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Addressing Additionality in REDD Contracts When Formal Enforcement Is Absent

Paula Cordero Salas
Brian Roe
Brent Sohngen

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Abstract

The success of reducing carbon emissions from deforestation and forest degradation depends on the design of an effective financial mechanism that provides landholders sufficient incentives to participate and provide additional and permanent carbon offsets. This paper proposes self-enforcing contracts as a potential solution for the constraints in formal contract enforcement derived from the stylized facts of reducing emissions from deforestation and forest degradation implementation in developing countries. It characterizes the optimal self-enforcing contract and provides the parameters under which private enforcement is sustainable when the seller type that is, the opportunity cost of the land, is private information. The optimal contract suggests that the seller with low opportunity cost receives a positive enforceable payment equivalent to the information rents required for self-selection, in contrast to when the buyer knows the seller type in which case all payments should be made contingent on additional forest conservation. When the buyer does not know the seller type, a first-best self-enforcing contract can be implemented if forest conservation is sufficiently productive. If the gains from forest conservation are small, self-enforcing contracts may induce some carbon sequestration by some or all seller types, depending on the value of the shared gains of the relationship.

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Addressing Additionality in REDD Contracts When Formal Enforcement Is Absent*

Paula Cordero Salas†, Brian Roe‡, and Brent Sohngen‡

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†Corresponding Author: Economics, Finance, and Legal Studies Department, The University of Alabama. Tel.:+1 205-348-5633. Email address: pcordero@cba.ua.edu. Postal address: 361 Stadium Drive, 250 Alston Hall, Tuscaloosa, AL 35487-0224.

‡AEDE Department, The Ohio State University

1 Introduction

Carbon emissions from deforestation and forest degradation account for approximately twenty percent of greenhouse-gas emissions (GHG) each year (Holloway and Giandomenico, 2009). Research has found that forest conservation may be a cost-effective option to mitigate climate change since deforestation and forest degradation (DD) is only marginally profitable, and it leads to additional benefits such as positive impacts on biodiversity and economic development (Angelsen, 2008; Sohngen and Beach, 2008). As a result, the use of reduced emissions from deforestation and degradation as a major component to mitigate global climate change has been part of the global debate under the United Nations Framework Convention on Climate Change (UNFCCC).

However, the implementation of a strategy for reducing emissions from deforestation and forest degradation (REDD) depends critically on the design of a financial mechanism that is feasible in practice, given existing institutions for establishing and enforcing contracts, and effective in providing the right incentives to land-holders to manage forests in a sustainable manner that contributes to GHG mitigation goals. Effective REDD contracts must address not only the rewards for those who reduce emissions from DD, but also the technical issues such as contract enforcement and the additionality of the carbon offsets. In particular a REDD mechanism should result in avoided DD that would not occur in the absence of such incentives. Moreover, REDD contracts should induce carbon offsets storage for a period of time with enough incentives for parties to overcome the lack of formal enforcement. Enforcement implies that both parties perform faithfully their contract obligations (i.e., sequester carbon and make payments) for the duration of the contract.

While such contracts may be key in implementing REDD policies, little is known about how conservation buyers should structure the contracts to maximize the likelihood of landholder participation and performance. This is particularly true for long-term contracts featuring landholders that have private information about the opportunity cost of their land and that participate in environments where contracts may be difficult to monitor and enforce.

This paper proposes a relational contracting approach as a new framework to examine the implementation of REDD contracts when the opportunity cost of the land is private information and there are no liquidity constraints. Because REDD contracts potentially will be implemented in many countries with different institutional frameworks, self-enforcing contracts are desirable to overcome different legal systems, enforcement structures and weak governance.

We consider a principal/agent model where the principal is a buyer of carbon offsets and the agent is a seller that has the option of providing the service by keeping part of her land in forest (i.e., landholder). We assume that the buyer is interested in paying only for land that otherwise would become deforested and keeping it permanently as forest. In the absence of any carbon payments from the buyer, the seller allocates a fraction of her land in forest depending on her type. The seller type is private information and identifies the opportunity cost of placing additional land in forest. The buyer offers a REDD contract which includes a two-part tariff including an enforceable base price and a contingent payment to induce the seller to avoid changing the land use and releasing the carbon to the atmosphere for a period of time t. Because forest conservation is implemented in different places operating under different legal regimes, we assume an imperfect enforcement regime. Therefore, after accepting the contract, the parties decide to adhere to or renege on the terms of the contract. We derive the optimal contract under these circumstances. To simplify the analysis, the optimal contract is derived under the assumption that its unique objective is achieving carbon sequestration and we do not consider any co-benefits of REDD.

We find that under the optimal REDD relational contract a seller does not get paid until the end of the period regardless of her type when the buyer can distinguish the seller type and REDD contracts are imperfectly enforceable. The optimal incentive provision is characterized by large contingent payments and base payments equal to zero because the base payment does not provide the seller incentive to perform. Thus, the full payment is made at the end of the contracting period and the size of payment depends on each seller type. As expected, the seller with a lower opportunity cost of the land keeps a higher proportion in forest than the seller with a high opportunity cost. The model also indicates that the extent of cooperation is negatively related to the total cost of forest conservation, i.e. the opportunity cost of the land, and positively related to the value of the carbon sinks from the contract. Additionally, if the benefit that the buyer accrues from the carbon sinks delivered by the contract is close to the benefits of getting carbon credits from alternative sources, such as an enforced market for emissions relating carbon offsets, cooperation is also difficult to sustain. Conversely, if forest conservation is worth a lot to the buyer because of the high opportunity cost of other compliance strategies, he will have a high interest in cooperation.

When the seller type is private information, the seller with a lower opportunity cost of the land benefits from an information rent paid through the enforceable price because she is more efficient in providing forest conservation than the seller with higher opportunity cost. Further, the model indicates that if the value of shared gains of the relationship is sufficiently high, a first-best self-enforcing contract can be implemented even when the buyer does not know the seller type. On the other hand, if the gains from the relationship are small, relational contracts may still induce some level of carbon offset conservation below the first-best level for some or all types depending on how restrictive is the self-enforcement constraint.

There is limited extant research to guide the contract design of conservation payments to ensure additionality of carbon offsets and long-term performance from sellers. Recent examples that employ contract theory to design carbon-sequestration contracts include Gjertsen et al. (2010); Mason and Plantinga (2011); Palmer, Ohndorf, and MacKenzie (2009); van Benthem and Kerr (2010); Guiteras, Jack, and Oliva (2011); and Bushnell (2011). In contrast with those papers, we assume that renegotiation is not reasonable given the slow reversibility of carbon stocks and that formal enforcement is weak given the multiple institutional frameworks in which REDD implementation is potentially embedded. Thus, this research proposes the use of self-enforcing contracts to overcome these issues. The results here also contribute to the literature on contract design for environmental services (Ferraro, 2008) and agri-environmental payment schemes (Chambers, 1992; Claassen, Cattaneo, and Johansson, 2008; Fraser, 2009; Latacz-Lohmann and Van derHamsvoort, 1997; Moxey, White, and Ozanne, 1999; Ozanne, Hogan, and Colman, 2001; Peterson and Boisvert, 2004; Spulber, 1988; Wu and Babcock, 1996; Yano and Blandford, 2009).

