other methods, including the internal rate of return (IRR) [41] and net present value (NPV) only considering single rotation [65], have shortcomings when comparing options of different rotation lengths, and these are required to annualize the respective values. The formula is specified as:

$$\mathrm{LEV}_{(\mathrm{rubber})} = \frac{\sum_{t=1}^{3} R_{(\mathrm{intercrop})t}(1+r)^{T-t} + \sum_{t=6}^{T} R_{(\mathrm{latex})t}(1+r)^{T-t} + R_{(\mathrm{timber})T} - \sum_{t=0}^{T} C_t(1+r)^{T-t}}{(1+r)^T - 1} \tag{1}$$

where R_t is the revenue in year t; C_t is the cost in year t (including establishment cost C_0); T is the rotation length in years; and r is the discount rate.

Equation (1) considers the effects of the final harvest income from rubberwood when replanting the plantation at year T, the income from intercropping conducted in years 1–3, and the annual income from latex from year 6 until replanting. The unit price of latex before processing into dry latex products (800 \$ t^{-1}) and the latex yield were retrieved from EIC [56], which was based on the interview survey with smallholders in Cambodia (Table 1). Fig. 1 exhibits the standardized monthly free-market average price of natural rubber (latex) with the maximum price in 4500 \$ t^{-1} (2010) and the minimum price in 500 \$ t^{-1} (2001). Although the figure (800 \$ t^{-1}) is close to the lowest value, it is the within the range of the historical price of latex and we adopted the unit price for the based case.

To estimate the wood revenue per hectare, we employed unpublished data of the Mean Annual Increment (MAI = 7.11 m^3 $year^{-1}$). This MAI is the average value for 6 clones at 23 years old in Cambodia. The methods for estimating this MAI were based on Ref. [52], and data for this were obtained in two rubber plantations, namely Peamcheang and Chup rubber plantations, located in Kampong Cham Province (104° 11°35′22″N to 12°31′ 27″N and 48′26″E, to 106°28′17″E) in the southeastern parts of the country. In base case, we assumed the figure of 15.6 \$ m^{-3} for stumpage price. It is based on the consideration of the market value of the wood sold is 3330 \$ ha^{-1} [56] and the total volume of stumpage is about 213 m^3 ha^{-1} at 30th year. Fig. 2 presents the standardized monthly average price of rubberwood excluding yarding cost in a traditional rubber-producing country (Malaysia). The maximum and minimum price is in 240 \$ m^{-3} (2008) and 30 \$ m^{-3} (2001) at log price excluding yarding cost, and it is equivalent to 84 \$ m^{-3} (2008) and 10.5 \$ m^{-3} (2001) at stumpage price considering the recovery rate of rubberwood (35%) [51]. The stumpage price at the base case (15.6 \$ m^{-3}) is close to the minimum value, but it is within the price range. The volatility of the latex and wood prices will be described on the sensitivity analysis referencing the historical price trend.

Interest rate has a strong influence on the results of financial analysis [66]. Two schools of thought exist on the discount rate that should be chosen for base-case analysis in

Table 1 – Cash flow ($ ha^{-1}) of rubber plantations in Cambodia for a 30-year rotation.

Equation	Notes (Unit)	Values	Sources
$R_{(intercropping)t}$	Revenue from intercropping ($ ha^{-1}), fixed value	250 ($1 \le t \le 3$)	[56]
$R_{(latex)t} = P_{latex} \times Y_{latex}$	Revenue from latex ($ ha^{-1})		
P_{latex}	Latex unit price ($ t^{-1}), base case	800 ($6 \le t \le 30$)	[56]
Y_{latex}	Latex yield (t ha^{-1}), fixed values	0.7 ($t = 6$) 1 ($t = 7$) 1.3 ($t = 8$) 1.5 ($9 \le t \le 15$) 1.8 ($16 \le t \le 25$) 1.2 ($26 \le t \le 30$)	[56]
$R_{(timber)T} = P_{timber} \times Y_{timber}$	Revenue from rubberwood ($ ha^{-1})		
P_{timber}	Stumpage unit price ($ m^{-3}), base case	15.6 ($t = 30$)	[56]
Y_{timber}	Stumpage yield (m^3 ha^{-1}), fixed value	211.3 ($t = 30$)	Our study.
$C_t = C_{labor} + C_{inputs}$			
C_{labor}	Labor cost ($ ha^{-1}), fixed values	339 ($t = 1$) 195 ($t = 2$) 130 ($t = 3$) 111 ($t = 4$) 93 ($t = 5$) 272 ($6 \le t \le 11$) 240 ($12 \le t \le 30$)	[56]
C_{inputs}	Inputs cost ($ ha^{-1}), fixed values	356 ($t = 1$) 112 ($t = 2$) 78 ($t = 3$) 85 ($t = 4$) 125 ($t = 5$) 71 ($t = 6$) 5 ($7 \le t \le 11$) 0 ($12 \le t \le 30$)	[56]

