Land use strategies for sustainable rural development under revenue uncertainty: A case from Indonesia

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Abstract

We investigated the economic attractiveness of different land uses and possible payments for carbon in rubber monoculture and agroforest, and biodiversity in agroforest under revenue uncertainty in Jambi, Indonesia. A multi-period programming with Monte Carlo simulation and Brownian motion were used. Findings showed that farm incomes would substantially vary, and to mitigate uncertainty the farmland would be diversified. Further increase in carbon prices would result in enhancing the area of rubber monoculture and would lead to possible trade-off in agrobiodiversity. When the payments for ecosystem services are targeted for agroforest then its returns would increase and reduce farm income variability.

Keywords: Payments for ecosystem services; revenue risk; trade-offs.

1. Introduction

Deforestation is one of the main contributors to global greenhouse gas emissions (IPCC, 2007), in addition, it leads to biodiversity loss, land degradation and hydrological disturbances, which in turn reduce population welfare. Indonesia has one of the highest deforestation rates in the world (van Noordwijk, et al., 2012). As few primary forests are left in Indonesia, maintaining agroforests is one of the land use options to provide various ecosystem services, e.g., carbon (C) sequestration, biodiversity conservation (Tomich, et al., 2004). Due to low returns of rubber agroforestry (Leimona, et al., 2011) the payments for ecosystem services (PES) could be an option to increase its financial benefits. In addition to agroforestry the rubber monoculture can be also considered as an option for storing greenhouse gases, yet this land use practice reduces biodiversity. Subsequently, while implementing PES for different land uses the potential trade-offs between the supply of different ecosystem services and the promise of rural livelihoods need to be considered (Affholder, et al., 2010, Rodríguez, et al., 2006). Meanwhile, land uses are subject to uncertainties affecting farm management activities. These uncertainties can stem from the fluctuations in yields and prices (Stringer, et al., 2012). Yield fluctuation may result from climate variability, lack of knowledge of farmers in management practices, pest outbreaks, and diseases (Hardaker, et al., 2004, Berg and Kramer, 2008). Prices, for example, may vary due to unpredictable currency exchange and change in production (Hardaker, et al., 2004). Ambarawati (1995) concluded that fluctuations in the world market price for rubber were one of the main factors affecting price instability of Indonesian rubber. For farmers who are risk averse, these can be a barrier to adopt the long-term sustainable practices (Koundouri, et al., 2006) as it will result in uncertain revenues from land use investments. Hence, for analyzing the economic and environmental attractiveness of land uses with PES the variability in revenues need to be taken into account. In this vein, studies by Castro et al. (2013) showed that the payments needed to preserve shaded coffee plantations were much greater under uncertainty in revenues than those estimated under the assumption that did not consider variability. In this study, we investigated the farm management decisions such as selecting crop types under a range of possible situations, i.e., uncertain production and prices of land uses and various discount rates for different risk-averse farmers. The objectives of the study were to: (1) investigate the uncertainty in returns of land uses and accordingly their management practices that would increase farm incomes; and (2) analyze PES and trade-offs under land use revenue uncertainty.

2. Methods

2.1 Study area

The study area is located in Jambi province, Sumatra in Indonesia. Majority of the farmers are small-scale rubber agroforest farmers with an average farm area of 4 ha. The average size of the household family is 4 which usually are involved in farming, and about

2.7 individuals or 709 days year^{-1} are available for farm activities (Wulan, et al., 2008). The main land uses are rice, jungle rubber agroforest (hereafter referred to as agroforestry or rubber agroforest), and rubber monoculture. The agroforestry system also includes fruit trees such as durian, jengkol, petai and other indigenous trees. The rice is the main staple food of the people, whereas rubber is traditionally considered by farmers as the main income generating crop. Due to high profitability of oil palm plantation (Budidarsono, et al., 2012), in the neighboring areas, particularly in the lowlands, farmers converted agroforests into oil palm. In the province, the average growth period of oil palm, rubber monoculture and agroforestry is about 30-40 years.

2.2 Simulation of variability in yields and prices

To capture uncertainty in yields we used the Monte Carlo simulation to generate various parameters. As the planting one crop would affect the yield of another closely planted crop the stochastic dependency between yields are considered by allowing their multivariate normal distribution:

$$\bar{Y}_t = Y + \sigma CSND \tag{1}$$

where $\tilde{Y}_t$ is multivariate distribution of yield over each analyzed year ($0, 1, 2, \ldots, T$, where $T=30$), Y is the average yield of crops, σ is the standard deviation of yield, and $CSND$ is the correlated standard normal deviated for yields.