In addition, this paper contributes to the economics literature by deriving a contract that may be more suitable for markets in which opportunity costs predominate the direct costs of performing the task. To study this, we derive a function that reflects the opportunity cost of the land and the optimal self-enforcing contract under asymmetric information. In this way, this paper generates new ideas for tackling the optimal contract design to guarantee participation of sellers who have private information about potential land use, a necessary condition for ensuring long-term performance of carbon sequestration when formal institutions to enforce contracts may be unavailable or too costly to use. These ideas also benefit practitioners charged with implementing carbon sequestration contracts around the world.

The structure of the paper is as follows. Section two presents the relational contracting model. Section three derives the optimal relational contract and the sustainability of self-enforcement when parties have symmetric information while section four derives the results for when there is asymmetric information. Finally, section five presents conclusions.

2 The Model

Consider two risk-neutral parties, a buyer and a seller, who have the opportunity to trade carbon offsets at dates $t = 0, 1, 2, 3 \ldots$. The buyer is interested in the additionality of carbon offsets to comply with REDD objectives.[1] He offers a seller a payment through a contract to avoid changing land use, but he prefers to pay only for the land that otherwise would become deforested.

Although in practice a buyer may interact with many sellers, in this model we consider a representative seller. The seller possesses total forested land of mass 1 and is interested in adopting the land use that maximizes her economic returns. She can conserve additional land in the forest, $\ell \in [\theta, 1]$, or she can change the land use to a non-forest activity such as agricultural and timber harvesting, resulting in carbon emissions. The seller is not liquidity constrained and is characterized by her type,[2] which is private information given by $\theta \in \{\theta_L, \theta_H\}$. We assume that seller type is not persistent across periods (Levin, 2003) but is perfectly persistent within periods. These assumptions align, in part, with the forestry situations we envision. For example, a seller opportunity cost might change considerably if the household suffers an idiosyncratic shock that creates a need to liquidate assets such

[1] In this paper we apply the relational contracting model to address the pure objective of carbon sequestration. See Cordero Salas and Roe (2012) for a version that includes a framework with other REDD co-benefits often included in REDD+, such as distribution.

[2] The seller type is the amount of land a seller places in forest absent any carbon payments. Given the returns of her land, a seller determines the opportunity cost of placing additional land in forest. For example, if the seller is a farmer, she deforests her land if the returns from farming are positive and keeps the forest if the returns of farming are non-positive absent carbon payments. If the seller is a timber producer, she keeps the forest if the returns from harvesting timber are not positive. If the seller has a high return on the non-forest activity, she has little incentive to keep the forest, and in the model she is referred as an L-type seller. In contrast, if the returns of the non-forest activity are small, the seller does not have much incentive to deforest and therefore she is an H-type seller. In practical terms, knowing if the seller is a farmer or a timber producer provides information about the seller type; however, historical information about land-use patterns or specific characteristics of the products and markets in which the landowner participates may better estimate the seller type. Furthermore, a seller type is important if the seller is a government. For instance, if the government has a strong conservation policy, it represents an H-type seller, while if the government is characterized by low conservation effort then it is an L-type seller. Contracting with governments may decrease the information asymmetry about the seller type because the type may be easier to observe through government-conservation history and policies.

as standing forests or to degrade forests through the harvest of other products. Like any assumption, this assumption might be overly restrictive because it implies that, in each period, there is an equal probability that a seller is type H. In other words, it implies that last period's type, which is revealed in the seller's choice of contract from the menu, carries no information concerning next period's type. However, it does allow us to capture the stochastic nature of opportunity cost between periods, including changes in the returns of the alternative economic activities.

In the absence of REDD payments, the seller allocates θ of her land to forest and $(1-\theta)$ to other economic activities. Let $U_A = \omega(1-\theta) - c(1-\theta,\theta)$ be the profit of the alternative economic activity where ω is the return of the activity and $c(1-\theta,\theta)$ is the cost. The cost is assumed to have the following properties: $c_1(1-\theta,\theta) \geq 0$ and $c_{11}(1-\theta,\theta) \geq 0$. The seller choses θ by maximizing U_A which leads to the first-order condition: $\omega = c_1(1-\theta,\theta)$ for all θ. When a seller faces the opportunity to participate in a REDD scheme, she can place some additional land in forest, $\ell \in (\theta, 1]$, receives a payment $P(\ell)$ and receives returns from alternative land use for some of the land: $\omega(1-\ell) - c(1-\ell,\theta)$. Her total profit in this case is: $U_C = P(\ell) + \omega(1-\ell) - c(1-\ell,\theta)$. The seller participates in the REDD program if $U_C \geq U_A$. By rearranging, the expression leads to $P(\ell) \geq \omega(\ell-\theta) - c(1-\theta,\theta) + c(1-(\ell-\theta)-\theta,\theta)$. Let $g(\ell,\theta) = \omega(\ell-\theta) - c(1-\theta,\theta) + c(1-(\ell-\theta)-\theta,\theta)$ be the opportunity cost function. Because $\omega = c_1(1-\theta,\theta)$ for all θ and $\ell \in [\theta, 1]$, the opportunity cost of keeping additional land in forest is increasing and convex—$dg/d\ell \geq 0$ and $d^2g/d\ell^2 \geq 0$[3] —and $g(\theta,\theta) = 0$.

The seller type determines the opportunity cost of keeping ℓ in forest because in the absence of carbon payments an L-type seller keeps θ_L of her land in forest, while an H-type seller keeps θ_H, where $\theta_H > \theta_L$; thus the opportunity cost is decreasing in type, $dg/d\theta < 0$ and $d^2g/d\ell d\theta < 0$.[4] That is, an L-type seller has a higher opportunity cost for the land than

[3]Note that $dg/d\ell = \omega - c'(1-\theta-(\ell-\theta),\theta)$ and $\omega \geq c'(1-\theta-(\ell-\theta),\theta)\ \forall\ \ell \in [\theta, 1]$.
[4]$d^2g/d\ell d\theta = -c_{12}(\ell-\theta,\theta)$ and $c_{12}(\ell-\theta,\theta) > 0 \Rightarrow d^2g/d\ell d\theta < 0$.

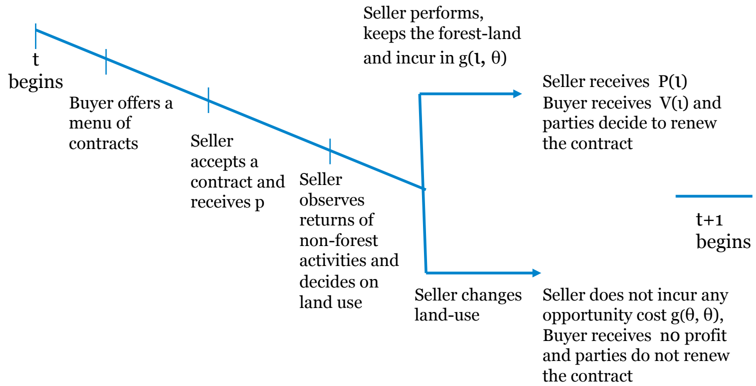

Figure 1: Timing line

an H-type seller, who keeps a larger fraction of her land in forest when the price for forest conservation is zero. The buyer may not observe the seller type before offering a contract, but he knows that a seller is H-type with probability α and L-type with probability $1 - \alpha$.

