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Enforcement-proof contracts with moral hazard in precaution: ensuring 'permanence' in carbon sequestration

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Abstract

Opportunistic behaviour due to incomplete contract enforcement is a risk in many economic transactions such as forest carbon sequestration contracts. In this paper, an enforcement-proof incentive contract is developed in which a buyer demands a guaranteed delivery of a good or service given a productive upfront payment, moral hazard in precaution, and the potential for opportunistic contract breach. The optimal design of forest carbon contracts to ensure permanence is derived. Buyer liability for loss of a carbon sink is shown to yield an inefficiently low level of sequestration. Yet it remains higher than the case where liability is neither allocated to the buyer nor the seller. Indexing contract prices to the seller's opportunity costs potentially boosts the upfront investment as does shifting liability to the seller but not beyond first-best levels. Assigning liability is shown to have implications for forest carbon contracts in an international climate policy regime.

JEL codes: K12; Q15

Keywords: Forest carbon offsets; Permanence; Contract design; Incomplete enforcement; Liability; Moral hazard

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1 Introduction

Opportunistic behaviour due to incomplete contract enforcement is a risk in many economic transactions, potentially leading to unfulfilled contracts (de Janvry and Sadoulet, 2007). Situations in which third-party enforcement is also incomplete need to be enforcement-proof if contract breach on the part of the seller causes a loss in the buyer's investment. Yet in many contexts, such as carbon sequestration contracts, a buyer is often held liable—at least *de facto*—for the continued existence of a good or service, which remains under the control of the seller. Thus, the contract needs to be designed in a way that not only minimises moral hazard in precaution, but also deters opportunistic contract breach under incomplete contract enforcement with full buyer liability.

In this paper, we develop an enforcement-proof incentive contract in which a buyer demands a guaranteed delivery of a good or service given a productive upfront payment, moral hazard in precaution, and the potential for opportunistic contract breach. We find that investing in a contract upfront is restricted by moral hazard and opportunistic contract breach. This limits the delivery of the good up to a specific level even if an infinite scale-up were beneficial in a situation without opportunism. The larger the moral hazard problem, that is the more expensive it is to induce effort, the smaller the distortion. A comparison of different contract settings shows that all of these distort the contract downwards in comparison to the first-best case. This distortion will be lower in situations where it is possible to index the conditional payment to the seller's opportunity cost. A change in liability regime so that replacement of a faulty good is no longer an issue but where moral hazard is a problem could potentially increase the upfront investment but not beyond first-best levels.

Our framework is motivated by the emergence of international contracts to sequester forest carbon in developing countries, for example through afforestation or reforestation activities contracted under the Clean Development Mechanism (CDM) of the Kyoto Protocol. Such contracts are made between buyers in industrialised countries looking to offset their greenhouse gas (GHG) emissions, and project developers who wish to create tradable emissions credits. However, the carbon dioxide sequestered is at constant risk of being returned through deforestation, whether by accident or design.[1] Despite having a potentially important role to play

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[1] Forestry carbon is particularly vulnerable to natural risks (e.g. pests and diseases, climate change), anthropogenic risks (e.g. encroachment, land management), political risks (e.g. weak property rights, non-

in future climate change policy (Eliasch, 2008), forest carbon contracts cannot entirely rely on coercive measures for contract fulfilment in terms of ensuring 'permanence' in forest carbon sinks.[2] Additional to the problem of incomplete contract enforcement, the allocation of liability for the loss of forest climate benefits to buyers precludes the use of extra-contractual sanctions based on tort law in those cases where the carbon sink is reversed by the seller.

The contribution of this paper is threefold. First, we have created a novel contract framework that guarantees contract enforceability and provides for an upfront payment that is both productive, in terms of carbon sequestration, and with respect to the opportunity cost of the seller. Second, the optimal contract shows the menu of contract options that help to ensure permanence in carbon sequestration. Given the potential cost-effectiveness of forest-based carbon sequestration as a climate change mitigation strategy (Chomitz *et al.*, 2006; Stern, 2007; Eliasch, 2008; Palmer and Engel, 2009), known as Reducing Emissions from Deforestation and Degradation (REDD), ensuring permanence is key to realising forest carbon benefits over a time-scale of decades. This may be crucial to the international community reaching agreement on the role of forest-based offsets in any post-Kyoto framework. Third, other than carbon sequestration, our model has potential applications to other transaction types. Permanence is an issue that applies more widely to the preservation of environmental services over time, and is not just a problem for carbon sinks per se (see, for example, Swart, 2003; McCauly, 2006; Engel *et al.*, 2008). Our model can also be applied to any situation where contract enforcement is weak, upfront financing is necessary, and where the seller's precaution is to be incentivised. This would, for example, be the case with foreign direct investments related to a specific (purchase) order in developing countries. In this sense, the model presented here can also be considered as a contribution to the literature on investment contracts (see, for example, Atkeson, 1991; Thomas and Worrall, 1994; von Thadden 1995).

The remainder of the paper is structured as follows. After giving a brief discussion on carbon sequestration contracts, section 2 introduces the model and formally describes the constraints on the seller. These relate to potential opportunism by the seller, namely an unwillingness to supply precautionary effort to prevent a contingency and contract breach due to changing

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enforcement), economic and financial risks (e.g. exchange rate fluctuations, changing opportunity costs), and institutional risks (Watson *et al.*, 2000).

[2] Carbon dioxide emissions from deforestation account for up to a fifth of annual global greenhouse gas emissions (Baumert *et al.*, 2005).

opportunity costs. Either type of opportunistic behaviour could lead to contract breach and hence, carbon reversal. Section 3 discusses the buyer's optimal choice of contract while section 4 investigates the optimal contract in a number of different contractual settings, including a discussion of contracts under alternative liability regimes. In section 5, we summarise our results and conclude.

1.1 Background: carbon sequestration contracts

Under the Kyoto principles, liability for forest carbon losses is transferred to those purchasing emissions credits from project developers (UNFCCC, 2005).[3] Thereafter, sellers are no longer liable for losses, although they maintain control over the forest via ownership and use rights.[4] This creates two types of incentive problems that need to be overcome. First, as the seller continues to influence the probability of future carbon release there exists a potential moral hazard in precaution, a situation common in forestry (see Provencher, 1990). Second, given incomplete contract enforcement in developing countries, the seller may put the project resources to a different use. In sum, the risks of carbon reversal could be high.

Under the Kyoto Protocol, the predominant contractual arrangement is a simple purchase contract known as the Emission Reduction Purchase Agreement (ERPA). These contracts, in addition to those made in the voluntary carbon markets, rarely provide upfront investments to potential sellers (Capoor and Ambrosi, 2008; 2009, Jindal *et al.*, 2008). The extent and number of sequestration schemes have, however, been limited by this lack of upfront financing, alongside constraints on demand formalised under the Kyoto Protocol and the latter's stringent regulatory regime (UNEP, 2004). Project developers find it difficult to obtain upfront third-party financing and hence, schemes struggle to get implemented (see Capoor and Ambrosi, 2008). Incomplete enforcement give further disincentives to buyers making upfront investments

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[3] 'Common but differentiated responsibilities' imply that the burden for climate change mitigation falls on industrialised, i.e. Annex I, countries (Vanderheiden, 2009). Under the CDM, carbon emissions credits (or certificates) eliminate the liability associated with a firm's (or country's) release of carbon into the atmosphere (Sedjo and Marland, 2004). 'Temporary' credits are issued, which must be renewed or replaced by permanent credits, either when the carbon sink ceases to exist or after their expiry. As soon as these credits are issued to the buyer, the seller is no longer liable for carbon reversal. Thus, liability for replacing invalidated certificates is implicitly attributed to the buyer as these need to be replaced within the National Registry of the buyer country (see UNFCCC, 2005 , Decision 5, Annex, paragraph 55).