To address fluctuations in prices we employed the geometric Brownian motion with drift, which is a stochastic process that has independent increments and the change in the process in any period is normally distributed with a variance that increases linearly with time (Dixit and Pindyck, 1994). We selected this approach as the prices can be affected by different local and international factors depending on crop type, and consequently multivariate distribution for prices may not be a suitable approach. Accordingly, we assumed that the prices have the following stochastic process:

$$\bar{P}_t = P_0\, exp\left(\left(\mu - \frac{\sigma}{2}\right) t + \sigma W_t\right) \tag{2}$$

where $\bar{P}_t$ is the price with the geometric Brownian motion path, P_0 is the initial value, W_t is a Brownian motion, μ is the is the percentage drift and σ is the percentage volatility and both are constants.

2.3 The model

We applied the farm level model as it allows to address the issues such as income, farming system complexities (e.g., interactions between crops, resource usage), long-term comparisons (e.g., planning horizon of activities); and preferences (e.g., for or against risk) (Pannell, et al., 2013). In the model, we assumed that a farmer faces a problem in selecting land uses under certain resource availability, knowing that the decision for one land use will affect other land uses. Also, a farmer has to decide in which land use activities to invest under different states of nature (S) corresponding to different levels of yields and prices. In cases where many farm alternatives exist and when farm planning processes and periods are involved, a multiple-period programming approach can be used. In order to address the risk involved, we applied the expected utility maximizing formulation ($E(U)$) with a power function that is widely used in farm modelling (Lambert and McCarl, 1985):

$$Max\ E(U) = \sum_{s=1}^{S} U(Profit_s, r)\pi(P_s) = \left(\frac{X_{j,t}\bar{p}_{j,t} - C_{j,t}\bar{Y}_{j,t}Z_{j,t}}{(1+d)^t}\right)^r \tag{3}$$

where the objective is to maximize expected farm profit $(Profit)$ with the probability $(\pi(P_s))$ for state of nature (s) in the Monte Carlo simulation and Brownian motion, where each outcome has the same probability and the number of states of nature (S). The state of nature of profit changes with respect to uncertain prices $(\overline{P_t})$ and sale (X_t) of land use (j) output and costs (C) that also change according to the uncertain output $(\overline{Y_t})$ and area of land use activities (Z) over 30 years (t), and discounted under three rates, i.e., 10, 20 and 28%. According to Tomich et al. (2008) an interest rate of 20% can be considered as a lower bound for the capital costs of smallholders in the study area. The risk aversion (r) was characterized by a constant absolute risk aversion level, meaning that it does not change with increasing or decreasing farm profit. To simplify presentation of results only hardly (0.95) and strongly risk-averse (0.65) levels were presented.

The constraints of the model included restrictions on farm area. It is assumed that durian, petai and jengkol are planted at rubber agroforest land uses. According to this constraint farmer allocates available arable land (b) for land use activities (Z) that have different states of nature over the analyzed period:

$$\sum_j Z_{j,t} \leq b_t \tag{4}$$

In the study area labor availability is another vital input for land use decisions of farmers. It was assumed that the labor use for land use activities (k) depends on varying crop output $(\overline{Y_t})$ and is subject to constraint of household members available for farming (l) (2.7 individuals or 709 days year^{-1} (Wulan, et al., 2008)) that has annual growth rate of 1.14% which was observed in Indonesia between 2000 and 2012:

$$\sum_j k_{j,t}\bar{Y}_{j,t}Z_{j,t} \leq l_t \tag{5}$$

The binding values (i.e., constraints) on labor allowed identifying their shadow prices, which are the values that farmers would be willing to pay to obtain each additional unit of these resources.

As the model considers smallholder farm, the farm production is also influenced by satisfying the food consumption demand of household members (f). We assumed that there are no other sources (e.g., market, neighbors) from where food consumption demand can be satisfied and accordingly it would be equal to production and sale of products:

$$\sum_j \bar{Y}_{s,j,t}Z_{j,t} - X_{j,t} = f_{j,t} \tag{6}$$

2.4 Data sources and scenario settings

Between February and March 2010, a total of 95 randomly selected farm households were surveyed in the study area. The objective of the survey was to explore farm's production and its household characteristics, preferences, and behaviors. We also collected data on prices and yields from the Ministry of Agriculture of Indonesia (2012) and Penot (2004) for rubber prices. The C sequestered amount were obtained from Rahayu et al. (2005). It was assumed that the C stock amount at these land uses vary with respect to their yield (e.g., depending on yield of rubber in agroforestry system the amount of carbon storage). To eliminate the effects of inflation rates the prices were converted to real prices using the USD exchange rate. Labor requirement at establishment and operational phase, and establishment and operational costs were obtained from literature (Wulan, et al., 2008, Benjamin, 1992, Papenfus, 2000). The labor costs at the study were assumed to be 5 USD day^{-1} capita^{-1} for oil palm, 1 USD day^{-1} capita^{-1} for rubber monoculture and agroforest, 2 USD day^{-1} capita^{-1} for durian, 1 USD day^{-1} capita^{-1} for petai and jengkol, and 2 USD day^{-1} capita^{-1} for rice.