forestry: (1) the long-term borrowing rate of the central bank [32,43,67,68], and (2) the risk-free interest rate of the government bond market [66,69,70]. For the base case analysis we adopted an interest rate of 6% y^{-1}, which is regarded as the long-term borrowing rate in the country [71]. We examined the contribution of rubberwood to LEV values to identify the role of rubberwood in the profitability of rubber plantations. We only calculated the ratio of rubberwood to LEV when LEVs were positive; it was not possible to calculate the contribution of rubberwood to negative LEV values.

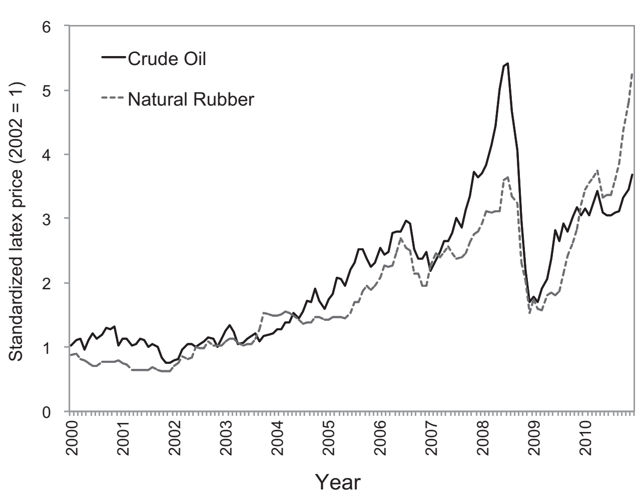

Fig. 1 – Standardized free-market monthly average price trend of latex (natural rubber) and crude oil from 2000 to 2010. Natural rubber price: Rubber TSR 20, New York; Crude oil: average of UK Brent (light)/Dubai (medium)/ Texas (heavy) equally weighted. Source: [76].

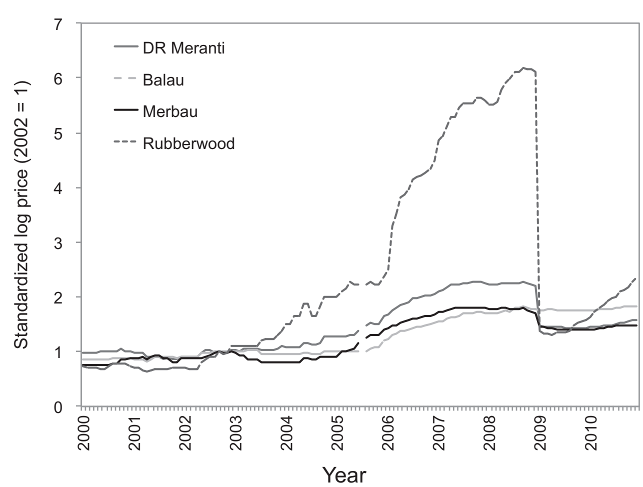

Fig. 2 – Standardized monthly average price trend of domestic log prices (rubberwood and other major wood species) from 1998 to 2010 excluding yarding cost in traditional the rubber-producing country, Malaysia. Price trends were presented in the range of maximum value and minimum value and we averaged the top and bottom price for each month. The data for July 2005 and March 2011 were not included due to the missing data on the reference. Source: [77].