[4] Yet property rights in many forest areas in developing countries reflect a diversity of tenure regimes in which rights overlap and are insecure, often leading to a situation of open access (Feder and Feeny, 1991; Sunderlin *et al.*, 2009).

in forestry projects. It may prevent contract fulfilment should there be a risk of opportunistic contract breach, for example, due to changes in the seller's opportunity cost.

Ensuring the permanence of forest carbon sinks has mainly been investigated using risk management, pricing, and accounting approaches. The former includes specialised carbon-pooling vehicles, and reinsurance approaches (see Bayon *et al.*, (2007) for a review), while the latter is more concerned with institutional design (Dutschke, 2002; Kim *et al.*, 2008). Risk management and liability in forestry carbon contracts have also been considered at the aggregate, i.e. national level in addition to the individual level (Eliasch, 2008). However, relatively little research has been undertaken on how *individual* contracts between buyers and sellers could be efficiently designed to ensure permanence (Dutschke and Angelsen, 2008). Moreover, the amount of carbon sequestered may depend not only on uncertain and changing opportunity costs but also on the ability of incentives to influence the seller's effort in preventing contingencies such as forest fires and parasites. Benitez *et al.* (2006) considered changing opportunity costs by applying stochastic dominance rules to identify the incentive payments needed to prevent land-use changes that reduces biodiversity in developing countries. One important implication of their analysis was that alongside the incorporation of insurance possibilities for small farmers, payments to a farmer could be made dependent on agricultural income. The effectiveness of this approach, however, rests upon the ability of buyers to observe farmers' opportunity costs and the assumption of complete contract enforcement. This study also neglected asymmetric information on the farmer's effort, although there is a considerable body of research on moral hazard in a range of contractual settings, including agriculture (see, for example, Eswaran and Kotwal, 1985; Wu and Babcock, 1995; Ghatak and Pandey, 2000; Ozanne *et al.*, 2001).

In our framework, the buyer and seller contract on an upfront payment along with a payment made conditional on carbon delivery. We model the upfront payment as a productive transfer, one that is not only productive in carbon sequestration but also productive in the seller's outside option. Potential changes in the seller's opportunity cost are anticipated at the time of contracting but only realise after the contract is already signed. The buyer's liability for loss of contracted output is reflected in the creation of a permanence constraint. Given the seller's uncertain opportunity cost, incomplete contract enforcement, the allocation of liability for losses and the problem of moral hazard, we consider the design of optimal carbon contracts to solve the contract fulfilment problem. In our context, this is to ensure permanence in the provision of forestry carbon benefits over the duration of the contract.[5]

2 The model

Consider a contract between a buyer and seller of carbon offsets, where both are assumed to be risk neutral. The buyer may be a firm attempting to comply with its obligations to reduce its GHG emissions within an emissions trading market, a national government complying with Kyoto Protocol requirements or a non-governmental organisation that voluntarily, but cost-effectively, attempts to reduce the GHG emissions from its activities via the purchase of carbon offsets. The seller could represent a CDM project developer with limited liability, or a regional or national government.[6] The seller has the ability to provide sequestration of carbon dioxide through investment in forestry, such as a tree planting or forest rehabilitation scheme.[7]

In exchange for sequestered carbon dioxide, henceforth carbon, the buyer offers a two-tiered payment scheme consisting of an upfront investment α as well as a per-unit price β, which is paid conditional on delivery of the carbon offsets. The contract corresponds to the standard setup of ERPA under the Kyoto mechanisms (see Capoor and Ambrosi, 2008).[8] The upfront investment α is a cash transfer to the seller, which is contractible to buy production inputs. It can be interpreted as a true upfront investment, i.e. α is assumed to have a positive influence on the amount of carbon sequestered, but is in itself not utility relevant to the seller. Such a provision of upfront capital *within* the contract is often a prerequisite for the project to be implemented. External capital funding is usually unavailable for most projects within the CDM, which can be attributed to the relative lack of experience of many private sector lenders with investment risks in nascent carbon markets.[9]

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[5] We assume a policy goal of carbon retention in biomass over several decades. During this time, technological changes may reduce the costs of alternative mitigation options thus enabling substitution from forestry carbon sinks to these other options (Chomitz *et al.*, 2006). CDM guidelines propose that Land Use, land Use Change and Forestry (LULUCF) projects have a duration of between 20 and 60 years (Harris *et al.*, 2009).

[6] Note that limited liability can be interpreted as reflecting extreme risk-aversion below a specific minimum income. See, for example, Basu (1982) or de Janvry and Sadoulet (2007). With this interpretation, we also account for a certain type of risk-aversion on the part of the seller.

[7] Tree planting could involve either reforesting a previously forested area or afforesting an area with no previous forest cover. Note that afforestation and reforestation projects are currently the only forestry projects eligible within Kyoto's CDM.

[8] A transaction that transfers carbon credits between two parties under the Kyoto Protocol.

[9] See, for example, Capoor and Ambrosi (2009). In the context of current climate policy discussions, α could also be interpreted as voluntary financial contributions, for example, from the World Bank Forest Carbon

There exists a moral hazard over precautionary efforts by the seller against some contingency that may lead to carbon reversal, for example, forest fires or illegal logging. For simplicity, we allow for only two states, either the contingency realises or not. We represent the contingency by the random variable $\tilde{\sigma} \in \{\underline{\sigma}, \overline{\sigma}\}$ with $\Delta_\sigma = \overline{\sigma} - \underline{\sigma} > 0$. The amount of carbon offsets produced by the seller is a function of the (productive) upfront payment α and the realisation of contingency, which we define as $\tilde{\sigma} \cdot q(\alpha)$, with $q'(\alpha) > 0$ and $q''(\alpha) \leq 0$. When no contingency occurs, the quantity of offsets is $\overline{\sigma} \cdot q(\alpha)$. If the contingency realises, offsets amount only to $\underline{\sigma} \cdot q(\alpha)$. Intuitively, the quantity of carbon offsets contracted *ex ante* are scaled down due to the realisation of the contingency after these offsets have been produced. The seller can influence the contingency by exerting effort of precaution e, which takes two values, $e \in [0, 1]$ at a cost $C(e)$, with $C(1) = C$ and $C(0) = 0$. Exerting effort e alters the probability of the occurrence of the contingency, with $\rho(e)$ being the probability of $\overline{\sigma}$ and $(1 - \rho(e))$ the probability of $\underline{\sigma}$. We define $\Delta_\rho = \rho(1) - \rho(0)$ and assume that it is large enough for moral hazard to be imminent. In particular we assume $v \cdot \Delta_\rho \Delta_\sigma \geq C$ where v denotes the buyer's per unit valuation of a carbon offset. Hence, the buyer will always want to induce the seller's effort if at least one unit of carbon is sequestered. Costs $C(e)$ can be considered sunk and therefore non-recoverable.