In our study, we considered that the PES can be additional incentive to follow sustainable land uses practices. In the model we analyzed two PES policy options: (1) the PES can be implemented for C sequestration in wood biomass of rubber monoculture and agroforestry, and biodiversity of agroforestry (hereafter referred as PES for perennial land uses), and (2) the PES can be implemented for C sequestration in wood biomass and biodiversity of only rubber agroforest (hereafter referred as PES only for agroforest). To analyze the effects of C prices on farming activities the five scenarios of C price were assumed, i.e., no C price, 5, 20, 50 and 100 USD t^{-1}. The payment for C sequestration can be given to farmers only in the years 10, 15, 20, 25 and 30. We also assumed if agroforest is followed then the biodiversity would increase and consequently payments to farmers for biodiversity services can be given depending on agroforest area. To analyze the effects of payments for biodiversity on farming activities we also simulated five scenarios, i.e., 0, 20, 80, 300 and 1,000 USD ha^{-1} for agroforest. In our model, we ran 100 scenarios with Brownian motion for prices and with Monte Carlo approach to generate correlated variability in yields, under two risk aversion levels, three discount rates and five scenarios for payments for stored C and area of agroforest that was assumed to provide biodiversity, which in total resulted in 15,000 scenarios in each PES policy option. The model was programmed in GAMS.

3 Results

3.1 Land use activities

Introduction of various PES levels would affect the land use activities of farmer. Under the scenario of 1,000 USD ha^{-1} for provision of biodiversity services and without C payments for both PES policy options, the area of agroforest would range between 0 to 3.8 ha with the average area of 0.08 ha (Figure 1). In this biodiversity price level, the main land uses would be oil palm plantations due to its high profitability. In the scenario of PES for perennial land uses the increase in C prices would lead to the decrease of agroforest area. At the expense of agroforests, the area of rubber monoculture plantations would grow (the higher biomass producing land use, which would allow storing more C and augment incomes by C payments). The further increase of C prices (to 100 USD tC^{-1}) would reduce the area also of oil palm plantations, and instead rubber monoculture would be preferred. In this scenario, the area of agroforest would only increase due to the increase in payments for biodiversity. In contrast, in the scenario PES only for agroforest, the area of agroforest would enlarge when there is increase in PES amount, and would be mainly as a result of C price increase. This shows that the payments for biodiversity even up to 1,000 USD ha^{-1} could be ineffective measure for conservation of agroforest. The area of rice would follow the similar trend in both PES policy scenarios and would be always cultivated. This would be as a result of food consumption demand of farm household, and the possibility to generate annual incomes that would reduce the waiting costs due to the high discount rate.

In addition to PES, the farmland would be diversified to avoid the negative effects of reduced yields and prices on income. The labor availability at farm would be another vital constraint for diversifying land uses, as can be shown by shadow prices of labor (Figure 2). In both PES scenarios, due to the insufficient labor at farm household and increased labor activities in certain years (mainly attributed to labor demanding operations in oil palm and rubber monoculture production) the shadow prices of labor would reach up to 28 USD day^{-1} capita^{-1}. In the PES for agroforest scenario, increase in C and biodiversity payments would reduce the shadow price of labor as the agroforestry would necessitate less labor than alternative crops and hence may reduce rural employment opportunities. Whereas, in the scenario PES for perennial land uses these values would raise up to 45 USD day^{-1} capita^{-1}, which would be attributed to the labor demanding activities in the production of rubber monoculture.