3.2.3. *Sensitivity analysis*

Both the scenario analysis and the sensitivity analysis have been popular tools to explore the responses of changes in model parameters [72,73]. Scenario analysis helps to explore possible futures under a series of differing conditions [74]. Sensitivity analysis helps examine the importance of each parameter to output values [75]. Sensitivity analysis can be conducted using stochastic methods to select values for prices and crop yields [32], but is difficult to apply if there is insufficient information on market conditions and production. Most therefore modify parameters one by one while holding all of the other variables fixed [44,73]. The latter procedure is the method we adopted in this study due to limitations on market price data. The variables we focused on were wages, inputs, market prices and yields of both latex and rubberwood, and the interest rate.

In our sensitivity analysis, we used the limits of the analysis based on the historical price trends of both latex and wood. In order to generate a scenario of commodity price change, we referenced the standardized latex from global commodity market and that of wood price from the major rubber-producing country, Malaysia. The historical price trends of latex (Fig. 1) and rubberwood log excluding yarding cost (Fig. 2) from January 2001 to December 2010 are collected from UNCTAD [76] and ITTO [77], respectively. We hypothesized that the stumpage price of rubberwood will have the same price trend of the log prices before yarding.

Due to the strict restriction of natural forests harvesting, the value of wood from rubber plantations has been increasing in Asian countries [43,50], and log price of rubberwood has been greatly changing [77,78].

We considered three cases to assess the response to different wood revenue: case A1, in which stumpage price increased into very high level, 84.5 $ m^{-3} (based on price level of 2007 when log price before yarding was about 240 $ m^{-3}); case A2, in which stumpage price increased into the middle level (case A1) and the base case, 35.7 $ m^{-3} (based on price level of 2010 when log price excluding yarding cost was about 100 $ m^{-3}); and case A3, in which no wood revenue was received. We included the case of without wood revenue assuming the case of heavily damaged tree with no economic value or the difficulty of wood sales such as smallholders in remote areas.

We set three cases to quantify the impact of changing the latex price on the 30th year LEV: in case B1, latex price increased into the highest level, 4500 $ t^{-1} (based on the price level of 2010); in case B2, latex price increased into the middle level, 2000 $ t^{-1} (based on the price level of 2007); and case B3, latex revenue decreased into 500 $ t^{-1} (based on price level of 2001).

Finally, we examined two cases to show the influence of higher wages on 30th year LEV: in case C1, the wage rate was increased by 25%; in case C2, the wage rate was increased by 50%. The 25% and 50% increase in wage rate came from the assumption that current wage rate on the base case (nominal wage of 60 $ month^{-1}) reached the ideal wage in capital city (about 75 $ month^{-1}) and the highest level of the average wage in Sihanoukville (about 90 $ month^{-1}) [79].

We examined interest rates of 2% y^{-1}, 6% y^{-1} (base case) and 10% y^{-1} in each of the cases to explore the impact of the discount rate on the profitability of rubber plantations as measured by LEV. We located the lower limit of interest rate at 2% y^{-1} from the figure in Europe [66] to describe the situation when the market risk was reduced in Cambodia. We set higher limit of interest rate as 10% y^{-1} from the figure of Cambodia in 1999 [67] to illustrate the condition of the increased market risk than current condition in Cambodia.

4. Results

4.1. *Share of rubber plantations against forest plantations and total forest areas*

The global area of rubber plantations is 6.5 million ha in 1990 and 9.2 million ha in 2010 [80]. The percentage of rubber areas in crop fields and forest plantations in a pan-tropical scale is marginal, but the share differs by countries (Table 2). In Latin

Table 2 – Percentage of rubber plantations areas in forest plantations and total forest areas in top 10 rubber-producing countries.

