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Working Paper **WP-17-019**

Opportunity costs and offsets acceptance in FI-REDD model

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Contents

Abstract

In previous studies, we have proposed financial instruments supporting REDD (FI-REDD). Within a microeconomic framework we modeled interactions between an electricity producer (EP), electricity consumer (EC), and forest owner (FO). FI-REDD allows for optional consumption of emission offsets by the EP (any amount up to the initially contracted volume is allowed), and includes a benefit-sharing mechanism between the EP and FO as it regards unused offsets. The modeling results indicated that FI-REDD might help avoid bankruptcy of CO_2-intensive producers at high levels of CO_2 prices. We demonstrated the impact of benefit-sharing and risk preferences on the contracted REDD offsets quantity.

Here, we further develop the FI-REDD model by introducing two modifications. Firstly, we add opportunity cost of the forest owner, i.e. forest value alternative to REDD. This change leads to a realistic risk-adjusted supply curves for REDD, which are generated by the indifference (fair) pricing model and calculated for all possible benefit-sharing ratios. Secondly, we introduce an uncertainty associated with acceptance (fungibility) of REDD offsets in the second stage of the model. Modeling results demonstrate in a quantitative way the impact of fungibility uncertainty and positive effects of the benefit-sharing mechanism. An optimal value of the benefit-sharing ratio can be found that guarantees contracting the highest amounts of offsets at the low equilibrium price. This qualitative feature of the benefit-sharing mechanism is robust with respect to the uncertainty parameters in the model. We also undertake an in-depth analysis of decision making of the electricity producer using 3D visualization tools.

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Dr. Nikolay Khabarov is a Research Scholar in the Ecosystems Services and Management Program at the International Institute for Applied Systems Analysis (IIASA). His expertise is mathematical modeling and optimization under uncertainty with a rich set of applications including natural disasters (e.g. forest fires and related GHG emissions) and risk-optimal portfolios (e.g. technological portfolios for power generation). Dr. Khabarov is working on improving IIASA’s methods, tools, and technologies for large-scale biophysical and economic modelling at regional and global scales.

Oppotrunity costs and offsets acceptance in FI-REDD model

Andrey Krasovskii
Nikolay Khabarov

1 Introduction

The 2015 Paris climate agreement encourages countries to “take action to implement and support activities relating to reducing emissions from deforestation and forest degradation (REDD+)” (United Nations Framework Convention on Climate Change, 2015). REDD has been suggested as a climate change mitigation strategy that is based on the philosophy to reward countries for reducing their deforestation and forest degradation by financial benefits via the generation of carbon credits (Plugge et al., 2013). REDD is a relatively low-cost mitigation option (Busch et al., 2009; Lubowski and Rose, 2013), and its integration in the global mitigation strategy has a potential to allow for larger emissions reductions and a lower overall abatement cost (Koch et al., 2017). This integration can be done by linking REDD as an emission reduction credit program to major cap-and-trade programs (Angelsen and Rudel, 2013). However, there is still an ongoing discussion related to uncertainties and risks in REDD implementation (Golub et al., 2017). It is difficult to anticipate the combined effects on carbon and other co-benefits owing to the disparity between the activities available under the REDD program (Corbera and Schroeder, 2011; Law et al., 2012). Accepting this uncertainty, we explore the relation between REDD supplier and GHG-emitting energy producer in the context of a potentially emerging REDD offsets market.

In this study we further develop the FI-REDD model proposed in a series of publications (Krasovskii et al., 2016a, 2016b, 2014). Here we explore the impacts of the benefit-sharing mechanism on the contracted amounts of REDD offsets under uncertainty coming from the future carbon (CO_2) price and possibly incomplete offsets acceptance. FI-REDD is a partial equilibrium model of interacting forest owners, electricity producers and consumers (Krasovskii et al., 2014). The model takes into account potential *market power* of the energy producers, which gives them flexibility in their decision-making under uncertain emission costs. We proposed an idea of fair price of the REDD offsets, which is based on the *indifference principle* in the two-stage problem setting. In the first stage (period), where details about the future REDD offsets market are uncertain, the parties (supplier and consumer of REDD offsets) assign their offsets (buying and selling) prices in the way, that their profits, or in general – utilities, in the second period (where the REDD offsets price reveals) stay the same, not matter if they contract REDD offsets in the first period, or not.

Methodologically, a two-period optimization problem under uncertainty formed the basis for modeling. The idea of *benefit-sharing* consists in possible sharing of offsets in the second period. The general idea of benefit-sharing is important within the REDD context

(Dunlop and Corbera, 2016). The benefit-sharing concept is also relevant in the international law context (Morgera, 2016). Here we consider specifically a situation where benefits are shared between the REDD supplier and consumer. It was shown that in the case of risk-neutral utilities, the benefit-sharing does not provide advantages if the supplier and consumer of REDD offsets have symmetric information about future price distribution, while it has positive impacts on increasing the contracted amount and lowering equilibrium prices under asymmetric information (Krasovskii et al., 2016a). The FI-REDD model expanded by introducing exponential utility functions (Krasovskii et al., 2016b) showed that the risk-averse behavior has positive effect on contracted amounts.