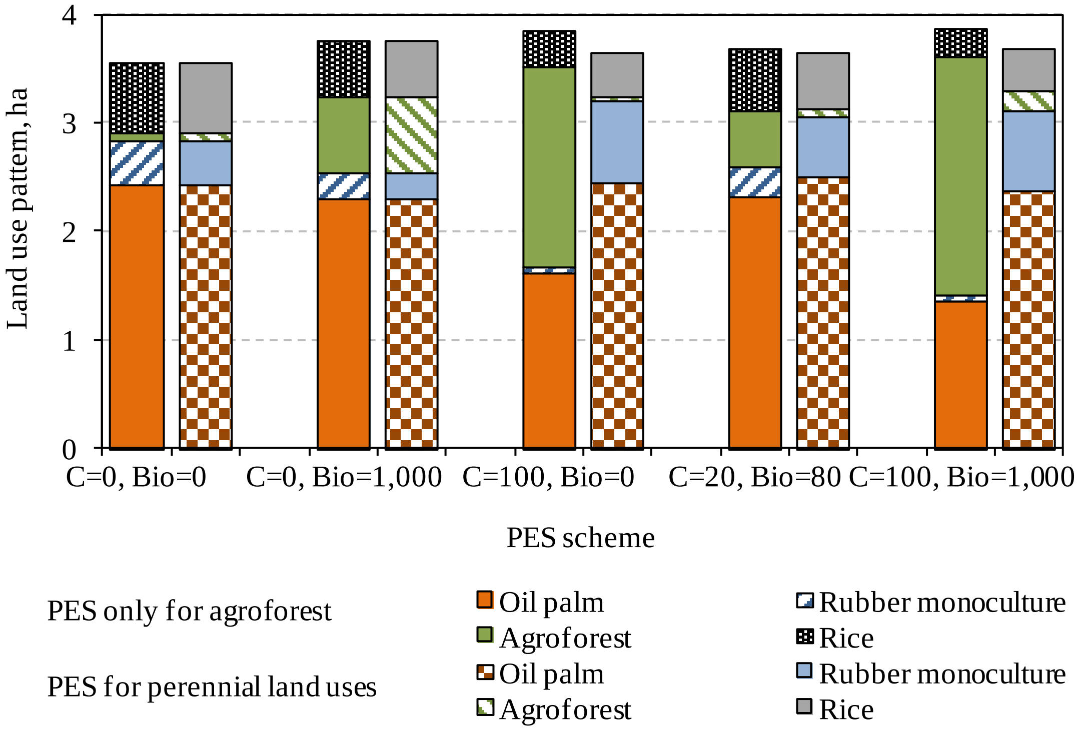


Figure 1. Averaged over 30 years the land use pattern of the strongly risk-averse farmer at different payments for ecosystem services (PES) policy options and levels of PES under the discount rate of 20%.

Note: C is the payment for carbon (0, 20 and 100 USD tC^{-1}); Bio is the payment for biodiversity of rubber agroforest (0, 80 and 1,000 USD ha^{-1}).