Country	Rubber plantation area in 2010 (million ha) (1)	Plantation forest area in 2010 (million ha) (2)	Total forest area in 2010 (million ha) (3)	%Annual forest area change, between 2005 and 2010 (% y^{-1}) (4)	%Rubber plantation in plantation forest area in 2010 (%) (1)/(2)	%Rubber plantation in total forest area in 2010 (%) (1)/(3)
Indonesia	3.1	3.6	94.4	−0.7	86.2	3.2
Thailand	1.9	4.0	19.0	0.1	48.4	10.2
Malaysia	1.3	1.8	20.5	−0.4	71.3	6.3
China	0.7	77.2	206.9	1.4	0.9	0.3
India	0.5	10.2	68.4	0.2	4.4	0.7
Vietnam	0.4	3.5	13.8	1.1	12.5	3.2
Nigeria	0.4	0.4	9.0	−4.0	92.1	3.9
Philippines	0.1	0.4	7.7	0.7	40.0	1.8
Côte d'Ivoire	0.1	0.3	10.4	NA	41.2	1.3
Sri Lanka	0.1	0.2	1.9	−0.8	68.4	7.0
Brazil	0.1	7.4	519.5	−0.4	1.6	0.02

Sources: (1): [80]; (2), (3), (4): [18].

America, the fraction of rubber plantations in forest plantations is low in Brazil (2%). In Africa, the rate of rubber plantation in forest plantations is very high in Nigeria (90%) and Cote d'Ivoire (40%).

The percentage of rubber areas in total forest areas is 10.2% in Thailand, 7.0% in Sri Lanka, 6.3% in Malaysia and 3.2% in Indonesia, and it is as little as 0.7% in India and 0.3% in China. In Latin America, the share of rubber plantations in total forest areas is 0.02% in Brazil. The fraction of rubber areas in total forest areas in Africa is 3.8% in Nigeria and 1.3% in Cote d'Ivoire. Five out of the ten countries are still under the net decrease of forest area from 2005 to 2010 [18], namely in Nigeria (−4.0% y^{-1}) Indonesia (−0.7% y^{-1}), Malaysia (−0.4% y^{-1}), Sri Lanka (−0.8% y^{-1}) and Brazil (−0.4% y^{-1}), while the rubber plantations are proportionally large when compared with forest plantations.

4.2. *Cash flow of rubber plantations*

Table 1 shows the standard cash flow per hectare of rubber plantations with a 30-year rotation period [56]. While there was no income from latex harvest from years 1 to 5, the aggregated cost through the same period was 1624 \$ ha^{-1}. The composition of cost from years 1 to 5 was that the costs of labor and materials (seedlings, chemicals and fertilizer) for the establishment of rubber plantations were 756 \$ ha^{-1} (46.5%) and 356 \$ ha^{-1} (21.9%), respectively. The revenue from latex was 560 \$ ha^{-1} in year 6, increasing to 1440 \$ ha^{-1} from year 16 to year 25, then decreasing to 960 \$ ha^{-1} from years 26 to 30. The revenue from rubberwood at the end of the rotation was 998 \$ ha^{-1} for a 9-year rotation and 3330 \$ ha^{-1} for a 30-year rotation.

4.3. *Sensitivity analysis*

4.3.1. *Change in discount rate*

Fig. 3 shows the relationship between land expectation value (LEV) and the proportion of LEV composed of wood revenue (wood revenue ratio) at discount rates of 2% y^{-1}, 6% y^{-1} and 10% y^{-1}. Land expectation values for production cycles (crop rotations) of less than 9 years were negative, and are therefore not shown in this study. The wood revenue ratio was non-linear regardless of the interest rate. The maximum wood revenue ratio was observed in the case of a 9-year rotation, which was followed by a sharp decrease as the rotation age increased. As rotation lengths increased from 25 to 30 years, the wood revenue ratio showed only a slight rate of decrease.

Since the higher interest describes a surrounding situation of business more conservatively, the LEV in 30-year production cycle decreased dynamically as interest rate increased. We found that the LEV at the end of cycle (in 30th year) was 4647 \$ ha^{-1} at an interest rate of 10% y^{-1} (Fig. 3c), only a half of the value at an interest rate of 6% y^{-1} (10,253 \$ ha^{-1}; Fig. 3b). The LEV in year 30 at an interest rate of 10% y^{-1} was a mere 11% of that at an interest rate of 2% y^{-1} (39,431 \$ ha^{-1}; Fig. 3a). Therefore, the profitability of establishing and managing rubber plantations is severely influenced by the interest rate being reflected by the magnitude of risk for doing rubber growing business in both nationally and locally.