In this study, we demonstrate a gap between risk-adjusted supply and demand curves that could lead to non-uniqueness of the equilibrium price. To avoid this situation, we expand the FI-REDD model by introducing *opportunity costs* of the forest owner. Opportunity costs include the forgone economic benefits of the alternative land/forest use. They can include social-cultural cost because preventing the conversion of forests to other land uses can significantly affect the livelihoods of many rural dwellers. Opportunity cost can also include indirect cost, because changes in economic activities, from timber and agriculture to other productive sectors, can affect downstream actors of associated product supply chains (White and Minang, 2010). As it is reasonable to assume that this opportunity cost sets a minimum amount that would have to be paid to keep the land in forest, regardless of the way it is done or the source of the funding for doing it, opportunity cost is the basic starting point for economic analyses of REDD (Boucher, 2008). In this paper, we introduce opportunity cost in the model. This modification leads to a realistic risk-adjusted supply curve, having a convex shape or U-shape, depending on the benefit-sharing ratio.

We also add an additional uncertainty source in the FI-REDD model by introducing the offsets acceptance (*fungibility*) uncertainty (Dooley and Gupta, 2017) in the second period. The fungibility assumption is that avoided emissions and removals from the land sector were interchangeable with emission reductions from fossil fuels. Carbon credits from REDD could be made fully interchangeable with those from other sectors, or limited in their fungibility (Bosetti et al., 2011; Neeff and Ascui, 2009). The approach proposed in the paper is related to the idea of partial offsetting (discounted REDD credits) (Beltran et al., 2013). For example, a developed country may be required to buy 2 REDD credits (tCO_2) in the market to offset 1 credit of domestic emissions (Angelsen et al., 2014).

The structure of the paper is as follows. In the first section, we sketch the structure of the FI-REDD model and present an in-depth results dealing with benefit-sharing mechanism. We indicated the possible issue of non-uniqueness of the equilibrium price of the REDD offsets at some benefit-sharing ratios. The second section is devoted to introduction of opportunity cost of the forest owner; we show how this modification affects the role of benefit-sharing mechanism. In the third section, we model uncertainty associated with acceptance (fungibility) of REDD-based offsets.

In this study we consider risk-averse electricity producer and forest owner (Krasovskii et al., 2016b). From the perspective of policy implications, we assume that there is a policy signal, which stimulated risk-averse behavior in the face of future uncertainty. The exogenously given benefit-sharing ratio can be also interpreted as a policy variable, which help to stimulate REDD market development.

2 FI-REDD Model

In this section, we describe the methodology behind FI-REDD. For a range of CO_2 prices and respective risks perceived by the forest owner (seller) and electricity producer (buyer), we apply a model of fair (indifference) pricing. Parties' risk preferences are reflected by exponential utility functions. The potentially contracted amounts of REDD offsets are analyzed under various risk preferences and for different benefit-sharing opportunities (Krasovskii et al., 2016b, 2016a, 2014). We consider the case when the energy producer has market power (Janssen and Wobben, 2009; Krasovskii et al., 2016a) – the ability to reduce the production output and charge higher electricity prices to consumers.

There are two periods in the FI-REDD model: in the first period ("today") the CO_2 price is low, and in the second period it is uncertain, i.e. given by a probability distribution. An interesting feature of the model is that electricity producer and forest owner have different perceptions of uncertainty. For the electricity producer the high CO_2 price realization is associated with high risk, as they lose more profit. On the opposite, for the forest owner the higher the price is the better, as in this case they could profit more from selling the offsets in the second period, compared to the first period (low price). Here we assume for simplicity that CO_2 price and market price of offsets coincide.

The benefit-sharing mechanism is included in the decision-making of the electricity producer; they can share a part of initially contracted (but not used for offsetting) amount of REDD offsets with the forest owner in the second period. The basis for sharing is an exogenously given *benefit-sharing ratio*. Due to the transparency in the decision-making process, the forest owner estimates the price of the offsets in the first period, depending on the sharing ratio and the known response function of the electricity producer at different carbon price realizations in the second period.