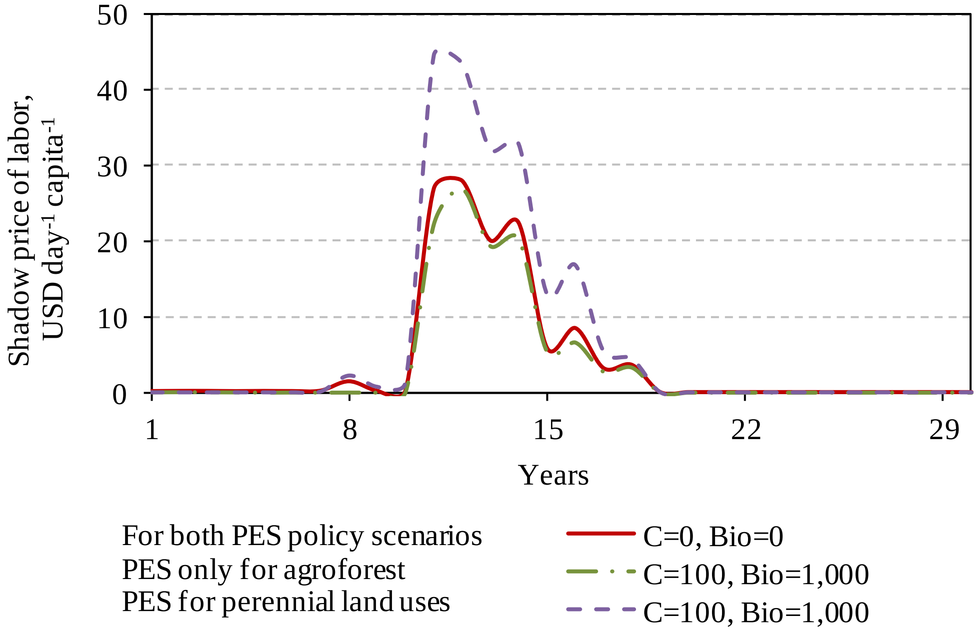
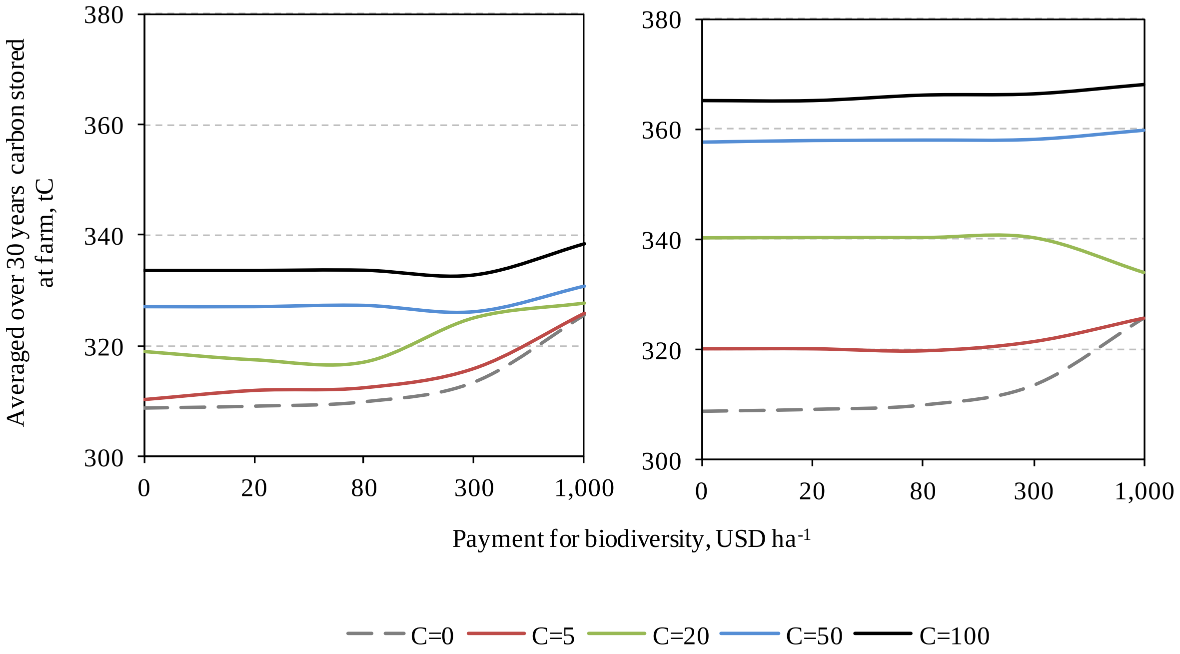


Figure 2. The shadow price of labor of the strongly risk-averse farmer at different payments for ecosystem services (PES) policy options and levels of PES under the discount rate of 20%.
Note: C is the payment for carbon (0 and 100 USD tC^{-1}); Bio is the payment for biodiversity (0 and 1,000 USD ha^{-1}).

3.2 The value of ecosystem services

The change in PES prices would affect the provision of ecosystem services such as C sequestered in biomass of perennial land uses (Figure 3). When there are no payments for PES, then the C sequestration amount would be 309 tC (averaged over the analyzed period). Under the policy scenario of PES only for agroforest, the C payments of 5 USD tC^{-1} and 100 tC^{-1} would result in C storage of 310 and 334 t respectively (Figure 3(a)). Simultaneous increase of PES for biodiversity services would store about 339 tC at farm. In contrast, in the PES for perennial land uses policy option the C stock at farm would be by about 30 t higher in case when the prices for C and biodiversity is at the highest level (C payment=100 USD t^{-1} and biodiversity payment=1,000 USD ha^{-1}). At the same time, raising the PES values would have trade-offs in provision of ecosystem services in the policy scenario PES for perennial land uses. For instance, the increase in C prices would reduce the biodiversity provided by agroforest (see Figure 1 for the area of agroforest), while increase in prices for biodiversity may reduce C storage possibility at farm.



(a) **(b)**

Figure 3. Averaged over 30 years the carbon (C) stored at farm with payments for ecosystem services (PES) only for agroforest (a) and PES for perennial land uses (b) policy options, and different levels of PES under the discount rate of 20%.
Note: C is the payment for carbon (0, 5, 20, 50 and 100 USD tC^{-1}).

3.3 Farm profit

In addition to the variability in yields and prices, and different PES levels, the farm profit was substantially affected by the risk aversion degrees and discount rates (Figure 4). Due to the initial investments into the oil palm plantations, rubber monoculture and agroforest, the positive returns would be generated after year three. In the situation without PES the incomes of the strongly risk-averse farmer would be the same. Considering the discount rate of 10% and hardly risk-averse farmer the incomes would increase by about 48% in comparison when the discount rate is 20% and the strongly risk-averse farmer. Also, raising the PES levels to the highest simulated level would substantially increase farm profit and would be one of the main sources of profit in years 5, 10, 15, 20, and 25 (i.e., in the years when the PES would be given to farmer).