4.3.2. *Change in wood revenue*

Table 3 shows the response in the LEV at 30th year at the three different discount rates under the three cases for wood revenue generation: stumpage price increased into 84.5 \$ m^{-3}

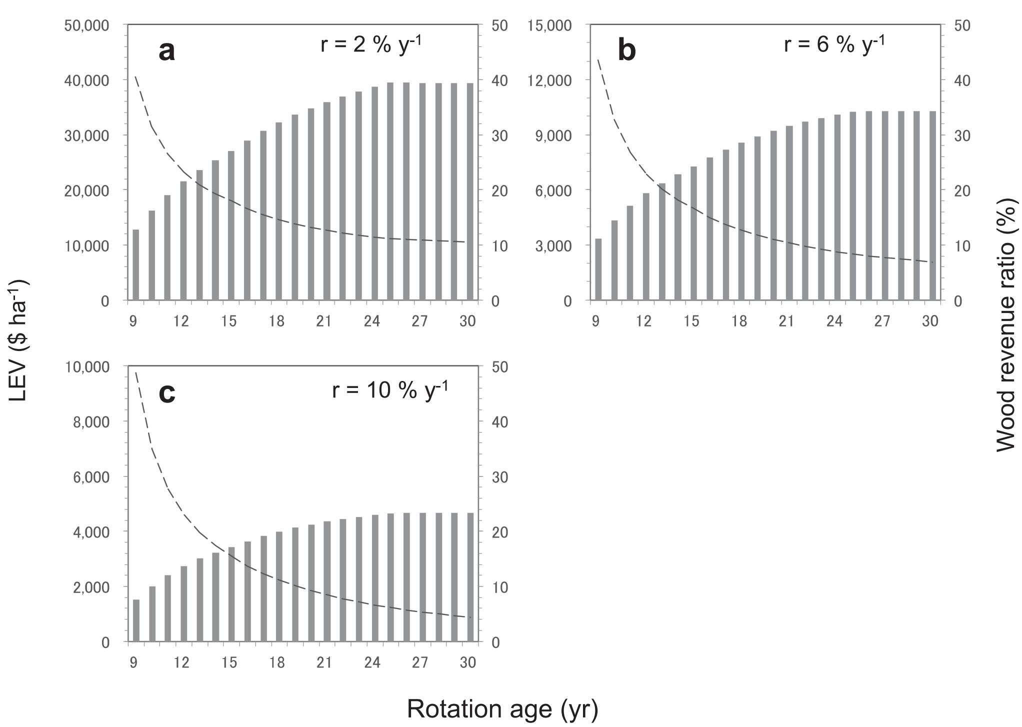

Fig. 3 – Responses of land expectation value (LEV; bars) and wood revenue ratio (lines) for a discount rate of (a) 2% y^{-1} (low interest rate scenario), (b) 6% y^{-1} (base case scenario), and (c) 10% y^{-1} (very high interest rate scenario). Wood revenue ratio is the proportion of LEV composed of wood revenue.

Table 3 – Land expectation value (LEV) values at 30th year achieved for different revenue levels from rubberwood production. Percentages within parentheses below the 30th year LEV values represent the difference from the base case for the respective discount rate. Wood revenue ratio is the proportion of LEV composed of wood revenue.

Discount rate (% y^{-1})	Case A1: stumpage price increased into 84.5 $ m^{-3}		Case A2: stumpage price increased into 35.7 $ m^{-3}		Base case: control (Stumpage price = 15.6 $ m^{-3})		Case A3: without wood revenue	
	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV
2	58,507 (148%)	38.7	44,966 (114%)	21.1	39,322 (100%)	10.5	35,181 (90%)	–
6	13,965 (135%)	28.4	11,330 (129%)	14.3	10,296 (100%)	6.9	9588 (93%)	–
10	5890 (126%)	19.7	5008 (107%)	9.4	4672 (100%)	4.4	4468 (96%)	–

from 15.6 $ m^{-3} (base case) (case A1); stumpage price is 35.7 $ m^{-3} (case A2); and no wood revenue generated (case A3). The wood revenue ratio was about 7% in the base case. The increase in stumpage price into 35.7 $ m^{-3} and 84.5 $ m^{-3} resulted in an increase in the wood revenue ratio by around 5 %–10 % and 15%–20% compared with the base case. The 30th year LEV changed by around 7%–14% and 25%–50% as stumpage price increased by about two-fold (case A2) and five-fold (case A1). In the case of no wood revenue, the 30th year LEV decreased by around 5%–10%.