Figure 1 shows the timing of actions and decisions. At the beginning of period t, the buyer offers the seller a menu of contracts that include a compensation scheme that the seller is entitled to if she maintains fraction ℓ of her land in forest. Compensation consists of an enforceable base payment, p_t, and a contingent payment, $b_t : \ell \to \Re$, where ℓ is the observed forest. Forest land and its carbon stocks are observable by both parties, but they are not enforceable because of the weak enforcement institutions and the multiple institutional frameworks in which REDD is embedded. Consequently, the requested area in forest, ℓ^*, may differ from the delivered quantity, ℓ_t, and it may also differ from keeping all the forest mass, 1, depending on the benefit and cost of forest conservation.[5] Because there are only two types of sellers, θ_L represents the minimum amount of land any seller keeps in forest given the opportunity costs, therefore $\ell_t \in \mathcal{L} = [\theta_L, 1]$.

The base payment, p_t, is paid independently of the final outcome and therefore it is

[5]The intuition is that the requested area in forest, ℓ^*, depends on the marginal benefit and marginal cost of keeping additional land as forest. It may be the case that the marginal cost of keeping all forest (mass 1) is greater than its marginal benefit. Therefore, it is optimal to contract for $\ell^* < 1$.

enforceable. The contingent payment is considered a *bonus*, a per-unit payment used to reward forest conservation.[6] Since the contingent payment depends on an unenforceable measure, it is not a legally binding obligation and it is also unenforceable. After observing the compensation scheme, the seller decides whether to accept the buyer's offer. If the seller accepts she receives p; observes the returns of alternative land uses, including non-forest activities; and decides to adhere to the contract or to change the land use by keeping only θ amount of land in forest.

If she decides to avoid DD, she incurs the opportunity cost for forest protection, $g(\ell_\theta, \theta)$. Because the contracts are on forest conservation there are no upfront costs associated with the activity, in contrast with afforestation projects, in which there is an upfront investment. The seller's economic profit is $U_{t\theta} = P_t(\ell_{t\theta}) - g_t(\ell_{t\theta}, \theta)$, where $P_t(\ell_{t\theta}) = p_{t\theta} + b_t(\ell_{t\theta})$ is the buyer's total payment. At the end of period t, the seller's forest land generates a direct net benefit for the buyer, $V_t(\ell_{t\theta})$, where $V'(.) > 0$, $V''(.) \leq 0$, and $V(\theta) = 0$. That is, the buyer only gets a benefit for additional land placed in forest relative to the business-as-usual scenario, and the benefit is net of the buyer's cost of observing the seller's performance.[7] $V_t(\ell_{t\theta})$ represents the buyer's value of the carbon credits generated by the forest conservation. It can be interpreted as the buyer's direct cost of doing his own carbon emission mitigation, and it can also reflect the buyer's value for non-carbon objectives such as biodiversity conservation. The buyer also chooses whether to pay $b_t(\ell_{t\theta})$ and his profit are given by $\Pi_t = V_t(\ell_{t\theta}) - P_t(\ell_{t\theta})$. The total joint surplus is defined by $S(\ell_{t\theta}, \theta) = V(\ell_{t\theta}) - g(\ell_{t\theta}, \theta)$, and ℓ^*_θ maximizes the surplus for each type.

If the seller rejects the contract, she does not incur the opportunity cost of keeping

[6] The optimal contract is designed to reward equally for either avoiding deforestation or avoiding forest degradation. The idea that the contracts are self-enforcing is that they give incentives to the landowners to not remove wood for markets or personal use. However, we acknowledge that in practice there are likely big cost differences in observing deforestation and degradation. As a consequence, REDD contracts may be more effective in reducing deforestation than forest degradation.

[7] We assume that the buyer's net value of the conservation is positive for a certain level of observation costs. The key focus here is on weak formal contract enforcement, which we assume is impossible.

additional land in forest, only keeps θ and $g(\theta, \theta) = 0$. Trade does not occur and the buyer looks for alternative carbon credits given by $\overline{\pi}$; for example, the buyer can get CDM credits from other projects or alternatively implement a REDD project in another country. The net social surplus from carbon sequestration is given by $S(\ell_{t\theta}, \theta) - \overline{\pi}$, and we assume that for both θ, $\max_{\ell_{t\theta}} S(\ell_{t\theta}, \theta) > \overline{\pi} \geq 0 \geq S(\theta_L, \theta)$.

This sequence of events repeats in each period t, and over the course of repeated interactions the parties know only the past actions of their previous trading partners, allowing for the creation of relationships. In addition, the party's objective is to maximize the future discounted stream of payments, where the common discount factor is $\delta \in (0, 1]$.

2.1 First-Best REDD Contracts

Consider the case in which forest land and carbon stocks are enforceable and there is not asymmetry of information between the buyer and the seller about the seller type. The buyer offers the seller a contract according to her type in which the most efficient production levels are obtained by equating the buyer's marginal value and the seller's marginal cost. The contract could explicitly include the area in forest and a single base payment in exchange for the carbon delivered by the forest land. Contingent payments are not necessary because a formal court enforces the contract. If parties breach the contract, they incur a formal penalty assumed large enough to motivate performance. Consequently, the buyer makes a take-it-or-leave-it type-dependent contract proposal defined as $y_{t\theta} = \langle P_{t\theta}, \ell_{t\theta} \rangle$ that maximizes his stream of future payoffs subject to the participation of the seller in the contract. The seller accepts the contract and avoids DD for the additional land if and only if the economic profit that she obtaines from participating in a REDD program is non-negative.[8] This is given by

[8]Notice that the focus of the modeling in this paper is on individual bilateral contracts with imperfect information in which the opportunity cost of the land determines the individual payment. As the model is of incomplete information, the seller with the lowest opportunity cost may earn economic rents.

the seller's individual rationality constraint (IRC)

$$U_{t\theta} = P_{t\theta} - g_t(\ell_{t\theta}, \theta) \geq 0, \tag{1}$$

and the buyer solves the following maximization program for each seller

$$\max_{P_\theta, \ell_\theta} \left(\frac{V(\ell_\theta) - P_\theta}{1-\delta}\right)$$
$$\text{subject to} \quad P_\theta = g_t(\ell_{t\theta}, \theta) \text{ and } \ell_\theta \in [\theta_L, \overline{\ell}]. \tag{2}$$

Substituting the seller's IRC into the buyer's profit option, we obtain the following first order condition for each type: $V'(\ell^*_\theta) = g'(\ell^*_\theta, \theta)$. Both seller types keep the optimal additional land in forest, ℓ^*_L and ℓ^*_H, and their net social value is nonnegative, $S(\ell^*_L) - \overline{\pi} \geq 0$ and $S(\ell^*_H) - \overline{\pi} \geq 0$. Furthermore, the net social value is greater for the H-type than for the L-type because the H-type has a lower opportunity cost for the land and therefore is more efficient in producing carbon offsets through maintaining more land in forest.[9] The optimal contract is given in Proposition 1.