The seller's opportunity cost of investing in forestry is given by the benefit obtained from alternative agricultural goods (e.g., soy bean, coffee) or rental prices. Sudden changes in the value of the opportunity cost may create an incentive for the seller to breach the contract. We assume that the value of the future opportunity cost is uncertain. For example, if it is driven by volatile commodities' or rental prices, the seller can be reasonably expected to be unsure of the precise value of his outside option. Hence, should this increase then the seller's commitment to adhere to the contract instead of switching land use is in doubt. The value of the seller's future opportunity cost is modelled as the production of an alternative good z with the seller's per unit valuation denoted $\tilde{t}$. For simplicity of the argument, we allow for two possible states of opportunity cost, which we denote as $\tilde{t} \in \{t_l, t_h\} \subset \mathbb{R}_+$, with $t_l < t_h$.[10] At the time of contracting the probability of a low value t_l realising is π, while the probability of t_h occurring is $(1 - \pi)$. After realisation, the value of the opportunity cost is publicly known.

Partnership Facility (FCPF) or the United Nations REDD Programme (Wertz-Kanounnikoff and Angelsen, 2009).

[10] Note that the assumption of only two levels of opportunity cost is made for simplicity. Assuming n states of opportunity cost would not alter our results.

Contrary to standard contractual setups, we allow the opportunity cost to be positively dependent on the upfront investment α by defining z as a function of the upfront payment $z(\alpha)$ with $z'(\alpha) > 0$ and $z''(\alpha) \leq 0$. Intuitively, investing in a larger upfront payment could indirectly benefit the seller through boosting the value of his opportunity cost. For example, capital inputs purchased with α could be used for the production of goods and services other than carbon sequestration activities. This is most obvious if the upfront payment is used by the seller to acquire additional land, which could in principle be used for agricultural production.[11] It is plausible that the initial investment for the intended use is more productive. We hence assume $z'(\alpha) \leq q'(\alpha)$ and $z''(\alpha) \leq q''(\alpha)$ over the relevant range.

We initially assume the realised level of the seller's opportunity cost is observable, where the backloaded part of the contract is made contingent on the realised opportunity costs, i.e. β_l for t_l and β_h for t_h realised. We relax this assumption in Section 4. Indexing the backloaded payment to the seller's opportunity costs in our framework is motivated by Benitez et al. (2006) and Dutschke and Angelsen (2008), who advocated payments indices to ensure permanence under uncertain landowner opportunity costs. Such a policy tool could be applied where opportunity costs in a given area are known to be influenced by farm-gate prices for commonly-produced agricultural commodities. For example, in parts of Brazil, the expansion of the soy and beef industries are key factors driving land-use changes, in particular deforestation (see, for example, Anderson *et al.*, 2002; Soares-Filho *et al.*, 2006).

The timing and pay-offs of the model are summarised in Figure 1. In period 0, the buyer offers a contract with a two-tiered payment scheme, represented by α and $\beta \in \{\beta_l, \beta_h\}$. Should the seller agree to this contract, he then immediately receives the upfront payment, α, in period 1 which is contracted for an optimal purchase in project resources. In period 2, the seller implements the scheme and chooses effort e with cost, $C(e)$. After effort is chosen, $\sigma \in \{\underline{\sigma}, \overline{\sigma}\}$ is realised. The buyer starts to use the generated offsets within a compliance regime or a voluntary scheme. Before the date of expiration of these certificates, the seller's opportunity cost, $\widetilde{t} \cdot z(\alpha)$, is realised in period 5. In period 6, the backloaded payment, amounting to $\beta_i \sigma q(\alpha)$ with $\beta_i \in \{\beta_l, \beta_h\}$, is received by the seller.

If the high opportunity cost level t_h is realised, the seller has an incentive to breach the

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[11] We note that missing and constrained markets for capital inputs such as land are, however, common in many countries, for example, in China (see Groom et al., 2010).

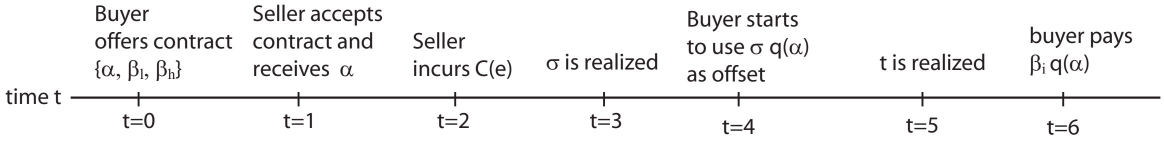

Figure 1: Timing of the contract

contract.[12] In case of breach, it is assumed that the seller reverses the carbon sink, for example, through cutting down the forest in order to switch his land use to the more attractive alternative. We first assume that the buyer will try to enforce the contract through a court order. However, in many cases, the judicial system is either incomplete or imperfect; enforcement of the contract is not guaranteed. Many developing countries experience elements of corruption, poor governance, weakly defined property rights, e.g., over land and natural resources, and incomplete enforcement of laws and regulations.[13] We account for this by introducing stochastic contract enforcement into our framework. In case of contract breach by the seller, the buyer succeeds in achieving a court order with probability γ. In case of successful litigation, the seller has to pay contract damages of $\theta \cdot t \cdot z(\alpha)$ to the buyer. The parameter θ represents contract damages that are determined by the host country's contract law and legal practice.[14] To a certain degree we allow for punitive damages, i.e. $\theta > 1$, which are however restricted by assuming $\gamma\theta < 1$.

In the event of contract performance, the expected value of the contract to the seller is given by:

$$EU = (\pi\beta_l + (1-\pi)\beta_h)(\rho(e)\overline{\sigma} + (1-\rho(e))\underline{\sigma})q(\alpha) - C(e). \tag{1}$$

Similar to standard complete contract frameworks, we solve for the optimal contract by maximising the buyer's expected utility subject to several constraints. The most important

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[12] This is in contrast to the standard case in the theory of complete contracts where full enforcement of feasible agreements is assumed *a priori* (Bolton and Dewatripont, 2005).

[13] Nevertheless, we note wide variation in third-party enforcement both among and within countries that host carbon sequestration projects, illustrated by the World Bank's 'Doing Business' project. This attempts to measure the quality of business regulations and their enforcement across 181 economies (see: http://www.doingbusiness.org/economyrankings/?direction=Asc&sort=10). One measure, 'enforcing contracts' ranks, for example, the important forest nations of Brazil and Indonesia at 100th and 140th, respectively. These are the kinds of countries that up to now have struggled to attract CDM sequestration projects due at least in part to a lack of investors willing to provide upfront investments.

[14] Note that if θ if $\theta = 1$ contract damages correspond to their efficient level under full enforcement (see Polinsky, 1984). In contrast to civil law the 'penalty doctrine' in case law does not allow for levels of damages that are deemed punitive by the courts (Hatzis, 2003).

constraint is based on the assumption that the buyer is interested in the permanence of the contracted carbon sequestered. This reflects the current attribution of liability for forest offsets within the CDM as noted in the introduction. Thus, liability for losses through carbon reversal will not lie with sellers, whether defined as project developers or governments in developing countries. As the buyer country will necessarily subrogate to the project investor, we can reasonably assume that the latter is always interested in permanence for σ large enough. Given the assumption of a buyer interested in the permanence of the carbon sink over the duration of the contract, the following set of *permanence* constraints need to hold for both $\overline{\sigma}$ and $\underline{\sigma}$:

$$\beta_l \cdot \underline{\sigma} q(\alpha) - (1-\gamma\theta)t_l \cdot z(\alpha) \geq 0, \tag{2}$$

$$\beta_h \cdot \underline{\sigma} q(\alpha) - (1-\gamma\theta)t_h \cdot z(\alpha) \geq 0, \tag{3}$$

$$\beta_l \cdot \overline{\sigma} q(\alpha) - (1-\gamma\theta)t_l \cdot z(\alpha) \geq 0, \tag{4}$$

$$\beta_h \cdot \overline{\sigma} q(\alpha) - (1-\gamma\theta)t_h \cdot z(\alpha) \geq 0. \tag{5}$$

Intuitively, these constraints ensure that the seller always finds it (weakly) preferable to comply with the contract and prefers to take the agreed rent rather than his outside option. More importantly, the constraints ensure permanence in the contracted carbon gains for the duration of the contract between the buyer and seller.