4.3.3. *Change in latex revenue*

Table 4 shows the response in 30th year LEV at the three different discount rates under the three cases for latex revenue: latex price is 4500 $ t^{-1} (case B1), 2000 $ t^{-1} (case B2) and latex price declined into 500 $ t^{-1} (case B3). The increase in latex price (case B1 and B2) decreased the wood revenue ratio by between 3% and 7% and between 4% and 9% from the base case. The 30th year LEV was relatively large, an increase by about three times and six to eight times of the base case when the latex price increased into 2000 $ t^{-1} (case B2) and 4500 $ t^{-1} (case B1). On the other hand, the decline in latex price into 500 $ t^{-1} increased the wood revenue ratio into about 10% and 20% when interest rate is 2% y^{-1} and 10% y^{-1}, and the 30th year LEV decreased by around 40 %–50 % compared with the base case.

4.3.4. *Change in wage costs*

Table 5 shows the response in 30th year LEV at the three different discount rates to wage rate increases of 25% (case C1) and 50% (case C2). The increased wage rate caused a lower 30th year LEV, but tended to increase the wood revenue ratio at the 30th year LEV. The reduction in the 30th year LEV ranged from about 5 % to 10 % for the 25% wage increase and from about 15% to 25% for the 50% wage increase under the different discount rates. The changes in wood revenue ratio were only about 2%–4%.

5. Discussion

5.1. *Justification of linking the wood from non-forests as industrial wood resources*

Agricultural expansion has been a major driver of the natural forests loss [81] and has already altered the forest areas, but there will be an opportunity and threat in the expansion of wood producible non-forest plantations. Threats accrue in the ecological question, to what extent altering natural forests to plantations may decline the ecological services (i.e. number of species and specie richness of flora and fauna). Koh and Wilcove [82] clarified that the establishment of rubber plantations declined by 63% in the number of species when compared with the primary forests. Carbon stock was lower than that of primary forests [83].

The potential opportunity of establishing non-forest plantations in addition to creating revenue stream in producing countries was to offer additional woody fiber to the wood-based industry and local energy sources. Our result showed that the area of rubber plantations is equivalent to from 1% to 90% of forest plantations and from 0.02% to 10.2% of total forest areas in top-ten countries in terms of rubber production areas (Table 2). Especially in countries experiencing high rate of annual forest area loss, it would be vital to utilize the hidden wood resources in non-forest plantations. Encouraging investment in the sustainable use of the biomass from non-forest plantations would be urgently needed, not only in Asia, but also in Latin America and Africa, where we observe ongoing expansion of rubber plantations.

It is true that rubberwood was seen as residuals of rubber plantations to be disposed until late 1980s [63], but the view has been gradually changing since 1990s in line with the quest of wood resources due to the strict protection of natural forests [50]. In order to enhance the utilization, persuading rubber owners to supply rubberwood to the wood-based industry would be vital in a pan-tropic scale where producing natural rubber, provided that the resource could be economically feasibly accessed. Assessing the potential impacts of the rubberwood revenue on the potential profitability of the plantations needs to be clarified and informed to the owners to realize the global objective, mitigating the pressure of clearing natural forests for wood production [84].

Our preliminary assumption in this study was that the wood revenue generally does increase the profitability of the rubber plantations, because the current price of rubberwood has been increasing by 7 times since 2000 (Fig. 2). However, the result shows rather conservative figures, and the great differences do exist in the contribution of wood revenue on the aggregated net revenue from 4% to 40% (Table 2). Nevertheless, one justification of linking rubberwood as industrial

Table 4 – Land expectation value (LEV) values at 30th year achieved for scenarios with different revenue levels from latex production. Percentages within parentheses below the 30th year LEV values represent the difference from the base case for the respective discount rate. Wood revenue ratio is the proportion of LEV composed of wood revenue.