2.1 Basic model constructions

For the sake of clarity, we partially reproduce the model; a full description is available in previous papers (Krasovskii et al., 2016a, 2016b). Let us consider the profit of the electricity producer Π_{EP}^{R} at a CO_2 price realization p_{CO_2} in the second period:

$$\Pi_{EP}^{R}(\hat{x}, p_{CO_2}) = \Pi_{\mathrm{e}}(\hat{x}) - p_{CO_2}[-\mathcal{E} + E(\hat{x})]_{+} + \delta p_{CO_2}[-E(\hat{x}) + \mathcal{E}]_{+} + p_E\mathcal{E}. \tag{1}$$

Here $[y]_{+} = \max(y, 0)$, $\mathcal{E}$ is the amount of offsets contracted (being evaluated) in the first period, $\hat{x} = \hat{x}(p_{CO_2})$ is the optimal technological mix that maximizes the profit at price realization p_{CO_2}, $E(\hat{x})$ is optimal amount of emission in the second period, $\Pi_{\mathrm{e}}(\hat{x})$ – optimal profit from electricity production without offsetting costs, p_E is the (buying) price that electricity producer pays for the offsets in the first period, $\delta \in [0,1]$ is the benefit-sharing ratio.

We denote by symbol $E_R(p_{CO_2}) = [\mathcal{E} - E(\hat{x})]_{+}$ offsets shared with the forest owner in the second period. Then the profit of the forest owner in the second period is calculated as follows:

$$\Pi_{FO}^{\mathrm{R}}(p_{CO_2}) = (1-\delta)E_R(p_{CO_2}) + p_F\mathcal{E}, \tag{2}$$

where p_F is the (selling) price of the offsets in the first period.

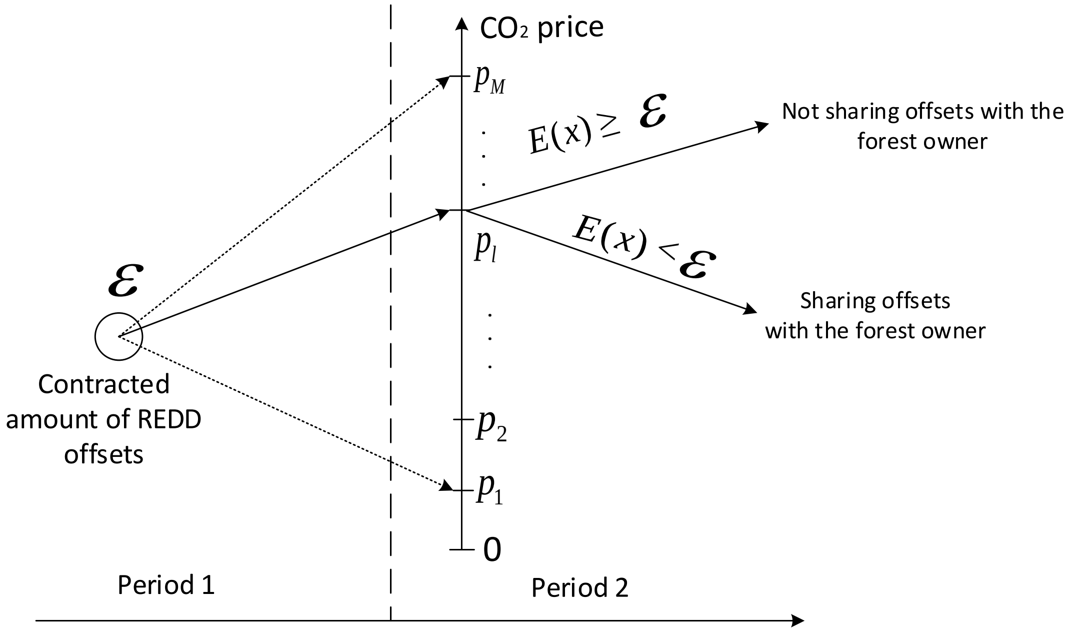

Figure 1. Decision-making of the electricity producer. Uncertainty in the second period is represented by a CO_2 price distribution.

Prices p_E and p_F are determined based on the indifference (fairness) principle for the given distribution of CO_2 prices, as proposed in (Krasovskii et al., 2016a).

The optimal (*profit-maximizing*) behavior of the electricity producer in the second period when CO_2 price is realized is shown in Figure 1. As the process of sharing is the basis for modeling, below we present detailed results for two price realizations. For the illustration purposes, the same setup and input data as in (Krasovskii et al., 2016b) is considered.

Figure 2 illustrates the key features of the model. With small value of the benefit-sharing ratio (big share for the forest owner), the electricity producer uses all the offsets without sharing with the forest owner. As the benefit-sharing ratio grows, the electricity producer starts to share the offsets; particularly, if contracted amount $\mathcal{E}$ is large. The shape of the graph is nonlinear, due to the model structure, including non-linear demand for electricity (see [2]). The "top of the hill" corresponds to the largest contracted amount and highest value of the benefit-sharing ratio (smallest share for the forest owner). At higher prices, the sharing starts at lower ratios (compare figures for CO_2 prices 40 US$/ton of CO_2 and 70 US$/ton of CO_2). These two examples show how the mechanism works in the second period.