Should the seller's (upper-level) opportunity cost t_h realise then the seller's utility from $\underline{\sigma}$ under a potential non-breach situation needs to be equal to or larger than the expected utility in case of contract breach. This includes the seller's expected costs from the possibility of contract enforcement.[15] Note that (4) and (5) will always hold if (2) and (3) are fulfilled. Technically, (2)-(5) are identical to what is often referred to as *enforcement-proofness* constraints.[16] As a consequence, most of the results that follow apply to contracts in which the buyer wishes to prevent the seller breaching the contract. Note further that (2) and (3) imply that the buyer would still prefer to ensure permanence even if part of the contracted forest has been lost due the realisation of the bad state $\underline{\sigma}$.

As the buyer always wants to induce precautionary effort on the part of the seller, the

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[15] In case the seller is indifferent between both options, we assume that the seller performs the contract. This might be interpreted as a propensity for abiding by contracts at the margin.

[16] See, for example, Laffont and N'Guessan (2001) or Laffont and Martimort (2002).

following *moral hazard* constraint must hold:

$$(\rho(1)\cdot\overline{\sigma}+(1-\rho(1))\cdot\underline{\sigma})\cdot(\pi\beta_l+(1-\pi)\beta_h)q(\alpha)-C \geq (\rho(0)\cdot\overline{\sigma}+(1-\rho(0))\cdot\underline{\sigma})\cdot(\pi\beta_l+(1-\pi)\beta_h)q(\alpha).$$

Intuitively, the seller's expected net benefits from the contract must be larger when the seller decides to invest in precautionary effort. This constraint can be rewritten as follows:

$$(\pi\beta_l + (1-\pi)\beta_h)\cdot q(\alpha) - \frac{C}{\Delta_\sigma \Delta_\rho} \geq 0. \tag{6}$$

When the permanence and moral hazard constraints are fulfilled, which implies $e = 1$, the seller's *participation* constraint is:

$$EU = (\pi\beta_l + (1-\pi)\beta_h)\left(\rho(1)\overline{\sigma} + (1-\rho(1))\underline{\sigma}\right) q(\alpha) - C(e) \geq 0. \tag{7}$$

As the buyer is assumed to be risk neutral his payoff corresponds, up to a linear transformation, to the buyer's utility, $V(q)$. In the following, we assume that $V(q) = vq$. Thus, the buyer's value per unit of carbon offset is constant. The opportunity cost of paying the contract price is not the buyer's own marginal abatement costs, but the market price for identical certificates. For example, in the context of Kyoto mechanisms, a buyer will equate his marginal abatement cost to the price of CDM certificates on the market. If abatement is costly, more certificates are bought. In contrast, if the buyer's marginal abatement cost exceeds the contract price, he could use the contracted certificates for fulfilling his reduction target instead of buying certificates on the market. Hence, in all cases the buyer's valuation of the contracted certificates will be equal to the market price for similar certificates on the secondary CDM market.[17] For simplicity, the market price for tradable emission rights is further assumed to remain constant, or as being at least perfectly foreseeable. If permanence of the carbon sink is assured, the buyer's payoff function is:

$$EV = (v - (\pi\beta_l + (1-\pi)\beta_h))\cdot(\rho(1)\cdot\overline{\sigma} + (1-\rho(1))\cdot\underline{\sigma})\cdot q(\alpha) - \alpha. \tag{8}$$

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[17] Note that this assumption is realistic, as within the Kyoto system certificates from the different mechanisms are completely fungible.

Note that the buyer's objective of permanence implies that contract breach cannot occur under any circumstances, including a situation where a contingency might arise. Therefore, potential contract damages granted by a court do not enter into (8). Given our permanence constraint, it is clear that the contract needs to be enforcement-proof and cannot entirely rely on coercive measures to incentivise the seller to perform.

3 Optimal choice of contract for observable opportunity costs

The optimal contract maximizes the buyer's payoff under the relevant permanence constraints, (2) and (3), and the moral hazard incentive constraint (6). To solve for the optimal contract payments, we will first ignore the participation constraint within the optimisation and then check (*ex post*) that constraint (7) is slack. The corresponding optimisation problem is:

$$\max_{\alpha,\beta_l,\beta_h} (8), \text{ subject to } (2), (3), \text{ and } (6). \tag{9}$$

The Lagrange multipliers for the constraints (2), (3), and (6) are denoted with λ_1, λ_2, and λ_3. For the high-outcome permanence constraint (t_h, β_h), the Lagrange multiplier is:

$$\lambda_1 = \frac{\pi\underline{\sigma}(v(\rho\Delta_\sigma + \underline{\sigma})q'(\alpha) - 1)}{(1-\gamma\theta)(\pi t_l + (1-\pi)t_h)z'(\alpha)}, \tag{10}$$

which is positive for a sufficient large v. The Lagrange multiplier for the low-outcome permanence constraint (t_l, β_l) is:

$$\lambda_2 = \frac{(1-\pi)\underline{\sigma}(v(\rho\Delta_\sigma + \underline{\sigma})q'(\alpha) - 1)}{(1-\gamma\theta)(\pi t_l + (1-\pi)t_h)z'(\alpha)}, \tag{11}$$

which is again positive for a sufficiently large v. The Lagrange multiplier for the moral hazard incentive constraint is:

$$\lambda_3 = \rho\Delta_\sigma + \underline{\sigma}\left(1 + \frac{(-v(\rho\Delta_\sigma + \underline{\sigma})q'(\alpha) + 1)}{(1-\gamma\theta)(\pi t_l + (1-\pi)t_h)z'(\alpha)}\right) \tag{12}$$

and is positive for a small $\underline{\sigma}$, which implies a severe enough moral hazard problem.[18]

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[18] It could be argued that with a very low $\underline{\sigma}$, the amount of carbon sequestered would be too small for the

In the remainder of this section we concentrate on the case where all constraints are binding and consider alternative scenarios in Section 4. We assume for the time being that problems of opportunism, i.e. moral hazard and opportunistic contract breach, are large enough to be taken into account within the buyer's choice of contract payments. In this case, contracted transfers are entirely determined by (2), (3), and (6), each holding with equality. Hence:

$$\alpha^* = z^{-1}\left(\frac{\underline{\sigma}}{(1-\gamma\theta)(\pi t_l)+(1-\pi)t_h} \cdot \frac{C}{\Delta_\rho \Delta_\sigma}\right), \tag{13}$$

$$\beta_l^* = \frac{C \cdot t_l}{(\pi t_l + (1-\pi)t_h)\Delta_\rho \Delta_\sigma q(\alpha)}, \tag{14}$$

$$\beta_h^* = \frac{C \cdot t_h}{(\pi t_l + (1-\pi)t_h)\Delta_\rho \Delta_\sigma q(\alpha).} \tag{15}$$

Substitution of (14) and (15) into (1) for a positive effort yields the following expected payoff for the seller at the time of contracting:

$$EU^* = \frac{\rho(0)\overline{\sigma} + (1-\rho(0))\underline{\sigma}}{\Delta_\rho \Delta_\sigma} C. \tag{16}$$

