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

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Opportunistic behaviour due to imperfect contract enforcement is a risk in many economic transactions. 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. Investing in a contract upfront is found to be restricted by moral hazard and opportunistic contract breach. This limits the size of investment up to a specific level even if an infinite scale-up of production were beneficial. A more severe moral hazard problem results in a smaller distortion. The framework is applied and extended to international carbon sequestration contracts. In comparison to alternative liability attributions, the current regime of buyer liability yields inefficiently low levels of investment in carbon sequestration.

JEL classifications: K12, Q15.

1. Introduction

Opportunistic behaviour due to imperfect contract enforcement is a risk in many economic transactions, potentially leading to unfulfilled contracts. For example, transnational firms investing abroad risk the expropriation of their investments due to weak contract enforcement (Thomas and Worrall, 1994). In such an environment, as found in many developing countries, the agent may have an incentive to opportunistically breach the contract when an attractive outside option arises. In non-repeated agreements, third-party enforcement is often the only coercive mechanism available (de Janvry and Sadoulet, 2007). Such relationships can arise, for example, in the context of supply contracts for custom-made inputs in a supply chain, concessions for the exploitation of a depletable resource, and payments for environmental services. If contract breach on the part of the agent causes a large enough loss in the principal's investment, contracts need to be enforcement-proof (Laffont and Martimort, 2002). As this incentive problem is likely to interact with other problems of opportunism, notably asymmetric information on the level of due care exercised by the seller, there is a need to better understand the optimal design of contracts in these settings.

In this paper, we develop an enforcement-proof incentive contract in which a principal demands a guaranteed delivery of a good or service given a productive upfront investment 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 size of investment up to a specific level even if an infinite scale-up of production 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 compared to the first-best case. We use our model to investigate international carbon sequestration contracts and show that the current institutional set-up results in inefficiently low levels of sequestration.

Enforcement-proofness is of particular importance for supply contracts for customized inputs with relatively high value to the principal. In many cases, such contracts—often associated with the outsourcing of production to developing countries—feature investments partially specific to the contracted transaction, i.e. the value of the investments in customization are higher within the buyer-seller relationship than outside the relationship. As shown by Grossman and Helpman (2005), such outsourcing agreements can be modelled as the combination of an investment contract and a subsequent order contract. First, the buyer provides the seller with the investment in customization, which might take the form of knowledge transfer or monetary compensation (potentially upon delivery of a prototype). The second contracted transfer is the payment for the ordered input upon delivery. Given that these contracts always involve an upfront transfer, they are particularly prone to opportunistic contract breach. This has important consequences for trade patterns (Antras, 2005; Acemoglu *et al.*, 2007). Countries with higher levels of contract enforcement specialize in industries where relationship-specific investments are most important, which engenders an institution-driven comparative advantage (Levchenko, 2007; Nunn, 2007; Costinot, 2009).

The relative weakness of contract enforcement in developing countries is generally well documented (see IBRD/WB, 2011), and plays an important role in economic performance (Anderson and Marcouiller, 2002; Levchenko, 2007; Nunn, 2007; Costinot, 2009). The effects of imperfect enforcement has also been theoretically analysed in a variety of contexts, both at the national and subnational level, including share contracts (de Janvry and Sadoulet, 2007), investment and lending contracts (Atkeson, 1991; Thomas and Worrall, 1994), and resource sector contracts (Aghion and Quesada, 2010; Engel and Fischer, 2010; Hajzler, 2010a). Such effects are of particular importance for high-value supply contracts, which often require an *ex ante* investment.