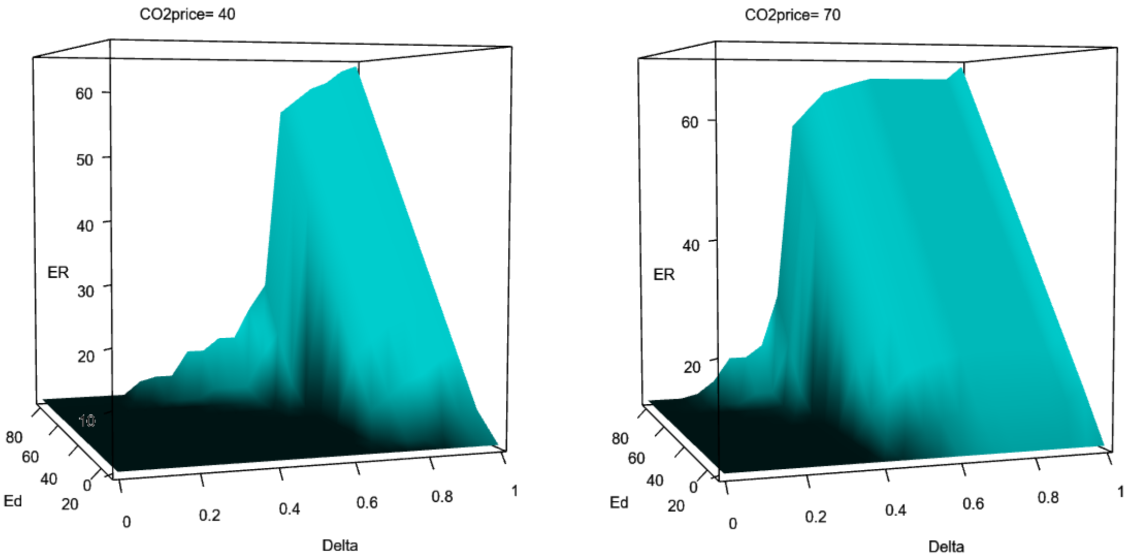

Figure 2. Impacts of benefit-sharing ratio, on the amount of offsets shared in the second period, at different CO2 price realizations. Notations: $E_d = \mathcal{E}$ – amount of offsets contracted in the first period, E_R – optimal amount of offsets shared with the forest owner in the second period, δ – benefit-sharing ratio.

2.2 Determining fair (indifference) prices

The fair prices of the forest owner, p_F, and electricity producer, p_E, are determined by the indifference principle; in a way that their utilities stay the same no matter if they are contacting REDD offsets in the first period, or not. The utilities are calculated based on the profits with and without REDD. For instance, the profit of the electricity producer without REDD is simply $\Pi_e(\hat{x}(p_{CO_2})) - p_{CO_2}E(\hat{x}(p_{CO_2}))$, while the profit of the forest owner is $\Pi_{FO}(p_{CO_2}) = p_{CO_2} \times \mathcal{E}$. Afterwards expected utilities (functions of profits) depending on the risk-preferences are calculated (see (Krasovskii et al., 2016b)).

The indifference prices can be determined for a given amount of REDD offsets, Ɛ, given distribution of CO2 prices and benefit-sharing ratio. Here we apply exponential utility functions – the same as in (Krasovskii et al., 2016b) – which allow for analytical derivation of fair prices. Further, we use the same input data, and consider risk-averse forest owner and electricity producer by taking the following parameters of exponential utilities: $\alpha = \beta = 0.1$ (see (Krasovskii et al., 2016b)). In the model, functions $p_F(\mathcal{E}, \delta)$ and $p_E(\mathcal{E}, \delta)$ represent risk-adjusted *supply* and *demand curves* for REDD offsets; they are used for determination of equilibrium price/quantity.

2.3 The role of benefit-sharing ratio

FI-REDD aims to find the equilibrium quantities of REDD offsets for different benefit-sharing ratios.

In Figure 3 the supply (solid line) and demand (dashed line) for REDD offsets are depicted for several values of benefit-sharing ratio, δ, in the model without opportunity costs (more generally: constant costs) for the forest owner. An amount of offsets can be contracted, when supply curve lays below the demand curve for this amount. The equilibrium price and quantity are found at the intersection, when this intersection exists.

The figure shows that intersection exists for $\delta = 0.5$ and $\delta = 0.55$. A gap between supply and demand curves appears for all $\delta \geq 0.6$. The resulting equilibrium quantities for δ from 0 to 1 with a step 0.5 are depicted in Figure 4 where the indicated equilibrium price for $\delta \geq 0.6$ is p_F that is the minimum of p_F and p_E.