The expected value is always positive, which implies that the participation constraint (7) is indeed slack. Thus, the seller receives a positive *ex ante* rent that is entirely determined by the moral hazard in precaution. In fact, the expected rent corresponds exactly to the rent given up to the seller in a standard moral hazard setting (see Laffont and Martimort, 2002). Consequently, the existence of the incomplete enforcement problem does not influence the seller's *ex ante* expected rent. This is due to the timing of the contract. Since the seller decides on providing effort before his opportunity cost is realised, the moral hazard incentive constraint (6) is formulated with respect to the *expectation* of those payoff components that are not affected by the contingency, i.e. $(\pi\beta_l + (1-\pi)\beta_h)q(\alpha)$. Note that the buyer can discriminate for the different realizations of opportunity cost by choosing the respective per unit contract price β_i, which is possible as the realisation of $\tilde{t}$ is observed. Thus, for different realizations of $\widetilde{t}$ the wedge in the seller's payoffs necessary to induce precautionary effort will differ. For $i \in [l, h]$ the respective difference in seller's payoffs is:

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buyer to demand permanence. Yet for a climate mechanism such as Kyoto's CDM to remain politically credible, permanence may be demanded even where the costs of ensuring this are high.

$$(\beta_i^* \overline{\sigma} q(\alpha^*) - C) - (\beta_i^* \underline{\sigma} q(\alpha^*) - C) = \frac{t_i}{\pi t_l + (1-\pi) t_h} \cdot \frac{C}{\Delta_\rho}. \tag{17}$$

Note that C/Δ_ρ represents the wedge for a standard moral hazard problem. Hence, equation (17) implies that the *ex post* difference in payoffs is larger than the standard moral hazard wedge if t_h realizes and, conversely, lower for a realisation of t_l. Yet considered *ex ante*, the expected difference corresponds exactly to the standard moral hazard wedge.

With all constraints binding, the buyer's choice of the contracted transfers is entirely driven by the need to prevent opportunistic behaviour on the part of the seller. Consequently, the choice of upfront investment as defined by (13) is independent of the buyer's marginal returns from the generated carbon offsets. Instead, α^* is dependent on the determinants of incomplete contract enforcement and moral hazard in precaution. As $z^{-1}(\cdot)$ is increasing and (quasi-)convex in its argument, α^* will be larger if incentivising precautionary effort becomes more expensive, i.e. if $\frac{C}{\Delta_\rho \Delta_\sigma}$ increases. The same holds for the seller's expected gain from opportunistic contract breach. The latter will be larger if contract enforcement in the host country is weak, i.e. if $\gamma\theta$ is low. Intuitively, this relationship reflects the general insight that foreign direct investment increases with contract enforcement.

The necessity of using the upfront investment α as an instrument to deter opportunistic behaviour by the seller has some important implications with respect to project size. To illustrate this, assume (23) and (24) are both linear for a specific range of α. A linear $q(\alpha)$ would imply that a doubling in upfront payment would also double the amount of carbon sequestered. Hence, if enforcement were complete scaling up a project would always be rational as long as the relationship between the upfront payment and carbon sequestration remains linear.[19] In a contract driven by moral hazard and incomplete enforcement, the contracted upfront payment is determined by (13), which in turn fixes the contracted offset at the level $q(\alpha^*)$. Therefore, the problem of potential opportunism on the part of the seller limits the size of carbon sequestration projects even if a scale-up were desirable otherwise.

Note from (13) that if the seller's expected gains from opportunistic contract breach increase, i.e. $((1-\gamma\theta)(\pi t_l) + (1-\pi)t_h)$, the contracted upfront investment tends towards zero. Limited

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[19] Note that over a restricted range of α, such a linear relationship is not implausible, as an increase in upfront payment could always be used to acquire the necessary combination of production factors for a linear scale-up. Hence, as long as prices for production factors—most importantly land—do not change, a linear scale-up might be plausible.

enforcement provides—at least in tendency—an explanation for the observed lack of upfront financing for CDM forestry projects. Indeed, upfront payments tend to exist only in contracts of the kind established by development-oriented institutions such as the World Bank's BioCarbon Fund, and not in the commercial contracts that have evolved under the CDM. The far smaller voluntary markets have witnessed wide experimentation in payment types and schedules including the provision of upfront payments.[20] Larger upfront investments could potentially enable the seller to acquire additional territory for afforestation or reforestation, which, as discussed, could help with scaling-up.

4 Comparisons of different contractual setups

Our framework lends itself to a comparison of alternative contract regimes. In this section, we present several comparisons that are of particular importance in the realm of carbon contracts. Yet most of the conclusions drawn can also be interpreted in a more general context of foreign direct investments related to purchase contracts for commodities produced in developing countries. First, we compare the contract established in Section 3 with a situation where the seller's opportunity costs are unobservable to the buyer. Second, we compare the contract with a situation where the buyer implements the project himself. The third case focuses on a contract without moral hazard while the fourth investigates alternative liability regimes for invalidated carbon certificates. Finally, we look at the case where the buyer can influence contract enforcement *ex ante*.

4.1 Contract with unobservable opportunity costs

In many areas, it is likely that the seller's opportunity cost is driven by multiple factors including commodities' prices. As a consequence, the precise levels of these are unlikely to be observed by the buyer with much degree of certainty. In the following, we relax the assumption that the seller's opportunity cost is observable to the buyer and hence, can be used to set the level of the backloaded payment. As a consequence, there exists only one contracted per unit price β and the buyer's contract design is altered as follows.

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[20] For example, the International Small Group Tree Planting Programme (TIST) in Tanzania makes upfront cash payments to farmers (Scurrah-Ehrhart, 2006).

Given that the backloaded payment can no longer be made contingent on the realisation of the seller's opportunity cost, the following moral hazard incentive constraint must hold:

$$(\rho(1)\cdot\overline{\sigma}+(1-\rho(1))\cdot\underline{\sigma})\cdot\beta q(\alpha)-C\geq(\rho(0)\cdot\overline{\sigma}+(1-\rho(0))\cdot\underline{\sigma})\cdot\beta q(\alpha). \tag{18}$$

Furthermore, there exists only one relevant permanence constraint, which is:

$$\beta\cdot\underline{\sigma}q(\alpha)-(1-\gamma\theta)t_h\cdot z(\alpha)\geq 0. \tag{19}$$

The buyer's objective function becomes:

$$EV_U=(v-\beta)\cdot(\rho(1)\cdot\overline{\sigma}+(1-\rho(1))\cdot\underline{\sigma})\cdot q(\alpha)-\alpha. \tag{20}$$

In order to obtain the buyer's optimal contract, the following programme (P) is solved:

$$\max_{\alpha,\beta}(20),\quad \text{subject to (19) and (18).}$$

We denote the Lagrange multiplier for the permanence constraint λ_1', and λ_2' for the moral hazard incentive constraint. The solution for the first multiplier is:

$$\lambda_1'=\frac{\underline{\sigma}(v(\rho\Delta_\sigma+\underline{\sigma})q'(\alpha)-1)}{(1-\gamma\theta)t_h z'(\alpha)},$$

which is again positive for v large enough. The Lagrange multiplier for the moral hazard incentive constraint is:

$$\lambda_2'=\rho\Delta_\sigma+\underline{\sigma}\left(1+\frac{(-v(\rho\Delta_\sigma+\underline{\sigma})q'(\alpha)+1)}{(1-\gamma\theta)(\pi t_l+(1-\pi)t_h)z'(\alpha)}\right),$$

which is again positive for $\underline{\sigma}$ low enough.