Proposition 1. *If REDD contracts are perfectly enforceable and there is symmetric information about the seller type, the buyer pays compensation equal to $P = g(\ell^*_H, \theta_H)$ to an H-type seller and $P = g(\ell^*_L, \theta_L)$ to an L-type seller during date t, and each seller maintains ℓ^*_H and ℓ^*_L area of land in forest respectively. The buyer gets profit equal to $\Pi^* = \frac{V(\ell^*_\theta) - c(\ell^*_\theta, \theta)}{1-\delta}$ and each seller gets economic profit equal to $U^*_\theta = 0$.*

A formal mechanism enforces the optimal contract, which implements full conservation of additional forest, and each seller receives payments according to her type. The buyer

[9] The H-type seller is closer to the margin, where the returns from non-forest activities are very low. But we assume that an H-type seller will still deforest absent conservation payments. As a result, contracting with the H-type seller provides more efficient additionality because her cost of keeping additional land in forest is lower than the L-type's cost of keeping additional forest; i.e., the opportunity cost of the land is lower for the H-type.

obtains the net benefits from the additional carbon offsets. Each seller receives economic profit equal to zero.

3 Relational Contracts and REDD

Because enforcement institutions are weak, formal enforcement of REDD contracts becomes difficult. If the buyer can observe the seller's conservation at a reasonable cost, then the parties may rely on relational contracting (i.e., informal incentives and good faith) as a private enforcement—i.e., self-enforcement—mechanism. However, the contingent payments are just a promise; therefore, the parties are tempted to deviate from the contract because they do not incur a formal penalty for reneging the original agreement. If the parties interact just once, the buyer can only make the base payment credible because it is paid regardless of the final outcome. Because this payment does not include additional incentives for any type of seller to conserve additional forest, keeping additional land from deforestation and degradation cannot occur in a static equilibrium. Consequently, trade does not occur.

In contrast, the ongoing interaction sustains the equilibrium by allowing the parties to support future terms of trade contingent on the satisfactory performance of present trade. This implies that the buyer observes the area in conservation and makes the contracted payment if the seller has kept the forest.[10] The parties cooperate if the history of play in all periods has been cooperation. The parties break trade forever if deviation is observed. We assume that deviation causes the parties to break trade forever because this outcome never happens in equilibrium (Levin, 2003). Furthermore, we assume that after deviation the parties do not trade anymore. This assumption reflects that the buyer will not trade with a seller who has deforested because she does not have forest to offer. If the buyer

[10] In practice, the contract defines a *period*, which can be a year or other convenient time unit. The buyer observes the forest conservation with some positive but low cost, such that the net value of conservation is positive.

deviates, the seller responds by changing the land use to a non-forest activity. Again, forests are destroyed along with the opportunity of future trade.

Additionally, parties cannot renegotiate the trading decision after forest conservation is observed because we assume that a self-enforcing contract is optimal given any history, thus the contract is strongly optimal. A strongly optimal contract has the property that parties cannot jointly gain from renegotiating even off the equilibrium path. Because behavior off the equilibrium path implies deviation, if either party deviates, additional forests are destroyed and with them the social surplus. Therefore, there is no gain from renegotiation.

Finally, each period is played following a Nash equilibrium, and the parties use a stationary contract in which the buyer always offers the same type-dependent payment scheme, the seller always takes the same action, and the rents to the relationship are attractive enough for the parties to self-enforce the contract (Baker, Gibbons, and Murphy, 1994; MacLeod, 2006; MacLeod and Malcomson, 1989, 1998). Repetition allows players to maintain a sub-game perfect Nash equilibrium where parties maintain long-term relationships. These assumptions allow for self-enforcing contracts since they contain a complete plan for the relationship that describes behavior on and off the equilibrium path.

3.1 Symmetric Information

Suppose that the buyer can distinguish L- and H-type sellers such that he can offer a self-enforcing contract to a seller according to her type. Because formal enforcement is imperfect but the buyer can distinguish sellers with high and low opportunity costs, he offers an explicit type-dependent contract $y^*_\theta = \langle p^*_\theta, b(\ell^*_\theta)\rangle$ through which he provides incentives for the seller to avoid DD in some additional land relative to in the absence of REDD incentives. Because enforcement is imperfect after the seller accepts y^*_θ, she decides how to use the land. She can cooperate by choosing $\ell_{t\theta} \geq \ell^*_\theta$ or shirk by choosing $\ell_{t\theta} = \theta$. The buyer, after perfectly observing the conserved area in forest, may cooperate by paying $P_{t\theta}(\ell^*_{t\theta}) = p^*_{t\theta} + b_{t\theta}(\ell^*_{t\theta})$ or renege by choosing the most profitable deviation, not paying the bonus, $b(\ell_{t\theta}) = 0$.

The buyer participates in REDD if the benefits from the contract with either type are greater than his alternative source of carbon reduction. This is given by his IRC:

$$\Pi = V(\ell_\theta) - p_\theta - b(\ell_\theta) \geq \overline{\pi}. \tag{3}$$

In addition, the buyer's offer has to meet the seller's IRC, inequality (1); i.e., the offer has to provide a credible incentive to perform in each period. Note that $P_{t\theta}$ in inequality (1) becomes $p_\theta + b(\ell_\theta)$. Because of the imperfect enforcement a dynamic incentive compatibility constraint (DICC) for each party has to be fulfilled such that the parties prefer to comply instead of reneging. The seller's and the buyer's DICCs are given by (4) and (5) respectively. A seller of type θ cooperates if and only if

$$\frac{p_\theta + b(\ell_\theta) - g(\ell_\theta, \theta)}{1-\delta} \geq p_\theta - g(\theta, \theta) \tag{4}$$

The left-hand side is the discounted economic profit of the seller for cooperating and maintaining additional land in forest $\ell_{t\theta} \geq \ell^*_\theta$ at the end of each date t. It represents the discounted gains from the relationship for a seller of type θ, i.e., the REDD payment minus the opportunity cost of the land. The right-hand side represents the payoff if she shirks. Note that the most profitable deviation for the seller is to change the land use to what she would choose absent payments for forest conservation, θ. In this case, she does not incur opportunity cost for forest conservation, $g(\theta, \theta) = 0$, which would cause the buyer, after observing the area kept as forest, to not pay the bonus. But she receives p_θ because the base payment is enforceable and independent of performance.