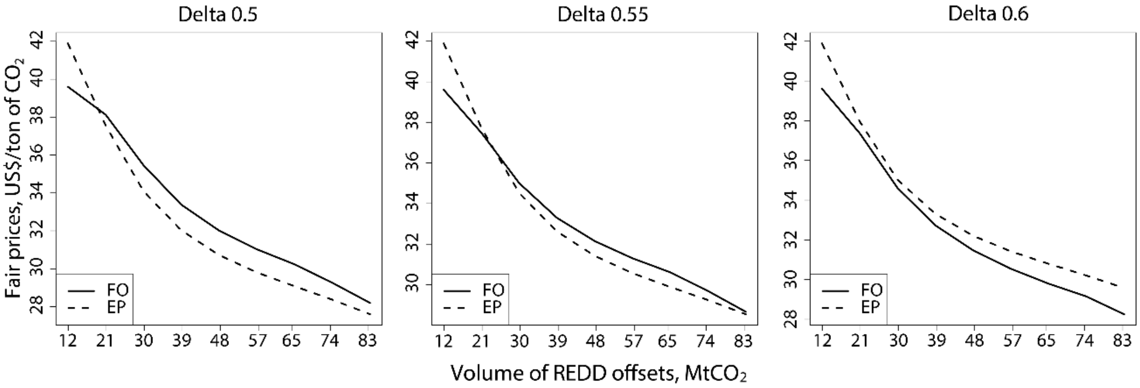

Figure 3. Fair prices of the forest owner (FO), and electricity producer (EP) for different amounts of REDD offsets at several values of benefit-sharing ratio. They represent risk-adjusted supply and demand curves, respectively. Risk-averse electricity producer and forest owner are considered, i.e. exponential parameters: $\alpha = \beta = 0.1$.

This results in the highest contacted amount, as indicated in Figure 4. At the values $\delta \geq 0.6$, the equilibrium price is not determined uniquely. In the figure we show the price of the REDD supplier (forest owner), but it could be the higher price of consumer (electricity producer), or any price between those two. An example, illustrating the gap for $\delta = 1$, is shown on the left of the figure. This situation creates room for speculation. In the next section, we introduce a modification, which helps to overcome this issue.

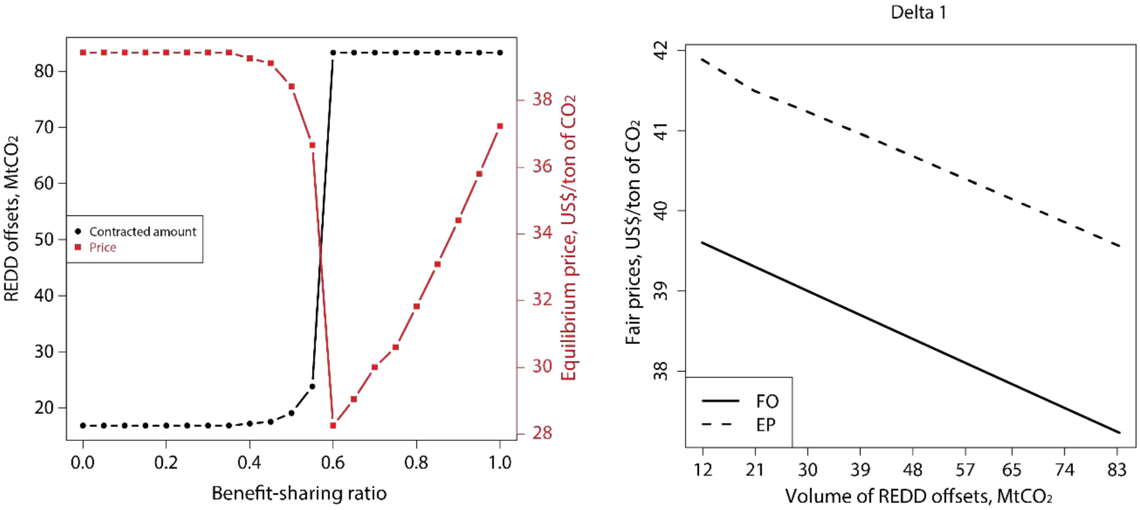

Figure 4. Impacts of benefit-sharing ratio on equilibrium price/quantity of REDD offsets in the model without opportunity costs (left panel). The indicated equilibrium price for $\delta \geq 0.6$ is p_F (here $p_F < p_E$ for $\delta \geq 0.6$). Demand (EP) and supply (FO) curves for $\delta = 1$ (right panel).

3 Opportunity costs of forest owner

The decreasing shape of the supply curve appears in FI-REDD due to the fact that forest owner considers the forest allocated entirely to REDD offsets. In reality, there are more values associated with the forest. They can be represented by the opportunity cost curve. Here we take an increasing shape of the opportunity cost. The interpretation is that the smaller offsets amount require smaller portion of forest, which has less alternative values, while the larger forest areas have higher opportunity costs. The shape of the exogenously given exponential cost curve is depicted in Figure 5 together with the corresponding update in the supply curve. The case of $\delta = 0$ corresponds to the situation when nothing is shared with the forest owner, so his supply curve exclusively for REDD is slightly decreasing (due to risk-aversion), and the opportunity costs define its increasing shape.