Solving (19) and (18) each holding with equality, the contracted transfers are given by:

$$\alpha_U^*=z^{-1}\left(\frac{C\underline{\sigma}}{(1-\gamma\theta)t_h\cdot\Delta_\rho\Delta_\sigma}\right), \tag{21}$$

$$\beta=\frac{C}{\Delta_\rho\Delta_\sigma q(\alpha_U^*)}. \tag{22}$$

A comparison of this contract with one defined by (13) to (15) reveals that coupling contracted per unit prices to the observed opportunity costs will always be (at least weakly) preferred by the buyer and the seller. To see this, note that the contract defined by (21) and (22) implies that the seller's expected rent is exactly the same as under observable opportunity costs, as defined by (16). This is quite intuitive as in both cases the expected rent is to incentivise the same level of precaution. At the time of contracting, the seller would be indifferent between both contracts. Furthermore, a comparison of (13) with (25) shows that $\alpha_U^* < \alpha_O^*$. Consequently, with a lower quantity of carbon sequestered, the buyer's gains from the contract will be lower when the seller's opportunity cost is unobservable.

Intuitively, the buyer is less willing to risk higher upfront payments if there is asymmetric information on the seller's opportunity cost. Both the amount of carbon sequestered and the buyer's rent from the contract will increase if backloaded payments are made contingent on the realisation of t. This result therefore provides support to the possibility of indexing the backloaded payment to the seller's opportunity cost wherever this is feasible.[21]

4.2 Comparison with an integrated relationship

In order to compare explicit levels of the upfront investment α in different contractual setups we first specify the functional relationships between the upfront investment, carbon sequestration, and opportunity cost. For simplicity, we assume the following specifications for the remainder of the paper:

$$q(\alpha) = \alpha^{1/2}, \tag{23}$$

$$z(\alpha) = d \cdot \alpha^{1/2}, \tag{24}$$

where we assume d to be small enough for constraints (2) and (3) to be quasi-concave. Note that the assumption of concave $q(\cdot)$ and $z(\cdot)$ is intuitive in a variety of cases where the offset project might be fixed in some of its production inputs, e.g. fertile land, labour supply, and so on. Moreover, the productivity of α for its intended use is plausibly not lower than for the seller's outside option. For (23) and (24), the corresponding transfers within the contract

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[21] For a different argumentation in favour of indexing based on risk-aversion, see Benitez *et al.* (2006).

determined by (13) to (15) is given by:

$$\alpha_O^* = \left(\frac{\underline{\sigma}}{d(1-\gamma\theta)(\pi t_l + (1-\pi)t_h)} \cdot \frac{C}{\Delta_\rho \Delta_\sigma} \right)^2, \tag{25}$$

$$\beta_l = \frac{t_l(1-\gamma\theta)d}{\underline{\sigma}}, \tag{26}$$

$$\beta_h = \frac{t_h(1-\gamma\theta)d}{\underline{\sigma}}. \tag{27}$$

Unsurprisingly, α_O^* decreases in the buyer's incentive for opportunistic contract breach, i.e. $d(1-\gamma\theta)(\pi t_l + (1-\pi)t_h)$. Hence, just as in the general case, the upfront investment will be lower if the expected opportunity costs are large, contract enforcement is low, or the productivity of the outside option is comparatively large. Yet the difference in the seller's payoffs necessary to induce positive effort in precaution, that is $\frac{C}{\Delta_\rho \Delta_\sigma}$, is only a determinant of α but not the the contracted per unit payment β_i. The wedge necessary to preclude moral hazard is thus created through the choice of α, while the role of β_i is reduced to guarantee permanence. Both of the contracted prices increase in the seller's incentive to breach the contract to counteract the corresponding decrease in upfront investment.

An important case for comparison is one in which the buyer chooses his investment in carbon sequestration through unconstrained optimisation. Intuitively, this corresponds to a situation where the buyer would implement the forestry project himself. In this case the upfront investment would not be affected by opportunistic behaviour since the buyer can be conceived of as a single entity. Hence, the objective function of the buyer would be:

$$EV_{FB} = v \cdot (\rho\overline{\sigma} + (1-\rho)\underline{\sigma})q(\alpha) - \alpha - C. \tag{28}$$

Note that as the buyer implements the project himself he will incur the costs of precaution C. No contract transfers are made. In order to determine the optimal level of investment the buyer optimises (28) without constraints. To compare explicit levels of α we specify the function $q(\alpha)$ as in (23). The result of the unconstrained optimisation of (28) with respect to α then leads to:

$$\alpha_{FB} = (\frac{1}{2}v(\rho\overline{\sigma} + (1-\rho)\underline{\sigma}))^2. \tag{29}$$

A comparison of (29) with (25) yields that α_{FB} is larger than α_O^* as defined in (25) if:

$$v(\rho\overline{\sigma} + (1-\rho)\underline{\sigma}) > \frac{2\underline{\sigma}}{d(1-\gamma\theta)(\pi t_l + (1-\pi)t_h)} \cdot \frac{C}{\Delta_\rho \Delta_\sigma}. \tag{30}$$

Given specifications (23) and (24), this is the condition for which the Lagrange multipliers for the permanence constraints, i.e. λ_1 and λ_2 as defined in (10) and (11), are positive. Hence, for the range of v for which the contract would be made, the contracted upfront investment is always distorted downwards compared to a situation where the buyer implements the project by himself. Integration of project investor and developer is always preferable as the amount of carbon sequestered is unambiguously larger.

In the real world, however, an integrated contract relationship is rare for a number of reasons. First, under the rules of the CDM, the host country is required to undertake a 'sustainability check', which often implies contracting with local people who in turn are supposed to benefit from implemented projects (Olsen and Fenhann, 2008). Second, host countries often express fear of 'carbon colonialism' whereby buyers take land out of alternative production such as for agriculture in order to offset own emissions but without seeking the participation of local people (see Lövbrand *et al.*, 2009). Third, search costs for international buyers, e.g. for appropriate project sites at the local level, while not explicitly modelled in this paper might be prohibitive.[22]

4.3 Contract without moral hazard

We now consider the case where the moral hazard constraint (6) is slack. The size of the overall contract payment on the left-hand side of each binding permanence constraint, (2) and (3), is large enough to incentivise due care. As can be seen from (12), this occurs if $\underline{\sigma}$ is significantly large. The only remaining problem of contractual opportunism is ensuring permanence. Note that this is where only a relatively low proportion of the carbon sink is lost in the event of a contingency. The upfront investment is then determined by substituting (2) and (3) holding with equality into (8) and optimizing with respect to α. For the specifications of (23) and (24), the corresponding upfront investment is then

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[22] Search costs have been extensively modelled in the economic literature, for example, see Weitzman (1979), Stahl (1989), and for international transactions, see Rauch (1999). These costs may be lower for a government buyer looking to contract with a government seller in contrast to project-level transactions.

$$\alpha_{Perm} = \left(\sqrt{\alpha_{fb}} - \frac{d(1-\gamma\theta)\left((1-\pi)t_{\mathrm{h}} + \pi t_{\mathrm{l}}\right)\left(\rho\overline{\sigma} + (1-\rho)\underline{\sigma}\right)}{2\underline{\sigma}} \right)^2 , \tag{31}$$

while β_l and β_h are determined by (26) and (27). The buyer's demand for permanence leads to a downward distortion of the upfront investment compared to the first best where the degree of distortion is determined by the subtrahend on the left-hand side. Intuitively, the distortion is larger if contract enforcement is weak, i.e. $\gamma\theta$ is low. This is due to the buyer's need to reduce α in order to reduce the seller's opportunity cost from alternative use. For the same reason, the distortion increases with the expected value of the seller's outside option and with d, which measures the productivity of z in α. If, for example, most of α is spent acquiring land that can be easily transformed into agriculture (i.e. large d), an expected cash-crop boom (i.e. large $((1-\pi)t_{\mathrm{h}} + \pi t_{\mathrm{l}})$ would, *ceteris paribus*, increase the risk of a potential contract breach by the seller.[23] To ensure permanence the transformation of land needs to become less attractive in comparison to keeping the forest standing. With weak enforcement, such a decrease in the overall value of the seller's outside option can only be achieved by decreasing the upfront investment. Even in the absence of moral hazard, the buyer's tendency to secure permanence leads to a reduction in investment and therefore in project size.