Imperfect enforcement of supply contracts is mostly represented as a problem of incomplete contracting (e.g. Antras, 2005; Grossman and Helpman, 2005; Nunn, 2007). Yet often, the problem lies not in the non-contractibility of specific contract features but in the agent's non-performance with respect to contracted variables. This could be, for example, non-compliance with respect to pre-specified quality standards or an outright non-delivery of the contracted good. A common situation of contract breach arises when the agent's opportunity cost from contract performance increase. In that case the agent might opt for non-performance while putting the resources from the investment to a different use. This might arise, for example, if market prices for the agent's next-best production option increase, or—in the extreme case—if the agent receives a third-party offer for the contracted good.[1] The incentive problem underlying opportunistic contract breach becomes more imminent if the upfront investment is (partially) productive in the agent's opportunity cost. This can be the case in contractual setups with frontloaded transfers where the level of due care within production is unobservable.

To account for these features, we develop the following contracting framework in Sections 2 and 3. A principal and agent contract on an upfront investment along with a payment made conditional on delivery of a good or service. We model the investment as a productive transfer, one that is not only productive in the production of the contracted good or service but is also (although potentially less) productive in the agent's outside option. Possible changes in the agent's outside option are anticipated at the time of contracting but only realize after the contract has already been signed. The principal's valuation of the good is assumed high enough to incentivize guaranteed delivery of the good, which is reflected in the introduction of an enforcement-proofness constraint. Additionally, the agent's production process might be subject to a contingency thus creating the need to incentivize precautionary measures. The second-best optimal contract is derived to give insights on the interaction of moral hazard in precaution and opportunistic contract breach.

Our framework lends itself to an analysis of inputs to a supply chain, concessions for depletable resources, and environmental service contracts. In Section 4, our model is used to explore the institutional arrangements established for carbon sequestration contracts such as the Clean Development Mechanism (CDM) of the Kyoto Protocol. Within these contracts a buyer provides an investment for afforestation or reforestation projects to a seller in a developing country. The certified offsets that are generated are transferred to the buyer in exchange for a per-unit payment while the forest remains under the control of the seller. Within the current climate policy framework, liability for replacing certificates in case of a reversal of the carbon sink (e.g. through forest-fires or deliberate premature harvest) lies with the buyer. This precludes extra-contractual sanctioning of the seller based on tort law, hence the need for enforcement-proofness if permanence of

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[1] Such situations of breach have been extensively analysed in a complete enforcement context (e.g. Shavell, 1980; Polinsky, 1983; Shavell, 1984; Cooter and Eisenberg, 1985).

the carbon sink is to be guaranteed. Our analysis reveals that compared to alternative liability attributions, the current scheme yields inefficiently low levels of investment in carbon sequestration. These results contribute to the discussion regarding 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), and its role in future global climate treaties. Section 5 concludes.

2. The model

Consider a contract between a buyer (principal) and a seller (agent) of a good. Both the principal and agent are assumed to be risk neutral with limited liability.[2] Production of the good requires an upfront investment, which can only be provided by the principal. The agent may, for instance, have limited access to financial markets. Alternatively, the investment may involve the provision of resources only available to the principal, for example, specific knowledge regarding production processes. Furthermore, contracting takes place in an environment where contract enforcement is imperfect such that there is a risk of opportunistic contract breach on the part of the agent. Such an environment often discourages third-party financing, and could reflect contracts made with a developing country entity such as a firm, landowner, or government. For example, a supply contract for purpose-built goods to be supplied by a firm, an environmental service contract with a landowner or a resource concession contract with a government. The principal in all cases is assumed to be either a private or a state actor. The latter could include state-owned enterprises or even governments.

In exchange for a quantity of the good q, the principal 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 good. The upfront transfer is assumed to be productive, i.e. α is assumed to have a positive influence on the amount of good that is delivered but is in itself not utility relevant to the agent. Such a provision of upfront capital within the contract is often a prerequisite for an investment project to be implemented and is thus assumed to be at least partly transaction-specific. Hence, α might reflect a technology transfer or a payment to finance the acquisition of production inputs such as machinery or land.