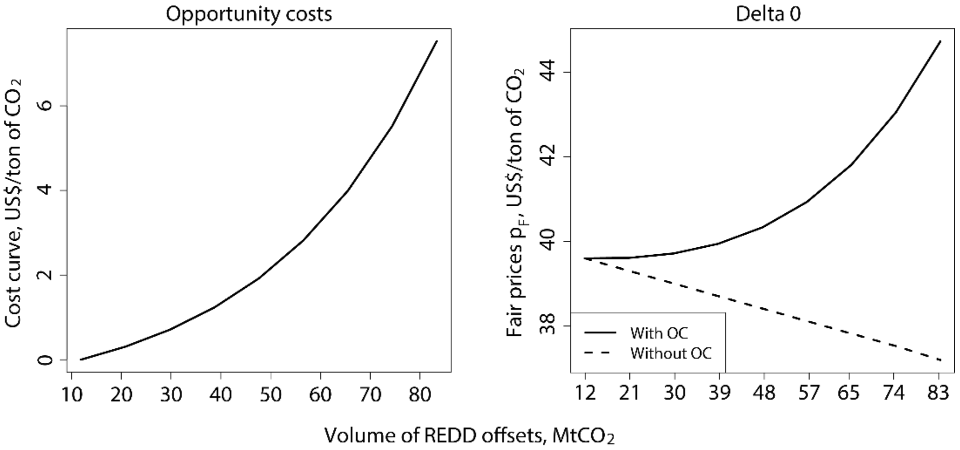

Figure 5. Opportunity cost curve (left) and supply curve with and without opportunity costs (OC) for $\delta = 0$ (right).

The updated supply curves are shown in Figure 6 for several values of benefit-sharing ratio. Implementation of opportunity costs led to the case when the intersection exists for all values δ. At small values of benefit-sharing ratio, e.g. $\delta = 0.15$, the supply curve has and increasing shape. When the ratio increases, the supply curve decreases for smaller REDD offsets amounts, however, it increases for larger amounts due to high opportunity cost compared to benefits from REDD. This leads to the U-shaped supply curves, e.g. for $\delta = 0.6$ and $\delta = 0.9$.

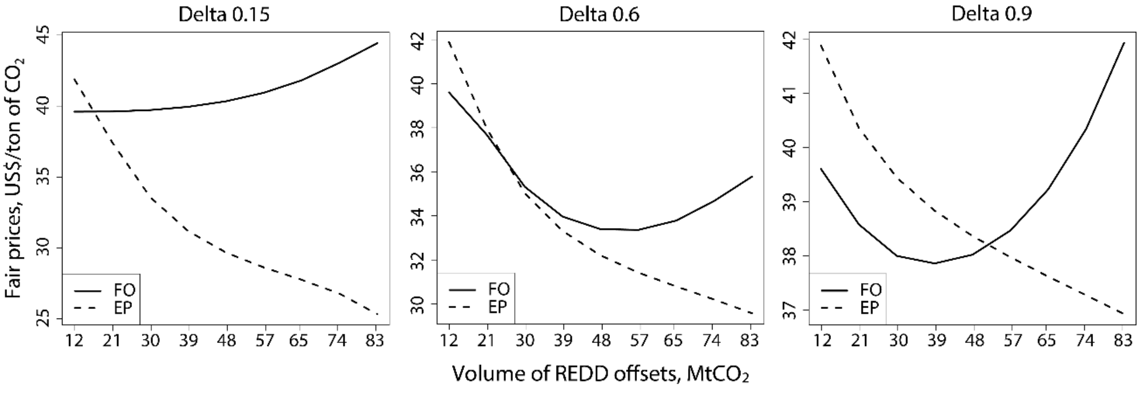

Figure 6. Supply and demand for REDD offsets with opportunity cost incurring to forest owner.

The resulting equilibrium quantities/prices with respect to benefit-sharing ratio are shown in Figure 7, where the demand and supply curves for the case of $\delta = 1$ (no sharing of benefits) are also presented. Compared to Figure 4 (right panel), one can see that the supply curve corresponding to $\delta = 1$ has an increasing shape, leading to unique intersection with the demand curve (EP). An interesting observation is that benefit-sharing ratio maintains its price-lowering and volume-boosting property (see Figure 4 left panel). Namely, one can choose a value at around 0.75, which leads to a high contracted amount and a low price at the same time.