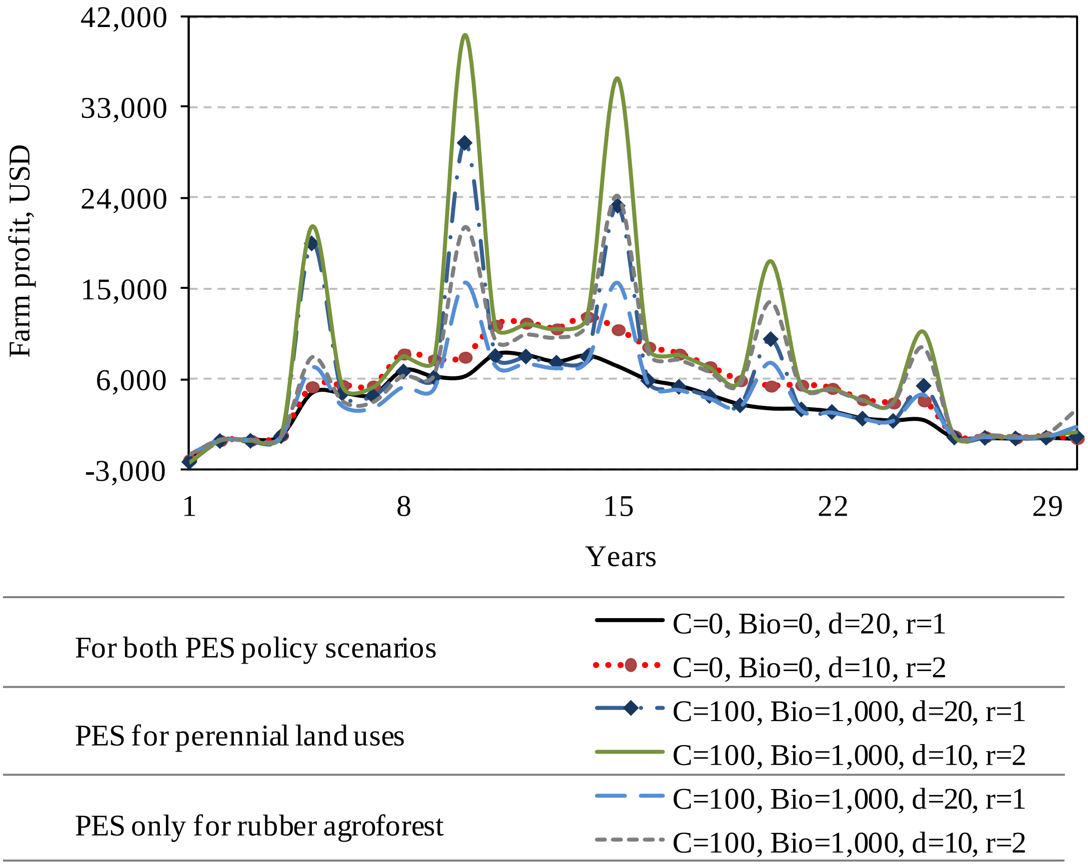


Figure 4. Discounted annual profit of farmer under different risk aversion levels and discount rates. Note: C is the amount for carbon payment (0 and 100 USD tC^{-1}); Bio is the payment for biodiversity services of rubber agroforest (0 and 1,000 USD ha^{-1}); d is the discount rate (10 and 20%), r is the risk aversion level (1=strongly risk-averse, 2=hardly risk-averse).

Due to uncertainty and various PES levels the farm net present value (NPV) over 30 years would substantially differ (Figure 5). For example, the NPV of the strongly risk-averse farmer would range between 2,000 to 772,000 USD and the average NPV would be about 105,000 USD under the discount rate of 20% and when there is no PES, i.e., no payments for C and biodiversity. When the highest C and biodiversity price is implemented, i.e., 110 USD tC^{-1} and 1,000 USD ha^{-1} respectively, for perennial land uses then that farmer would have the expected NPV over 30 years of 168,000 USD, with the minimum value of 63,000 USD and the maximum of 828,000 USD. In the policy scenario when the PES is given only for the agroforest, the farm NPV would be lower than in the policy scenario that has PES for all perennial crops, yet would also have lower variability. For instance, the standard deviation of NPV at this scenario would be about 130,000 USD in contrast to 139,000 USD in the PES for all perennial crops. The cumulative probability function of the scenario for PES only for the agroforest indicated a 20% chance of the NPV being lower than 56,000 USD, a 40% chance of being lower than 60,000 USD, a 60% chance of being lower than 74,000 USD and an 80% chance of being lower than 161,000 USD. At the same time, the highest simulated profit under this PES policy scenario would be the same as in the scenario when no PES is given (i.e., 772,000 USD). This shows that under such case the high NPV can be attributed to the increased prices and yields.