There exists a moral hazard over precautionary efforts by the agent against some contingency that may lead to a reduction in the contracted amount or quality of the good. For example, the seller might not always succeed in delivering the desired level of customization. Similarly, investments in forestry or other natural resources could be at risk of destruction by natural hazards, like fire. For simplicity, we allow

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[2] Limited liability can be interpreted as reflecting extreme risk-aversion below a specific minimum income. See, for example, Basu (1992) or de Janvry and Sadoulet (2007). Thus, we can also account for a certain type of risk aversion on the part of the agent.

for only two states, either the contingency realizes 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 usable quantity of good produced by the agent q is a function of the upfront payment α and the realization of the contingency, which we define as $\tilde{\sigma} \cdot q(\alpha)$, with $q'(\alpha) > 0$ and $q''(\alpha) \leqslant 0$. When no contingency occurs, the quantity of delivered good is $\overline{\sigma} \cdot q(\alpha)$. If the contingency realizes, the delivered good amounts to $\underline{\sigma} \cdot q(\alpha)$. Intuitively, the quantity of good contracted *ex ante* is scaled down due to the realization of the contingency at the time of production. The agent 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 $v \cdot \Delta_\rho \Delta_\sigma \geqslant C$ where v denotes the agent's per unit valuation of the good. Hence, the principal will always want to induce the agent's effort if at least one unit of the good is delivered. Costs $C(e)$ can be considered sunk and therefore non-recoverable.

Furthermore, we assume that, when proposing the contract, the principal takes into account the possibility of opportunistic contract breach on the part of the agent. The agent might have an incentive to breach the contract if his opportunity cost from contract performance increases. This might be driven by the benefit of using the invested resources for the production of alternative goods. Alternatively, it can be assumed that the agent produces the contracted good, but receives either a third-party offer or considers selling the good (or even some part of it) on the market. We generalize the value of the agent's future opportunity cost by modelling it as the result z of an alternative activity with a per unit valuation denoted $\tilde{t}$. Hence, the agent's opportunity cost is $\tilde{t} \cdot z(\alpha)$. Contrary to standard contractual setups, we allow the agent's 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 $z''(\alpha) \leqslant 0$. Intuitively, investing more upfront could indirectly benefit the agent through boosting the value of his opportunity cost. For example, the production of alternative goods might increase by use of invested resources α. In the special case of a third party offer for the (unaltered) contracted good, $z(\alpha)$ would be identical to $q(\alpha)$, while $\tilde{t}$ represents the per unit price offered by the third party.

We assume that the value of the future opportunity cost is uncertain. Should the opportunity cost increase then the agent's commitment to adhere to the contract is in doubt. For simplicity, we allow for two possible levels of opportunity cost, which we denote as $\tilde{t} \in \{t_l, t_h\} \subset \mathbb{R}_+$, with $t_l < t_h$.[3] At the time of contracting, the probability of a low value t_l realizing is π, while the probability of t_h occurring is $(1 - \pi)$. After realization, the value of the opportunity cost is publicly known. It is, however,

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

plausible that the initial investment is more productive in its intended use. We hence assume $z'(\alpha) \leqslant q'(\alpha)$ over the relevant range. Moreover, we assume that the realized level of the agent's opportunity cost is observable with the backloaded part of the contract paid contingent on this level, i.e. β_l for t_l and β_h for t_h realized. We relax this assumption in Section 4.3.

Hence, in the event of contract performance, the expected value of the contract to the agent is given by:

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

If the high opportunity cost level t_h is realized, the agent potentially has an incentive to breach the contract.[4] For example, higher prices for mineral resources have been shown to lead to opportunistic expropriation of the investment by governments (Cole and English, 1991; Duncan, 2006; Hajzler, 2010b). In the case of supplying environmental services say from forest, inputs such as land could potentially be switched to agricultural production should the latter provide more attractive returns to landowners (Richards and Andersson, 2001; van Kooten *et al.*, 2002). Note that we assume the opportunity to breach to be one-sided, i.e. the principal is effectively deterred from contract breach due to (relatively) stronger judicial institutions in his home country.