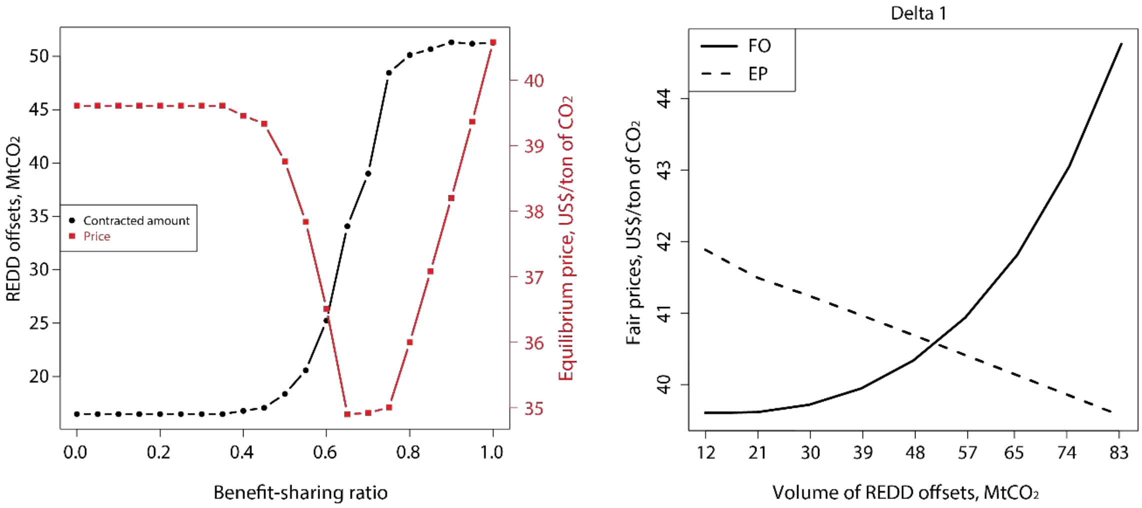

Figure 7. Impacts of benefit-sharing ratio in FI-REDD model with opportunity costs (left panel). Demand (EP) and supply (FO) curves for $\delta = 1$ (right panel).

4 Modeling acceptance uncertainty

The REDD acceptance i.e. future fungibility of emission offsets and those REDD-based is still under discussion. The fungibility assumption, i.e. that avoided emissions and removals from the land sector were interchangeable with emission reductions from fossil fuels, is debated in political and scientific circles (Dooley and Gupta, 2017). Carbon credits from REDD could be made fully interchangeable with those from other sectors, or limited in their fungibility (Angelsen et al., 2014; Bosetti et al., 2011; Neeff and Ascui, 2009).

Here we introduce the modification into the FI-REDD model that allows us to estimate the influence of this uncertainty on the behavior of REDD supplier and consumer. Along with the realization of the CO_2 price, there is also unveiling of REDD acceptance in the second stage. For simplicity, we model two alternatives: first, full fungibility of REDD-based offsets, and, second, only the part of the REDD offsets will be accepted, i.e. 1 ton of offsets covers only 0.25 ton of emissions.

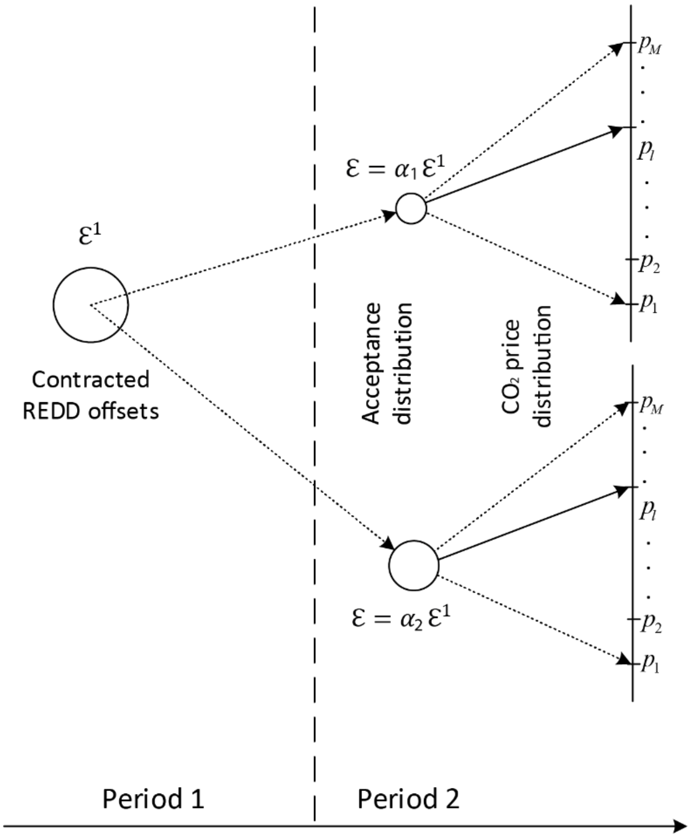

Figure 8. Model with acceptance uncertainty, represented by a discrete probability distribution in the second period.