Additionally, the buyer cooperates with each seller type if his DICC given by (5) is satisfied. He cooperates if he gets the long-term benefits of the forest conservation net of the payments he makes. If he deviates he does not pay the bonus and in all future periods he guarantees himself the benefits of the alternative options for carbon credits:

$$\frac{V(\ell_\theta) - p_\theta - b(\ell_\theta)}{1-\delta} \geq V(\ell_\theta) - p_\theta + \frac{\delta}{1-\delta}\overline{\pi} \tag{5}$$

A REDD contract is self-enforceable if the long-term returns from the current relationship are at least as good as the present value of the forgone returns from the alternate uses of land, so that the seller of type θ remains trading with the same buyer and vice versa. Thus, since both parties can deviate from the contract, the contingent payment must be sufficient to ensure a self-enforcing contract. It follows that the compensation scheme is bounded by the future gains of the relationship. The buyer solves for each seller the following optimization program under imperfect enforcement and symmetric information:[11]

$$\begin{aligned} &\max_{p_\theta, b(\ell_\theta), \ell_\theta} \left(\frac{V(\ell_\theta) - p_\theta - b(\ell_\theta)}{1-\delta}\right) \\ &\text{subject to} \quad p_\theta + b(\ell_\theta) = g(\ell_\theta, \theta), \\ &\qquad \tfrac{p_\theta + b(\ell_\theta) - g(\ell_\theta,\theta)}{1-\delta} \geq p_\theta, \\ &\qquad \tfrac{V(\ell_\theta) - p_\theta - b(\ell_\theta)}{1-\delta} \geq V(\ell_\theta) - p_\theta + \tfrac{\delta}{1-\delta}\overline{\pi}, \\ &\text{and} \quad \ell_\theta \in [\theta_L, 1]. \end{aligned} \tag{6}$$

As the buyer can observe the seller type, he offers just enough incentive for a seller of type θ to participate; the seller's IRC can be rearranged as $p_\theta = g(\ell_\theta, \ell) - b(\ell_\theta)$ and expression (4) can be restated as

$$p_\theta \geq \frac{g(\ell_\theta, \theta) - b(\ell_\theta)}{\delta}, \tag{7}$$

By substituting p_θ from (1) in (7), we get the minimum bonus that needs to be offered

[11] Note that since $g(\theta, \theta) = 0$, the seller's DICC reduces to $\frac{p_\theta + b(\ell_\theta) - g(\ell_\theta,\theta)}{1-\delta} \geq p_\theta$.

in a REDD relational contract for inducing long-term cooperation from a θ-type seller: $b(\ell_\theta) \geq g(\ell_\theta, \theta)$. The presence of the performance payment allows the buyer to offer a lower base payment. Thus, by isolating $b(\ell_\theta)$ in (1) and substituting in (7), we get the upper bound on the base payment, p_θ, for inducing long-term seller cooperation: $p_\theta \leq 0$.

The buyer's IRC and DICC also impose limits into the payment structure. To see this note that the buyer's DICC is binding while the IRC is not binding.[12] By substituting p_θ from (5) into (3), we get the lower bound of a bonus that satisfies the buyer's constraints: $b(\ell_\theta) > 0$. Finally, by substituting p_θ in the same way we get that $V(\ell_\theta) - \overline{\pi} > p_\theta$. Note that the minimum bonus derived from the seller's constraints satisfy the minimum bonus derived from the buyer's constraints; therefore, the minimum bonus from the seller's constraints binds in the contract. In the same way, the maximum price from the seller's constraints binds as $0 < V(\ell_\theta) - \overline{\pi}$. Thus, the optimal distribution of the total compensation among the base payment and the performance bonus is established. The optimal stationary REDD contract is defined in Proposition (2).

Proposition 2. *If contract enforcement is imperfect and the buyer can distinguish H-type and L-type sellers, an optimal self-enforcing REDD contract for each type, $\langle p^*_\theta, b^*(\ell^*_\theta)\rangle$ implements additional forest conservation, ℓ^*_θ. The incentive scheme is characterized by:*

$$p^*_\theta \leq 0 \tag{8}$$

$$b(\ell^*_\theta) \geq g(\ell^*, \theta) \tag{9}$$

$$P(\ell^*_\theta) = g(\ell^*, \theta) \tag{10}$$

Equality (10) identifies the total compensation that the buyer offers a θ-type seller.

[12]If the IRC binds $V(\ell_\theta) - p_\theta - b(\ell_\theta) = \overline{\pi}$ and substituting in the DICC, we get that $p_\theta > V(\ell_\theta) - \overline{\pi}$ which violates the buyer's IRC. The IRC then does not bind. If the DICC binds, $V(\ell_\theta) - p_\theta - b(\ell_\theta) = (1-\delta)(V(\ell_\theta) - p_\theta) + \delta\overline{\pi}$. By substituting it in the IRC we get that $V(\ell_\theta) - \overline{\pi} > p_\theta$, which is possible, the DICC then binds.

The contract compensates the seller for the opportunity cost of the additional land placed in forest. Equalities (8) and (9) give the structure of the total payment. Note that under the optimal relational contract nothing is paid as a contractible base payment. A seller receives the total payment contingent on performance. The contract structure reflects the nature of the problem. Because a contractible payment is not conditioned on performance, it does not give the seller incentive to remain in the relationship, and so the buyer needs to provide the seller additional incentives to perform under imperfect enforceability of forest conservation. Moreover, because the contingent payments are limited by the future gains from the relationship, all compensation is shifted to the contingent payment so that the seller has enough incentive to perform. The result is highlighted in the following corollary.

Corollary 1. *When formal enforcement is weak, self-enforcement can be used in forest conservation contracts in which all compensation is paid as a performance payment upon observed forest conservation regardless of the seller's alternative use of land.*

3.2 Sustainability of Self-enforcing Contracts under Symmetric Information

Self-enforcing contracts are sustainable if the parties find the optimal strategy is to cooperate in every period. The cooperation decision depends on each party's discounted payoff stream from the contract (i.e., the relationship's returns) and on how much each party values the future relative to the present (discount factor). If the parties hold a very low discount factor—δ near zero—the value of the relationship shrinks and contract compliance becomes less attractive. Therefore, it is more difficult to enforce contracts privately. As a consequence, social efficiency is potentially offset by the lack of formal enforcement.

In the case of the optimal REDD contract described in Proposition 2, the parties find self-enforcement to be the best strategy if they value the future relationship is enough (given by each party's DICC). Combining the parties' dynamic constraints given by (4) and (5) yields the self-enforcement constraint necessary to achieve cooperation under the optimal REDD contract.

Proposition 3. *Long-term contracts are sustainable if the gains from the relationship are greater than the contingent payments needed to induce forest conservation:*

$$\frac{\delta}{1-\delta}(S(\ell,\theta)-\overline{\pi}) \geq g(\ell_\theta,\theta). \tag{11}$$

Proposition 3 reports the self-enforcement dynamic constraint for a cooperative equilibrium under the optimal REDD contract. If the relationship with each type is productive enough to cover the necessary incentives to perform, then self-enforcement can implement first-best conservation with both types of sellers.

Note that the total compensation (eq. 10) is weakly increasing because the contingent payment is limited by the gains from the relationship. If the opportunity cost of the land is too high, then the future gains from the relationship may not be enough for the parties to perform and self-enforce the contract. In addition, the higher the total payment, $g(\ell_\theta,\theta)$, is relative to the net surplus of the additional forest procured by the contract, the higher the discount factor needed to maintain cooperation is. As a consequence, only parties who value the future a lot find cooperation to be the optimal strategy. A high discount-factor is needed when the seller's opportunity cost is too high.