4.4 Contract under different liability regimes

Until now, we have assumed that the buyer would be constrained by the need to ensure permanence, an assumption informed about the allocation of liability for reducing GHG emissions as defined by the UNFCCC. These regulations prescribe that any forest carbon certificate not covered by an actual offset is to be replaced within the registry of the buyer's country of origin. This (implicit) system of buyer liability originates from the Kyoto Protocol in which only buyer countries can face credible sanctions.[24] Yet, in a future climate agreement liability might be shared with developing countries that host forestry carbon projects (Dutschke and Angelsen, 2008). Thus, liability for carbon reversals could be included in the form of sanctions and penalties for sellers. Another interesting case is one in which no liability for replacing invalidated

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[23] Note that the seller's *ex ante* rent is given by $\frac{(\rho\overline{\sigma}+(1-\rho)\underline{\sigma})^2}{2\cdot\underline{\sigma}^2} \cdot (v\underline{\sigma} - x)x - C$ with $x = d(1-\gamma\theta)(\pi)t_l + (1-\pi)t_h$.

[24] The Kyoto compliance regime features sanctions such as deeper emissions cuts or exclusion from trading mechanism. These obviously require the existence of an emission reduction target, which exist only for Annex I countries (see UNFCCC, 2005, Decision 27). Therefore, developing (i.e. non-Annex I) countries, being CDM host countries cannot be held liable *within* the Kyoto system.

offsets exist. Recent voluntary bilateral forest carbon contracts between Norway, and respectively, Brazil and Guyana, perhaps best illustrate this case.[25] Liability is assigned neither to the buyer nor the seller, which implies that any carbon reversals remain uncompensated, whether intentional or not.

Such a situation *without liability* corresponds to a contract in which the permanence constraints are irrelevant for the buyer's investment decision since the purchased certificates would never lose their value. In this case only the moral hazard problem would persist. If t_h is large enough, the buyer would no longer be inclined to design an enforcement-proof contract. Instead, he would accept that the seller might breach the contract if the high level opportunity cost realizes. He would receive contract damages with probability γ. The buyer's objective function is given by:

$$EV_{NoPerm} = (\pi(v-\beta)q(\alpha))(\rho(1)\cdot\overline{\sigma} + (1-\rho(1)) - \alpha + (1-\pi)\gamma\theta t_h z(\alpha). \qquad (32)$$

Note that we assume the timing of the contract is still the same as set down in Section 2. The corresponding moral hazard incentive constraint is altered to:

$$\pi\beta\cdot q(\alpha) - \frac{C}{\Delta_\sigma\Delta_\rho} \geq 0.$$

The corresponding participation constraint is non-binding for $(1-\pi)(1-\gamma\theta)t_h z(\alpha)$ large enough. The optimal level of upfront investment is then found by substituting this constraint holding with equality into (32) and optimizing with respect to α. Note that this optimisation might also be sensible under buyer liability if the buyer's valuation of forestry offsets is particularly low. Regarding the latter case, buyer liability does not create a strong enough incentive for the buyer to offer a β high enough to guarantee permanence. In the following we focus on the interpretation of a liability-free regime. The optimisation yields:

$$\alpha_{NoPerm} = \frac{1}{4}\left((1-\pi)\gamma\theta t_{\mathrm{h}} + \pi v\left(\rho\overline{\sigma} + (1-\rho)\underline{\sigma}\right)\right)^2 = \left(\pi\cdot\sqrt{\alpha_{fb}} + (1-\pi)\frac{1}{2}\gamma\,\theta\,t_h\,d\right)^2. \qquad (33)$$

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[25] The contract between Norway and Guyana, for example, can be seen in the form of a Memorandum of Understanding at:
http://www.regjeringen.no/upload/MD/Vedlegg/Internasjonalt/miljosamarbeid_utviklingsland/mou__norway_guyana.pdf

The level of upfront investment is determined by the probability-weighted average of the first-best investment and the slope of the marginal expected contract damages. Comparing (33) with (25) and (31) yields several interesting insights. First, if the outside option is very productive in α, i.e. if d is large, then the upfront investment might be considerably higher in a liability-free system than in one with buyer liability. Second, even if α_{NoPerm} is larger than the investment under buyer liability this does not necessarily mean that carbon sequestration is greater. This is due to the fact that in the absence of liability, sequestration will only persist with probability π, that is only if opportunity costs remain low. Therefore, if π is small enough, establishing buyer liability might be beneficial from a sequestration perspective in contrast to a liability-free system.

Interestingly, if t_h is large enough α_{NoPerm} could *in principle* be larger than the first-best level determined by (29). Hence, if the seller can invest α in an alternative use that yields high returns, the buyer might even benefit from receiving damages as a consequence of contract breach. Note, however, that this comparison is only valid if the buyer does not have the opportunity to invest in the outside option if he implemented the project by himself. If the alternative investment were open to the buyer, equation (28) would have to be altered accordingly. A subsequent optimisation would then yield levels of upfront investments that are strictly larger than α_{NoPerm}.

The most obvious alternative to buyer liability would be to establish seller liability. In this case the seller would have to replace certificates cancelled due to carbon reversal.[26] If we maintain our assumption of a sufficiently large replacement value v of a certificate the seller would never choose his outside option. Under these circumstances the buyer would simply optimise as if contract enforcement were complete. His objective function is then

$$EV_{NoPerm} = (v - \beta)q(\alpha))(\rho(1) \cdot \overline{\sigma} + (1 - \rho(1)) - \alpha, \tag{34}$$

which is optimised subject to

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[26] Within an international treaty, this liability would be attributed to the seller *country* which is not necessarily identical to the entity implementing the project. In the following we abstract from this by assuming that the host country would be able to effectively deter the project developer from reversing the carbon sink. Within our setup this implies that the host country has a better enforcement technology than the buyer under buyer liability.

$$\beta \cdot q(\alpha) - \frac{C}{\Delta_\sigma \Delta_\rho} \geq 0, \tag{35}$$

as the buyer would still want to incentivise due care. The buyer chooses β such that (35) holds with equality and optimises over α. Obviously, in this case the optimal upfront investment is equal to α_{FB}. Hence, establishing seller liability would lead to the same investment level as if the buyer implemented the project himself.