The case of full acceptance corresponds to the situation when at every CO_2 price realization REDD offsets are fully accepted with probability 1. This is the case of fungible REDD offsets. However, the scenario of partial offsetting (discounted REDD credits) is also possible (Angelsen et al., 2014; Beltran et al., 2013). The idea of acceptance uncertainty as implemented in our study is illustrated in Figure 8. Let us denote the initially contracted amount of offsets by symbol $\mathcal{E}^1$, in the second period this amount can be fully or partially accepted. For example, the fraction α_1 is accepted with probability w_1, and a fraction α_2 is accepted with probability w_2. At each realization the corresponding amount available for offsetting emission is calculated as $\mathcal{E} = \mathcal{E}^1\alpha_1$ and $\mathcal{E} = \mathcal{E}^1\alpha_2$, respectively. Then the tree continues to the decision branches equivalent to the one in Figure 1 – decision on actual emissions and consequent sharing of benefits from selling on the market a part of initially contracted yet unused offsets.

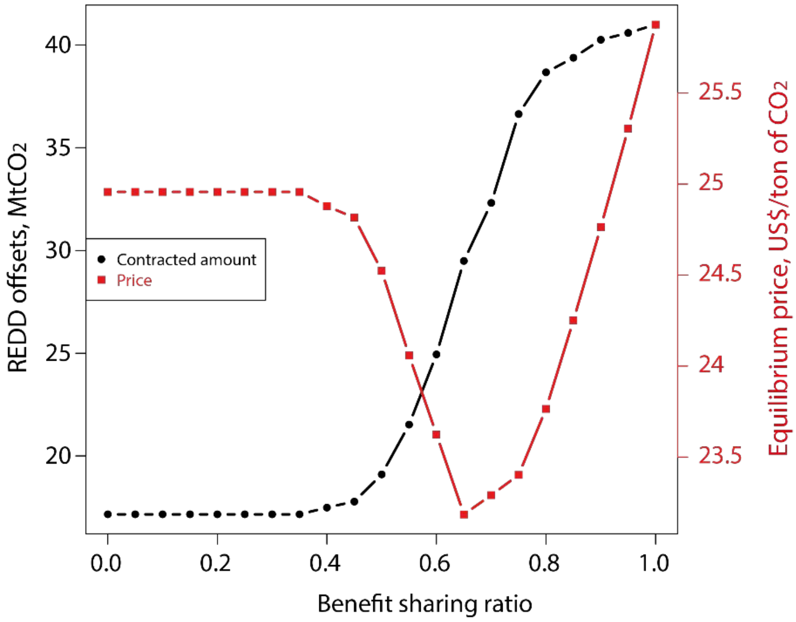

Figure 9. FI-REDD with partial acceptance. At every CO₂ price realization REDD offsets are fully accepted, i.e. $\alpha_1 = 1$*, with probability* $w_1 = 0.5$*, and a quarter,* $\alpha_1 = 0.25$*, of offsets are accepted with probability* $w_2 = 0.5$*.*

Here we present results for the following values of parameters; every CO₂ price realization REDD offsets are fully accepted, i.e. $\alpha_1 = 1$, with probability $w_1 = 0.5$, and a quarter, $\alpha_1 = 0.25$, of offsets are accepted with probability $w_2 = 0.5$. The price distribution is discrete and consists of values $\{0, 10, 20, \dots, 80\}$ with equal probability $p = 1/9$. The resulting contracted amount with respect to benefit-sharing ratio are depicted in Figure 9. The figure shows that the shapes of both quantity and price curves remains similar to the case of full acceptance (see Figure 7). However, due to the possible partial acceptance the contracted amounts and prices are lower (by approximately 25% and 35% respectively). The role of the benefit-sharing ratio stays the same, i.e. the value of 0.75 still leads to the best outcome in terms of the high amount of contracted offsets and low price. This indicates that the proposed benefit-sharing mechanism is robust with respect to acceptance uncertainty and efficient for reduction of the initial amount of funds required to contract large quantities of REDD offsets.

5 Conclusions

We have improved the FI-REDD model by introducing opportunity costs of the forest owner, as well as reflecting the REDD acceptance uncertainty in the model. The first modification is significant in determining the fair price of the forest owner; it leads to the realistic risk-adjusted supply curve for REDD offsets, which guarantees the existence of a unique equilibrium price for all benefit-sharing ratios. We have demonstrated that the property of the benefit-sharing mechanism to increase the contracted amount of offsets and decrease their price is valid in this case. The second modification consists in modeling acceptance of REDD offsets. We proposed an approach for modeling acceptance uncertainty, when REDD offsets may become not fully fungible in the future. The results show that the benefit-sharing mechanism is robust with respect to this uncertainty. Namely, there is an optimal benefit-sharing ratio, which guarantees a large contracted offsets amount at a low price. This result has two important implications for REDD financing. Firstly, the benefit-sharing is an instrument which provides flexibility to the contracting parties, as they can use it to adapt contractual prices and quantities to uncertain realizations in the second period. Secondly, the benefit-sharing ratio could be a control variable, settled by governments or other bodies in order to expand the flows of REDD offsets and keep the transparent fair profit distribution. Further work can be devoted to a more qualitative modeling of REDD options including benefit-sharing.

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