Discount rate (% y^{-1})	Case B1: latex price increased into 4500 $ t^{-1}		Case B2: latex price increased into 2000 $ t^{-1}		Base case: control l (Latex price = 800 $ t^{-1})		Case B2: latex price decreased into 500 $ t^{-1}	
	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV
2	252,826 (642%)	1.6	109,910 (279%)	3.8	39,322 (100%)	10.5	21,836 (55%)	19.1
6	72,787 (706%)	1.0	30,541 (296%)	2.3	10,296 (100%)	6.9	5235 (51%)	13.5
10	36,029 (771%)	0.6	14,872 (318%)	1.4	4672 (100%)	4.4	2146 (46%)	9.6

wood resources is that the wood revenue is sufficient to cover the cost of re-establishing rubber plantations. The wood revenue in the 30th year is 3300 $ ha^{-1} [85]. This would be an important source of income for smallholders to manage the business continuously; if the owners do not have sufficient capital stocks then they cannot finance preliminary investment for re-establishment.

Another justification in the increasing use of wood from non-forest plantations for wood-based industry is that it does provide additional supply of wood, which might warrant mitigating the pressure of harvesting other forest areas including natural forests. In the process of forest cover reversal in Vietnam, both domestic and imported rubberwood was pivotal to satisfy the demand once largely filled with the natural forests [20]. In most of the emerging rubber-producing countries, the use of wood from agricultural plantations was neglected [19]. An effective transaction of wood resources as much as latex should be integrated into the management strategy of such plantations with a function of wood production.

5.2. *Impacts of latex price on the profitability of rubber plantations*

Tropical non-forest plantations primarily being established for trade have been argued as a major cause of forest loss and degradation [9,81,86–89]. The drivers of the expansion have been changing into an industrial-scale export-oriented production rooting from the demand from urbanized population in developing countries [90–92]. The international market price of the commodities would be favored by the increasing demand, but it would be temporarily affected by the negative economic events namely financial crises. To what extent such price dynamics may affect the profitability of the plantations in reference to the historical price trend was rarely discussed.

Our result did indicate that the latex is the most sensitive factor to the profitability of the plantations among all of the price and cost factors. Although rubber price is less volatile than that of other commodities, including pepper and coffee [93], the price of natural rubber has been fluctuating. The overall trend of latex price from 2000 to 2010 was on the increase, and on the upward trend, the latex price increased by 75% in 2010, from 2861 $ t^{-1} (May 2010) to 5007 $ t^{-1} (June 2011). However, there were several times when the latex price dropped. The largest decline was observed from 2008 to 2009, and the latex price was halved from 3183 $ t^{-1} (July 2008) to 1610 $ t^{-1} (June 2009). Historically, the price was sharply declined by 70% from 1996 (1850 $ t^{-1}) to 2001 (500 $ t^{-1}) [94]. The recent forecast of natural rubber market indicates the slight decrease of the price into 2200 $ t^{-1} in 2020 [95].

Our study showed that under the assumption of the increased latex price into recent level (4500 $ t^{-1}), the 30th year LEV was about six-fold to eight-fold of the base case (latex price of 800 $ t^{-1}). The greatly improved financial performance of rubber plantations arises an expansion risk; it might justify more intensive establishment of the plantations by clearing natural forests [96,97], food [98] and non-food crop fields and

Table 5 – Land expectation value (LEV) values at 30th year achieved for scenarios with different levels of wages. Percentages within parentheses below the 30th year LEV values represent the difference from the base case for the respective discount rate. Wood revenue ratio is the proportion of LEV composed of wood revenue.

Discount rate (% y^{-1})	Base case: control		Case C1: wage rate increased by 25%		Case C2: wage rate increased by 50%	
	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV	LEV at 30th year ($ ha^{-1})	%Wood revenue at 30th year LEV
2	39,322 (100%)	10.5	36,400 (96%)	11.4	33,610 (85%)	12.4
6	10,296 (100%)	6.9	9336 (91%)	7.6	8377 (82%)	8.5
10	4672 (100%)	4.4	4105 (88%)	5.0	3537 (76%)	5.8

other land uses, as observed in the juggernaut of rubber plantations in the mainland of Southeast Asia since 2000s [99]. The development of non-food crops mainly for trade encouraged by the hike of international price is discussed in other type of crops (oil palm) in other tropical regions (South America, mainly Brazil) [100]. In order to stabilize the lucrative nature of business alluring further conversion into tropical crop fields, policy makers should consider regulating the large-scale concession allowing conversion of forests in combination with the investments of increasing the productivity (yield).