In contrast, the lower the opportunity cost of forest conservation is relative to the net benefits from keeping additional land in forest under the contract, the smaller the discount factor needed to self-enforce the contract. In these situations, REDD contracts are more likely to achieve their objective. We end by summarizing these insights in Corollary 2.

Corollary 2. *Cooperation under the optimal REDD contract is more likely to occur when the opportunity cost of maintaining forest is low, the reservation options for the buyer are* *low, and the buyer's value of additional forest is high.*

4 Asymmetric Information

Suppose that the seller type is private information.[13] However, the buyer knows that a seller is of H-type with a probability of α. The buyer offers a menu of contracts, $\{(p_{\theta_L}, b(\ell_L)); (p_{\theta_H}, b(\ell_H)\}$, that are self-enforcing and that induce each type θ to keep the designated land in forest ℓ_θ instead of mimicking the other type.

A seller selects the land she keeps in forest ℓ_θ by maximizing $U_\theta = P(\ell_\theta) - g(\ell_\theta, \theta)$. Let U_L and U_H be the per-period economic profit each seller gets from the REDD contract. The contract must satisfy the following incentive compatibility constraints (ICC):

$$U_L \geq P(\ell_H) - g(\ell_H, \theta_L) \quad \text{and} \tag{12}$$

$$U_H \geq P(\ell_L) - g(\ell_L, \theta_H). \tag{13}$$

The individual rationality, self-enforcement, and incentive compatibility constraints characterize the set of feasible additional forest conservation achievable through a menu of contracts when formal enforcement is incomplete and there is hidden information. In addition, regardless of the payment, the per-period economic profit for a θ-type seller, U_θ, is increasing in θ (by the Envelope Theorem). The need for the ICCs reduces the set of feasible contracts, and the contracts are implementable only if they satisfy the following monotonicity constraint:

$$g(\ell_H, \theta_L) - g(\ell_H, \theta_H) \geq g(\ell_L, \theta_L) - g(\ell_L, \theta_H). \tag{14}$$

[13]We assume that a seller type is invariant within a period but is non-persistent over time. This allow us to address if there are stochastic events such as a family illness or change in prices that may drive a change in seller's type. Therefore, the seller's information in one period does not reveal enough information about her type for the following periods.

Because $\theta_H > \theta_L$, $dg/d\ell > 0$, $dg/d\theta < 0$, and $d^2g/d\ell d\theta < 0$, the contracts are incentive compatible (IC) if and only if ℓ_θ is nondecreasing. Incentive compatibility implies that the fraction of land requested to be kept as forest from a L-type seller cannot be higher than that requested from an H-type seller. This is intuitive because a H-type has a lower opportunity cost for forest conservation than a L-type.

Let $\Delta_L = g(\ell_L, \theta_L) - g(\ell_L, \theta_H)$ and $\Delta_H = g(\ell_H, \theta_L) - g(\ell_H, \theta_H)$ be the difference in the opportunity cost of keeping additional land in forest, ℓ_L and ℓ_H. An H-type seller's ICC is relevant because she could mimic a L-type seller and get economic profit equal to $P(\ell_L) - g(\ell_L, \theta_H) = P(\ell_L) - g(\ell_L, \theta_L) + g(\ell_L, \theta_L) - g(\ell_L, \theta_H) = U_L + \Delta_L$. Even if the L-type seller's economic profit is set to the lowest possible level fixed at 0 from the IRC, the H-type seller benefits from an information rent Δ_L.[14] In contrast, the L-type does not benefit by imitating the H-type. If the L-type does, she gets $P(\ell_H) - g(\ell_H, \theta_L) = U_H - \Delta_H$. If $U_H = 0$, the L-type seller gets negative profit. Then from the ICC we have

$$U_H = P(\ell_H) - g(\ell_H, \theta_H) = U_L + \Delta_L \quad \text{and} \tag{15}$$

$$U_L = P(\ell_L) - g(\ell_L, \theta_L) = 0. \tag{16}$$

Assume that ℓ_H and $P(\ell_H)$ satisfy IC. This means that $\ell_H \geq \ell_L$ and inequality (15) can be rewritten as

$$P(\ell_H) = g(\ell_H, \theta_H) + U_L + \Delta_L. \tag{17}$$

In addition, the contract for each type must satisfy $U_\theta = P(\ell_\theta) - g(\ell_\theta, \theta) \geq P(\hat{\ell}) - g(\hat{\ell}, \theta)$, where $\hat{\ell} \notin \mathcal{L} = [\theta_L, 1]$; neither type of seller prefers an $\hat{\ell}$ that is not ℓ_L or ℓ_H. This implies that, since either type can deviate to $\ell = \theta$ and $g(\theta, \theta) = 0$, then $U_L = P(\ell_L) - g(\ell_L, \theta_L) \geq P(\theta_L)$.

[14] Δ_L can be thought of as the buyer's expected additional per-period cost due to asymmetric information. Hence, it sets the upper limit on per-period expenditures the buyer would save by eliminating information asymmetries.

Combining this with equality (17) results in

$$P(\ell_H) - P(\theta_L) \geq g(\ell_H, \theta_H) + \Delta_L. \tag{18}$$

Note that $P(\ell_H)$ is the maximum payment that the buyer gives to a seller and $P(\theta_L)$ is the minimum, which equals zero because the buyer does not pay for a θ_L amount of land in forest. Without knowing the seller type, the buyer knows that any seller would maintain at least θ_L forested land because in the absence of payments sellers maintain some land in forest such that $\theta_H \geq \theta_L$. Long-term self-enforcement implies that the difference between the highest and lowest payment the buyer pays, $P(\ell_H) - P(\theta_L)$, must be less than or equal to the expected future gains from the relationships, $\frac{\delta}{1-\delta}(S - \overline{\pi}) \geq P(\ell_H) - P(\theta_L)$, where $S = \alpha(S(\ell, \theta_H) - g(\ell, \theta_H)) + (1-\alpha)(S(\ell, \theta_L) - g(\ell, \theta_L))$ is the expected surplus. This relationship results in the next proposition.

Proposition 4. *When the buyer does not know the seller type, a REDD contract can implement the conservation of additional land in forest, ℓ_θ, that generates an expected surplus S if and only if ℓ_θ is nondecreasing and*

$$\frac{\delta}{1-\delta}(S - \overline{\pi}) \geq g(\ell_H, \theta_H) + \Delta_L. \tag{19}$$

Inequality (19) combines the self-enforcing constraint with the standard IC constraint. The gains from the relationship should be at least as great as the cost of providing the highest level of forest, and the information rent to induce self-selection. The optimal payment depends on how restrictive the self-enforcement constraint is and the optimal contract is now given by

$$\max_{\ell_H,\ell_L}\left(\frac{\alpha(V(\ell_H)-g(\ell_H,\theta_H))+(1-\alpha)(V(\ell_L)-g(\ell_L,\theta_L))}{1-\delta}\right)$$

$$\text{subject to} \quad \frac{\delta}{1-\delta}(S-\overline{\pi}) \geq g(\ell_H,\theta_H)+\Delta_L \quad \text{and} \quad \ell_\theta \quad \text{is nondecreasing.} \tag{20}$$

Because of the hidden information, the buyer has to provide information rents to an H-type seller such that she reveals her type. The information rents depend only on the quantity of land that the buyer requests from the L-type to keep in forest and not on the quantity requested from the H-type. As a consequence, incentive compatibility allows the buyer to request from the H-type the first-best forest conservation. But the more forested land that is requested from the L-type, the higher the cost for the buyer to induce the H-type is to deliver ℓ_H because he needs to pay higher information rents.