In case of breach, it is assumed that the agent does not deliver the good and instead expropriates the investment. We assume that the principal will attempt to enforce the contract through a court order. With a weak judicial system, contract enforcement is not guaranteed. Many developing countries are subject to poor governance and weakly-defined property rights, e.g. over land and natural resources, and imperfect enforcement of laws and regulations.[5] If the agent is a national government then the problem of contract enforcement is even more pronounced despite possibilities for international arbitration (see, for example, Dezalay and Garth, 1998). We account for this by introducing stochastic contract enforcement into our framework. In case of contract breach by the agent, the principal succeeds in achieving a court order with probability γ. In case of successful litigation, the agent has to pay contract damages of $\theta \cdot t \cdot z(\alpha)$ to the principal. The parameter θ represents contract damages that are determined by the host country's contract law and legal practice.[6] To a certain degree we allow for punitive damages, i.e. $\theta > 1$, which are, however, restricted by assuming $\gamma\,\theta < 1$.

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[4] 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).

[5] Nevertheless, we note wide variation in third-party enforcement both among and within countries as illustrated by the World Bank's 'Doing Business' project, see: http://www.doingbusiness.org/economyrankings.

[6] Note that if $\theta = 1$ contract damages correspond to their efficient level under full enforcement (see Polinsky, 1983). 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 (see Hatzis, 2003).

Similar to standard complete contract frameworks, we solve for the optimal contract by maximizing the principal's expected utility subject to several constraints. The most important constraint is based on the assumption that the principal is interested in the guaranteed delivery of the contracted good. This implies that the principal's valuation for the contracted delivery of the good is high enough. In supply contracts for customized goods, guaranteed contract performance would be beneficial if the principals's valuation v were first larger than any third-party offer and second, higher than the gains obtained by the agent from utilizing production inputs alone.[7] Contracts established in the Clean Development Mechanism of the Kyoto Protocol follow a similar logic (see Section 4). Given the assumption of a principal interested in the assured delivery of the good, the following set of enforcement-proofness constraints therefore need to hold for both $\overline{\sigma}$ and $\underline{\sigma}$:

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

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

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

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

where, in order to ensure quasi-concavity of the constraints, we assume $z''(\alpha) \geqslant q''(\alpha)$.

Intuitively, these constraints ensure that the agent always finds it (weakly) preferable to comply with the contract and prefers to take the agreed rent rather than his outside option (see, for example, Laffont and N'Guessan, 2001; Laffont and Martimort, 2002). As a consequence, most of the results that follow apply to contracts in which the principal wishes to prevent the agent breaching the contract. In Section 4.2, we relax this assumption. Note further that (2) and (3) imply that the principal would still prefer to ensure delivery of the good even if part of the contracted good has been lost due the realization of the bad state $\underline{\sigma}$. More importantly, the constraints ensure delivery of the contracted good for the duration of the contract.

Should the agent's (upper-level) opportunity cost t_h realize then his utility from $\underline{\sigma}$ under a potential non-breach situation needs to be equal to or larger than the expected utility in case of breach. This includes the agent's expected costs from the possibility of contract enforcement.[8] Note that (4) and (5) will always hold if (2) and (3) are fulfilled.

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[7] The latter is likely if the agent has less expertise in subsequent production processes. While the agent would only be able to sell it on the market, the principal would have a specific use for the input. This is the case, for example, with rare earth metals used in electronic goods.

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

As the principal always prefers to induce precautionary effort on the part of the agent, the 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 agent's expected net benefits from the contract must be larger when he 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 enforcement-proofness and moral hazard constraints are fulfilled, which implies $e=1$, the agent's participation constraint is:

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

Since the principal is assumed to be risk neutral his payoff corresponds, up to a linear transformation, to the principal's utility, $V(q)$. In the following, we assume that $V(q)=vq$, where the principal's value per unit v of the good is constant.[9] If delivery of the good is assured, the principal's payoff function is:

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

Note that the principal's objective of assured delivery implies that contract breach cannot occur under any circumstances, including a situation where a contingency might arise. While the principal cannot entirely rely on coercive measures to incentivize the agent to perform, enforcement-proofness of the contract effectively deters opportunistic contract breach. Therefore, potential contract damages granted by a court do not enter into (8).