At first sight the current liability regime within Kyoto looks particularly unfortunate. Buyer liability for forestry offsets is likely to yield lower levels of investment in sequestration than a situation where the seller is held accountable for replacing emissions credits lost through carbon reversal. As can be seen from (25) and (31), this inefficiency is larger where host country contract enforcement is weaker. However, within the current framework, seller liability would require an effective sanctioning of CDM host countries. But since these countries were unwilling to take on emissions cuts, this ruled out any possibility of sanctions. This left two choices for Kyoto negotiators, either a system with no liabilities or buyer liability. The former would have implied the non-renewal of carbon credits in the event of carbon reversal, which was not politically feasible given concerns about the use of offsets in lieu of reducing own emissions (IISD, 2001; Ohndorf, 2009). Given worries about high risks of carbon reversal in host countries, a system of no liability gave way to the sole remaining choice of buyer liability. While not perfect, this system reflects the institutional and political realities of Kyoto. It is nevertheless preferable to a liability-free system from a sequestration perspective so long as the probability of realising the high state opportunity cost is minimised. Policy to prevent price speculation during cash crop booms and times of rapid agricultural expansion could be applied to this effect.

4.5 Endogenous enforcement probability

Up to this point, we have assumed that the probability of contract enforcement is exogenously set. In the context of forestry projects, particularly those in a CDM-type setting, this assumption is justified on the basis that project developers implementing individual contracts may have relatively little control over the local institutional setting. Instead, they will depend on third-party contract enforcement, whether undertaken by government institutions or those that utilise more informal group sanctioning, for example, based on customary law or social norms. Contracts made with host country governments instead of with project developers even more strongly justifies the assumption of exogenous contract enforcement due to sovereignty issues. In other words, it is unlikely at the current time that a buyer would be able to influence a country's ability or capacity to enforce contracts.

While policy discussions on the role of forestry carbon activities in a post-2012 international climate agreement gradually move towards a national-level approach, pilot projects continue to be established at the local level in many countries (Sills *et al.*, 2009). Projects will thus continue to play an important role in policy to secure forest climate benefits. Much experimentation is currently taking place on the efficacy of different types of contractual arrangements and incentives implemented in varying contexts. It is becoming increasingly apparent that project developers are putting in place systems and procedures for monitoring activities on the ground, which could influence the enforcement capacity of a given area. In particular, contracts implemented in remote forest areas lacking any kind of institutions for contract enforcement might benefit from these investments. In our framework, this type of investment is conceptualised by assuming that enforcement probability is endogenously set by the buyer.

Following Laffont and Martimort (2002), we assume that the buyer can choose the probability of enforcement $\gamma \in [0,1]$. He will then incur the costs $\kappa(\gamma)$ which are increasing and convex in γ with $\kappa(0) = 0$ and $\kappa(1) = \infty$. For example, $\kappa(\gamma)$ may reflect the cost of establishing monitoring systems or training more forest rangers to operate in project areas. Again, both moral hazard and permanence constraints are binding, and we assume observable opportunity costs. The objective function then becomes:

$$EV_{enf} = (v - (\pi\beta_l + (1-\pi)\beta_h)) \cdot (\rho(1) \cdot \overline{\sigma} + (1-\rho(1)) \cdot \underline{\sigma}) \cdot q(\alpha) - \alpha. \tag{36}$$

If all constraints are binding we can substitute equations (13) to (15) into (36) and then perform an unconstrained optimisation over γ. For this we assume the following functional form for $\kappa(\gamma)$:

$$\kappa(\gamma) = \frac{1}{1-\gamma} - 1. \tag{37}$$

For simplicity we additionally assume $\theta = 1$. Under these assumptions the optimal level of

γ is:

$$\gamma^{*} = 1 - \frac{2C^{2}\sigma_{\mathrm{l}}^{2}}{h\left(h + C(vw - 2d)\sigma_{\mathrm{l}}\right)}, \tag{38}$$

where $h = (\pi t_l + (1-\pi)t_h)\Delta_\rho\Delta_\sigma$ and $w = (\rho\overline{\sigma} + (1-\rho)\underline{\sigma})$. Substitution of (38) into (13) then yields the corresponding optimal upfront investment:

$$\alpha_{Enf} = \left(\sqrt{\alpha_{fb}} - \frac{d\left((1-\pi)t_{\mathrm{h}} + \pi t_{\mathrm{l}}\right)\Delta_\rho\Delta_\sigma}{2C\underline{\sigma}}\right)^{2}. \tag{39}$$

Just as for all contracts with binding moral hazard and permanence constraints, α_{Enf} is increasing in $\frac{C}{\Delta_\rho\Delta_\sigma}$. Hence, the need to ensure due care on the part of the seller reduces the distortion of the upfront investment compared to the first best.

5 Conclusion

Opportunistic behaviour due to incomplete contract enforcement is a risk in many economic transactions. Contracts need to be designed in a way that not only minimises moral hazard in precaution, but also deters opportunistic contract breach under incomplete contract enforcement.

In this paper, an enforcement-proof incentive contract is developed in which a buyer demands a guaranteed delivery of a good or service given a productive upfront payment, moral hazard in precaution, and the potential for opportunistic contract breach. A direct application of our model is the optimal contract design that ensures 'permanence' in forestry carbon offsets—something crucial to any forthcoming international agreement on controlling climate change.

We first determined the optimal contract that ensures both due care in precaution and permanence of the carbon sink. We showed that the seller's expected rent is the same as in a standard moral hazard framework. Upfront investments are, however, restricted and entirely determined by moral hazard and opportunistic contract breach. This restriction in investment leads to a cap in sequestration up to a specific level even if an infinite scale-up would be beneficial in a situation without opportunism. The larger the moral hazard problem, that is the more expensive it is to induce effort, the smaller the distortion. This unexpected result is due to the fact that by increasing the upfront payment, the buyer also increases the seller's payoff at the end of the contract.

Our framework provides an argument in favour of indexing the contracted per unit payment with respect to parameters that might determine the value of the seller's outside option, like agricultural prices. Pegging the contract price increases the upfront investment, as deterrence from unlawful disappropriation is less costly to the buyer. Of course, the relative usefulness of this policy recommendation depends on the observability of the seller's outside option. More explicit modelling of indexing through the dynamic extension of our simple contracting problem to two periods would enable an analysis of the optimal contract to manage changes in opportunity costs *ex post*. We also showed that an integrated relationship, where the buyer implements the project by himself, is always preferable under the current liability regime. The reason for this is that incentives to deter opportunistic contract breach lead to a downward distortion of the upfront investment ceded to the seller. Interestingly, this distortion is reduced with increasing costs to induce precaution effort. Finally, we compared contract incentives under buyer liability, to those under alternative liability regimes. Where neither buyer nor seller is assigned liability for replacing invalidated certificates, the upfront investment is likely to be larger than under buyer liability. Note, however, that under these circumstances the carbon sink will be reversed if a higher state of opportunity costs is realised. By contrast, under a system of seller liability, the carbon sink will persist and the upfront investment corresponds to the first best. Hence, under the assumptions made here, seller liability is likely to be the most efficient system of all.

Introducing a regime of seller liability would require the existence of potential sanction for seller countries, which does not exist under the current international climate policy regime. This has to be resolved if forest carbon, for example, in the form of Reducing Emissions from Deforestation and Degradation (REDD), is to be adopted on a wide scale in a post-2012 international climate regime (UNFCCC, 2007). A post-2012 framework could incorporate the sharing of liability between buyer and seller countries, for example, through the establishment of emissions reductions targets in current non-Annex 1 countries (Eliasch, 2008). If this is not possible then buyer liability is certainly preferable to a liability-free system. Our general discussion of different liability systems suggests wider application to contracts other than carbon sequestration.

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