If the relationship is sufficiently productive and the discount factor is sufficiently high, the self-enforcing ICC (inequality 19) is not binding for the H-type seller at the efficient fraction in forest for both types, ℓ_L^* and ℓ_H^*. Consequently, the buyer is able to achieve first-best forest conservation for both types of sellers (Proposition 5).

Proposition 5. *When the buyer does not know the seller type and the self-enforcing constraint* $\frac{\delta}{1-\delta}(S-\overline{\pi}) \geq g(\ell_H,\theta_H)+\Delta_L^*$ *is satisfied, REDD contracts can implement first-best additional conservation of forest such that* $\ell_L^* \leq \ell_H^*$*. The compensation schemes are characterized by:*

$$p_{\theta_L}^* \leq 0 \quad \textit{and} \quad p_{\theta_H}^* \leq \frac{\Delta_L^*}{1-\delta}; \tag{21}$$

$$b(\ell_{\theta_L}^*) \geq g(\ell_L^*,\theta_L) \quad \textit{and} \quad b(\ell_{\theta_H}^*) \geq g(\ell_H^*,\theta_H)-\frac{\delta\Delta_L^*}{1-\delta}; \textit{ and} \tag{22}$$

$$P(\ell_{\theta_L}^*) = g(\ell_L^*,\theta_L) \quad \textit{and} \quad P(\ell_{\theta_H}^*) = g(\ell_H^*,\theta_H)+\Delta_L^*. \tag{23}$$

The optimal contract offers the L-type seller the same compensation and payment structure (i.e., full payment contingent on the conservation of forest) that she would receive if the buyer could distinguish types. But the H-type seller must receive a higher total payment by including the information rents corresponding to the first-best allocation of land in forest for an L-type, Δ_L^*. Furthermore, the optimal contract prescribes a contractible payment equivalent to the present value of the information rents while the contingent payment is smaller than when there is symmetric information. Nevertheless, if the expected surplus is sufficiently high, the first-best level of conservation is implemented by self-enforcing contracts.

If the discount factor is small, the future gains from the forest-conservation relationship become too small to support any level of forest conservation. In this case, no schedule may satisfy the constraints, and forest conservation is not possible under a relational contract.

However, even if the expected gains from the relationships are small, relational contracts may still implement conservation, depending on how restrictive the self-enforcement constraint is. In this case, inequality (19) binds with $\theta = \theta_H$ for $\ell_H = \ell_H^*$. If the self-enforcement constraint is very restrictive, it is better to reduce the quantity of land in forest for both types below the first-best level and request some levels of conservation from both types instead of having only the H-type providing the first-best level and the L-type not participating. Requesting additional land in forest from the L-type implies an increase in the slope of the H-type payment schedule (due to information rents). Because the total payment is limited by the expected gains from the relationship, giving additional incentives for the H-type seller means decreasing incentives for the L-type seller. This is sub-optimal because a marginal reduction in forest conserved by the H-type reduces the surplus generated but allows for more area in forest from the L-type. As the L-type conservation is substantially below the first-best, ℓ_L^*, increasing ℓ_L raises the overall surplus. As a result, the requested quantity of forest for each type is given by ℓ_{LR} and ℓ_{HR}, for which the marginal gains of inducing ℓ_L equals the marginal cost of reducing ℓ_H.

If the self-enforcement constraint is less restrictive, the seller with low opportunity cost (H-type) is asked to keep a higher quantity of land in forest (but below first-best) because she is more efficient in providing carbon sequestration. Requiring a given-type seller to place more land in forest requires an increase in the size of the bonus. As the requested land in forest increases, raising the land maintained in forest by the L-type becomes more expensive relative to the H-type. Therefore, the buyer screens L-type sellers, who provide lower forest conservation, while H-type sellers provide higher amounts of carbon offsets. This is summarized in the next corollary.

Corollary 3. *When the discounted expected value of the forest conservation is small, a relational contract may still implement sub-optimal but strictly positive forest conservation. If self-enforcement is too restrictive, the contracts lower provision of both types to a similar level of forest conservation. If self-enforcement is less restrictive, the L-type seller provides less forest conservation than the H-type seller, who provides less forest conservation than first-best levels.*

5 Conclusions

Among the alternative measures to mitigate global climate change, reducing emissions from deforestation and forest degradation has been identified as a cost-effective option. However, REDD contract implementation is challenging because of technical, financial and institutional considerations, including the verifiability, additionality and permanence of the carbon offsets. These elements make contract design and enforceability a key issue for the implementation of a REDD mechanism. Previous research on REDD contracts assumes that there exists some given probability of enforcement (Palmer, Ohndorf, and MacKenzie, 2009) or that contracts are fully enforceable (Mason and Plantinga, 2011). However, because of the multiple different institutional frameworks in which REDD may operate, this may not be the case. In this paper, we propose the use of informal incentives and good faith as key elements to enforce contracts and overcome incomplete enforcement. We have derived the optimal REDD contract and shown how the optimal level of incentive provision is characterized when participants have symmetric and asymmetric information about the opportunity cost of the land. We have also derived the parameters under which self-enforcement and cooperation are sustainable.

When the buyer cannot distinguish seller types, the model predicts that he can induce first-best conservation if the expected gains from forest conservation are sufficiently large. However, if the gains from the relationship are smaller, first-best forest conservation is not achievable through self-enforcing contracts. In this case, a second-best level of conservation is possible depending on how small the gains from the relationship are. Both types of sellers can be induced to maintain similar levels of forest, or if the gains are larger, the H-type seller conserves a higher amount of forest than the L-type seller. But if the gains from the relationship are too small, self-enforcing contracts are not implementable.

This paper takes a first step to apply the relational contracting framework to a REDD environment when the the owner of the land has private information about her opportunity cost. The results provide insights on the power of informal enforcement mechanisms that support incentives even when REDD explicit contracts are incomplete. It also highlights the limits of the use of self-enforcement when there is hidden information. From the policy perspective, the results of the paper provide insights on the situations in which self-enforcing contracts can be successfully implemented to achieve additional and permanent carbon offsets.