In response to the downturn of the international market, if the latex price decreased by about 40% from the base case, the 30th year LEV dropped by as much as 45 %–55 % at the discount rates of 2% y^{-1}–10% y^{-1} (Table 3). The sharp drop of price might cause another stream of challenge, a capital risk for the producers, especially for some smallholdings owners with less capital flexibility. Our analysis of cash flow structure (Table 1) indicates there was a relatively high capital requirement for the first 5 years. The aggregated costs from years 1–5 were 20% of the total cost from years 1–30, yet there is no revenue from latex production through those first 5 years. There might therefore be a need to procure much greater amounts of capital for rubberwood establishment than in cash crop production, considering the much earlier commencement of income generation in cash cropping [56]. But if rubber owners borrowing capital for establishment faces a sharp decline of price, they might need to face difficulty for the repayment of loans. Lower interest rates loan therefore needs to be considered in case of longer lasting price decline, though such access is in most cases lacking in rural areas of developing countries [68].

5.3. *Applicability and limitations of the analysis framework including wood revenue in wood producing non-forest tropical plantations*

The Faustmann model has been widely adopted not only in financial analyses but also in policy impact assessment studies for more than 150 years [27,31,36,101]. Nevertheless, it is very rare to apply the Faustmann formula for the purpose of clarifying the potential contribution of wood revenue in non-forest plantations. This might be because it has been traditionally possible to satisfy timber demand with wood from natural forests. However, tropical natural forests have been increasingly withdrawn from wood production for biodiversity and other environmental benefits [102], and wood from non-forest plantations is needed to meet the increasing global wood demand [19,21].

Our analysis framework applying the Faustmann formula and later Harman theory [103] could be applied to examine the financial impact of wood revenue in other wood producing non-forest plantations. Such information is vital to demonstrate the benefits of supplying wood, both to the owners of the plantations and to policy makers for the forestry and agriculture sectors. In future studies, the economic analysis should integrate the cost (concession or a purchase of land) and the revenue from the wood (from previous land use if the plantations should be established in expense of forests) and social benefits of supplying timber [104,105], which would alter the outcome of the analysis. In addition, it would be beneficial to explore the marketing flow of wood from non-forest plantations. This is because the supply chain of wood could also be affected by government policy and socioeconomic circumstances of both plantations and agricultural crops [106].

The discount rate had a greater influence than other parameters. A trend towards shorter rotations under a higher discount rate was observed in all of the sensitivity analyses, because rubber production declines after a certain age and thus is less profitable requiring a need to clear the stand and re-establish new trees far earlier under a high interest rate environment. Earlier studies have also suggested a strong influence of discount rate on LEV [66,69]. Obiri et al. [44], studying the shade-cacao production system in Ghana, demonstrated the decisive impact of discount rate on the profitability of the plantations. Therefore, a choice of discount rate is an important factor for accessing the potential profitability of plantations.

6. Conclusions

This study has clarified the major financial features of rubber plantations and quantified the contribution of wood revenue to their financial performance. Rubberwoods' contribution to the profitability of the plantations changes greatly from about 4% to 40%. A financial justification of transacting rubberwood does exist to secure fund for replanting the plantation, and the use of timber from wood producing non-forest plantations might also mitigate the pressure of depleting natural forests by providing new wood resources from such plantations. The rubber plantations are proportionally not small areas against forest plantations, even in countries with high rate of forest area loss, and the area covered by rubber plantations was equivalent to up to 90% (Nigeria) of forest plantations and 10% (Thailand) of total forest areas. Encouraging investment for linking timber with crop production in wood producible non-forest plantations would be pivotal to maximize the benefits of plantations, which might alleviate the further clearance of natural forests by offering additional wood fiber to the market.

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