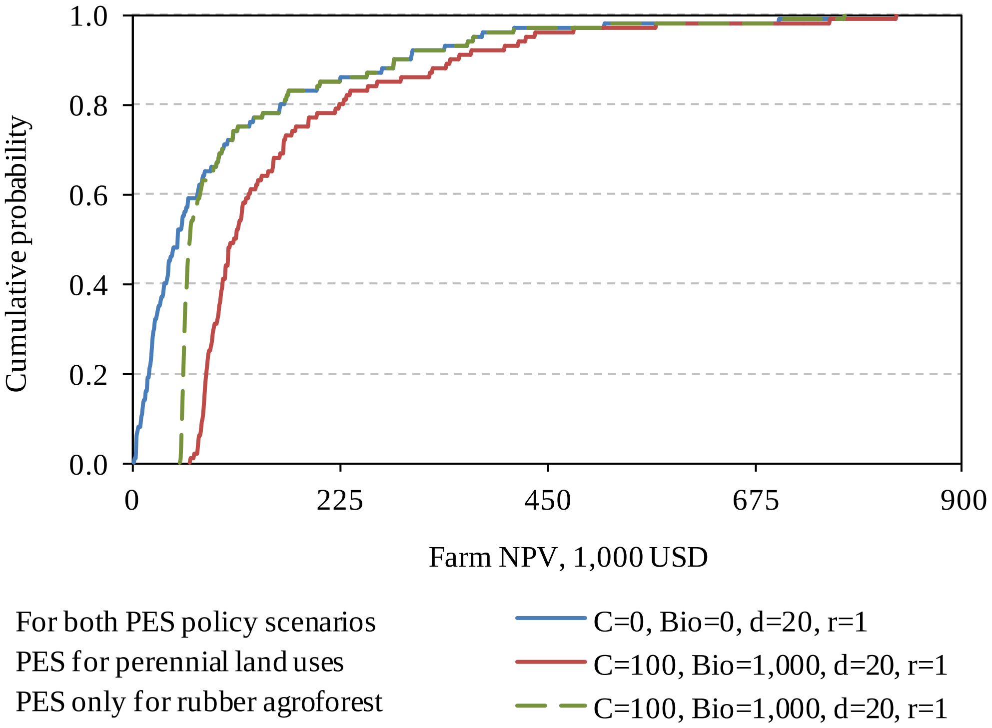


Figure 5. Cumulative distribution of the net present value (NPV) of farm over 30 years.
Note: C is the amount for carbon payment (0 and 100 USD tC^{-1}); Bio is the payment for biodiversity services of rubber agroforest (0 and 1,000 USD ha^{-1}); d is the discount rate (10%), r is the risk aversion level (1=strongly risk-averse).

3.4 Risk-efficient strategies

The risk-efficient points of each PES policy scenario are presented in Figure 6 with the expected and standard deviation of NPV under different C and biodiversity payments. The efficient strategies for farmers would be the points that would have high expected NPV and low standard deviations. The Figure 6 shows that as the price for PES increases the standard deviation of farm incomes would reduce. Yet, the magnitude of such trend would be different in two PES policy options. For example, in the scenario with PES for both rubber monoculture and agroforest, the standard deviation of farm NPV would reduce by 1% and its expected value would increase by 60% in contrast to the case when there is no PES. While in the scenario of PES for only agroforest, the standard deviation of farm NPV would reduce by 8% and its expected amount would augment by 18% in comparison to no PES. Accordingly, the fixed level of PES may reduce the risks affecting farm incomes; however, inclusion of PES for rubber monoculture would not result in such a substantial risk-reducing option due to high variability of its revenues.