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Appendix

Proof of Proposition 2. Let y^* be the equilibrium contract that a buyer offers to a θ-type landholder, where $P(\ell_\theta) = p_\theta + b(\ell_\theta)$. The contract must satisfy the landholder's IRC and $DICC$. Solving for p_θ in both her IRC ($p_\theta \geq g(\ell_\theta, \theta)) - b(\ell_\theta)$) and $DICC$ ($p_\theta \geq g(\theta, \theta) + \frac{g(\ell_\theta,\theta)-g(\theta,\theta)-b(\ell_\theta)}{\delta}$). The buyer maximizes his profit holding the seller's IRC with equality, $P(\ell_\theta) = g(\ell_\theta, \theta)$. Substituting her IRC into her $DICC$ and rearranging we get $b(\ell_\theta) \geq g(\ell_\theta, \theta)$. Substituting back into the IRC and rearranging leads to $p_\theta \geq g(\theta, \theta)$, which is zero because by assumption $g(\theta, \theta) = 0$ for each type. The buyer's IRC and DICC also impose limits into the payment structure. To see this we check the buyer's constraints. If the IRC binds $V(\ell_\theta) - p_\theta - b(\ell_\theta) = \overline{\pi}$ and substituting in the DICC, we get that $p_\theta > V(\ell_\theta) - \overline{\pi}$ which violates the buyer's IRC. The IRC then does not bind. If the DICC binds, $V(\ell_\theta) - p_\theta - b(\ell_\theta) = (1-\delta)(V(\ell_\theta) - p_\theta) + \delta\overline{\pi}$. By substituting it in the IRC we get that $V(\ell_\theta) - \overline{\pi} > p_\theta$, which is possible, the DICC then binds. By substituting p_θ from (5) into (3), we get the lower bound of a bonus that satisfies the buyer's constraints: $b(\ell_\theta) > 0$. Finally, by substituting p_θ in the same way we get that $V(\ell_\theta) - \overline{\pi} > p_\theta$. As the seller's constraints satisfy the minimum bonus and the base price derived from the buyer's constraints, then the seller's constraints binds in the contract. Thus, combining p_θ and $b(\ell_\theta)$ from the seller's constraint the total payment is $P(\ell_\theta) = g(\ell_\theta, \theta)$.

Substituting $P(\ell_\theta)$ into the buyer's objective function and solving for the first-order Kuhn-Tucker conditions gives

$$V'(\ell_\theta) \begin{cases} < g'(\ell_\theta) & \text{if } \ell^*_\theta = \theta \\ = g'(\ell_\theta) & \text{if } \theta < \ell^* \leq \overline{\ell} \end{cases}$$

Because by assumption the buyer is only going to contract with types for which the benefit of forest conservation exceeds or equal its cost and $\ell_\theta \in [\theta_L, 1]$, forest conservation is optimal when the marginal cost equals its marginal benefit, which is given by the following first order condition for each type: $V'(\ell^*_\theta) = g'(\ell^*_\theta, \theta)$. Then the buyer requests ℓ^* such that it maximizes the surplus. $P(\ell^*) = p + b(\ell^*) = g(\ell^*, \theta)$. Let's check the seller's IRC: substituting $P(\ell^*)$ we get $g(\ell^*, \theta) - g(\ell^*, \theta) \geq 0$, and DICC: substituting $P(\ell^*)$ we get $0 \geq p_\theta$ and $p_\theta \geq 0$, then, $p_\theta = 0$. Let's check the buyer's IRC. Substituting $P(\ell^*)$ we get $V(\ell^*) - g(\ell^*, \theta) \geq \overline{\pi}$, which ends up being $S(\ell^*) - \overline{\pi} \geq 0$, which is true since the net surplus from conservation exceeds zero. Finally, for the contract to be sustainable, the buyer's DICC needs also to be satisfied: $\delta(V(\ell^*) - \overline{\pi}) \geq g(\ell^*, \theta)$. Solving for the discount factor we get $\underline{\delta} \geq \frac{g(\ell,\theta)}{V(\ell)-\overline{\pi}}$. Hence, cooperation takes place for all values of δ that satisfy $\underline{\delta}$ □

Proof of Proposition 3. For cooperation to be achievable, the DICC for the buyer and for the θ-type seller must hold. Then combining equations (4) and (5) we get the self-enforcing constraint: $\frac{\delta}{1-\delta}(S(\ell, \theta) - \overline{\pi}) \geq g(\ell_\theta, \theta)$. As in proof 1, solving for the discount factor we get $\underline{\delta} \geq \frac{g(\ell,\theta)}{V(\ell)-\overline{\pi}}$, which is the same value obtained before. □

Proof of Proposition 4. From the ICC for each seller type we get equation (18): $P(\ell_H) - P(\theta_L) \geq g(\ell_H, \theta_H) + \Delta_L$. A buyer makes the highest payment to the H-type seller and the lowest payment to the L-type seller. Self-enforcement dictates that the difference between the highest possible payment and the lowest payment should be lower or equal to the gains from the relationship: $\frac{\delta}{1-\delta}(S(\ell,\theta)-\overline{\pi}) \geq P(\ell_H)-P(\theta_L)$. Combining this with equation (18) we get $\frac{\delta}{1-\delta}(S(\ell_\theta,\theta)-\overline{\pi}) \geq g(\ell_H,\theta_H)+\Delta_L$. □

Proof of Proposition 5. Because of the asymmetric information about the seller type, an incentive compatibility constraint (ICC) for each must be added to have each seller to reveal her true type. Given the ICCs (equations (12) and (13)), the L-type seller does not benefit by mimicking the H-type seller because she gets $P(\ell_H)-g(\ell_H,\theta_L)=U_H-\Delta_H$. If $U_H=0$, the L-type seller gets negative economic profits. Then the L-type seller's ICC binds. In contrast, if the H-type seller mimics an L-type seller, she gets profits equal to $P(\ell_L)-g(\ell_L,\theta_H)=P(\ell_L)-g(\ell_L,\theta_L)+g(\ell_L,\theta_L)-g(\ell_L,\theta_H)=U_L+\Delta_L$. Even if the L-type seller's economic profit is 0 from the participation constraint, the H-type seller benefits from an information rent Δ_L. Therefore, the H-type IRC does not bind while the ICC binds. By substituting the IRC into the self-enforcing constraint for the L-type (see proof of proposition 2), we get the payment structure given in proposition 5. To get the payment structure for the H-type, the ICC and DICC are combined as the IRC does not bind: $p_H=\Delta_L+g(\ell_H,\theta_H)-b(\ell_H,\theta_H)$ and $p_H \geq g(\theta_H,\theta_H)+\frac{g(\ell_H,\theta_H)-g(\theta_H,\theta_H)-b(\ell_H)}{\delta}$. Substituting and arranging we get the optimal payment. The H-type seller's IRC is satisfied: $\Delta_L+g(\ell_H,\theta_H)-g(\ell_H,\theta_H) \geq 0$, and the buyer's IRC is satisfied if: $V(\ell_H)-g(\ell_H,\theta_H)-\pi \geq \Delta_L$. Finally, self-enforcement is sustainable and both parties' DICC are satisfied if $\frac{\delta}{1-\delta}(S-\overline{\pi}) \geq g(\ell_H,\theta_H)+\Delta_L$, where S is the expected surplus.

□