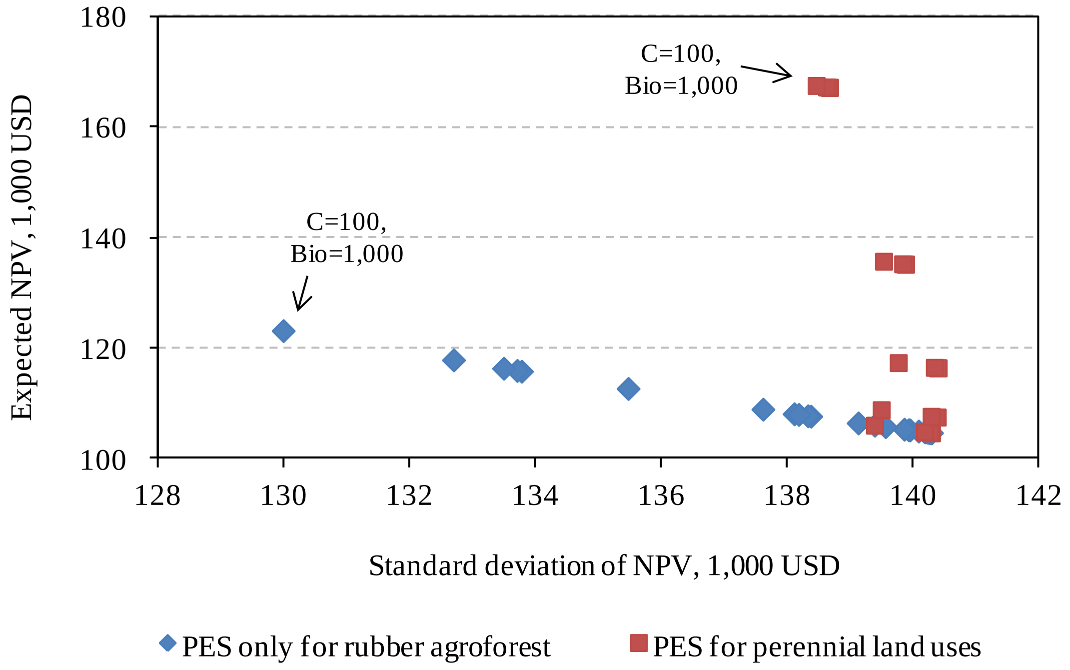


Figure 6. Expected and standard deviation of the net present value (NPV) of the strongly risk-averse farmer under the different payments for ecosystem services (PES) only for agroforest and PES for all perennial land uses at the discount rate of 20%.
Note: C is the amount for carbon payment (100 USD tC^{-1}); Bio is the payment for biodiversity services of rubber agroforest (1,000 USD ha^{-1}).

4 Discussion and conclusions

Introduction of PES for land uses is a vital step in commodification of scarce ecosystem services and promoting sustainable development (Kallis, et al., 2013). Our study showed that when implementing high C payments for various perennial land uses the farm incomes, employment at farming activities and C stock would substantially increase, which would be as a result of rubber monoculture plantations. In such a policy scenario the establishment of the rubber agroforestry plantations, that are considered environmentally friendly land use, would be reduced and accordingly the provision of biodiversity. Raising the PES amount given only for agroforest would increase both C and biodiversity and at the same time, would increase the area of agroforestry while reduce the area of oil palm and rubber monoculture plantations. Increase of PES values would lead that farmer obtain more stable and less varying farm incomes, which would allow reducing the repercussions of farm revenue risks. Our result is consistent with the study of Baumgärtner and Quaas (2010), who argued that with increasing agricultural risks, farmers would alter land uses towards agrobiodiversity and enhancement of environmental services. At the same time, the viability of PES schemes is also determined by the preferences and perceptions of farmers and other stakeholders affecting land use choices (Villamor and van Noordwijk, 2011), and hence only certain farmers and stakeholders may opt for PES for maintaining rubber agroforest. Thus, in addition to monetary incentives, such as rewards in the form of PES, other factors impacting adoption or participation in PES schemes should be considered. Developing PES as reward mechanism along with it developing extension services so as to disseminate information about its benefits, and further development of markets would be required. The effectiveness of implementation of PES schemes would highly depend on the institutional design (Vatn, 2010). To increase the adoption of PES options they need to be targeted to the areas and land uses that are environmentally deteriorating, i.e., where there is high deforestation rate. Most famous PES examples, such as in Costa Rica, achieve low degree of conservation effectiveness due to that the program often target areas with low deforestation risk (Sanchez-Azofeifa et al., 2007). According to Le Coq, Froger, Legrand, Pesche and Saenz-Segura (2013) such PES allocation was determined under the influence of the forestry sector, which saw the PES as an opportunity to earn from public funds. In addition, when targeting PES at certain locations the various groups of rural population should be included, so as to avoid exclusion of the poorest (Pagiola, et al., 2005). In our study in the scenario of PES for agroforest the C storage and labor demand at farm would be lower in contrast to scenario of PES for perennial land uses. Reduced working activities at farm may reduce remuneration to labor and consequently have negative impacts on rural livelihoods (Djanibekov, et al., 2013). Therefore, monetization of ecosystem services should be targeted for certain land uses and its value assigned in balance to tackle the issues of trade-offs in provision of ecosystem services, rural employment and income.

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