The timing and pay-offs of the model are summarized in Fig. 1. In period 0, the principal offers a contract with a two-tiered payment scheme, represented by α and $\beta\in\{\beta_l,\beta_h\}$. Should the agent agree to this contract, he then immediately receives the upfront investment α in period 1. In period 2, the agent implements the scheme and chooses effort e with cost $C(e)$. After effort is chosen, $\tilde{\sigma}\in\{\underline{\sigma},\overline{\sigma}\}$ is realized.

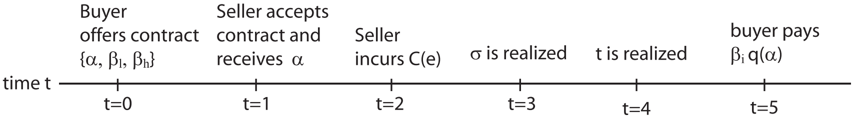

Fig. 1 Timing of the contract.

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[9] Alternatively, a concave utility function could be assumed for the principal. In this case our results hold as long as $V(q)$ is sufficiently steep over the relevant range. Yet, assuming constant per unit valuation is helpful for the interpretation of the model presented in Section 4.

The agent's opportunity cost, $\widetilde{t}\cdot z(\alpha)$, is realized in period 4. In period 5, the backloaded payment, amounting to $\beta_i\tilde{\sigma}q(\alpha)$ with $\beta_i\in\{\beta_l,\beta_h\}$, is received by the agent.

3. Optimal choice of contract

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

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

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

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

which is positive for a sufficiently large ν. The Lagrange multiplier for the low-outcome enforcement-proofness constraint (t_l,β_l) is:

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

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

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

and is, given a large ν, positive for a small enough $\underline{\sigma}$, which implies a severe enough moral hazard problem.

In the remainder of this section we concentrate on the case where all constraints are binding, and consider an alternative specification in Section 4. We assume that problems of opportunism, i.e. moral hazard and opportunistic contract breach, are large enough to be taken into account within the principal'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 agent 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 agent 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 agent in a standard moral hazard setting (Laffont and Martimort, 2002). As a consequence, imperfect contract enforcement does not influence the agent's *ex ante* expected rent. This is due to the timing of the contract. Since the agent decides on providing effort before his opportunity cost realizes, 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 principal can discriminate for the different realizations of opportunity cost by choosing the respective per unit contract price β_i, which is possible as the realization of $\tilde{t}$ is observed. Thus, for different realizations of $\tilde{t}$ the wedge in the agent's payoffs necessary to induce precautionary effort will differ. For $i \in \{l, h\}$ the respective difference in agent's payoffs is:

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

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 the realization of t_l. Yet considered *ex ante*, the expected difference corresponds exactly to the standard moral hazard wedge.

With all constraints binding, the principal's choice of contracted transfers is entirely driven by the need to prevent opportunistic behaviour on the part of the agent. Consequently, the choice of upfront investment as defined by (13) is independent of the principal's marginal returns from the delivered good. Instead, α^* is dependent on the determinants of imperfect contract enforcement and moral hazard in precaution. As $z^{-1}(\cdot)$ is increasing and (quasi-)convex in its argument, α^* will be larger if incentivizing precautionary effort becomes more expensive, i.e. if $\frac{C}{\Delta_\rho \Delta_\sigma}$ increases. The opposite holds for the agent's expected gain from opportunistic contract breach. The latter will be larger if contract enforcement is weak, i.e. if $\gamma\theta$ is low. Hence, the need to incentivize due care exerts an upward pressure on the upfront investment, while an increase in the risk of expropriation acts in the opposite direction.

The necessity of using the upfront investment α as an instrument to deter opportunistic behaviour by the agent has important implications with respect to the size of the venture. To illustrate this, assume $q(\alpha)$ and $z(\alpha)$ are both linear for a specific range of α. A linear $q(\alpha)$ with slope 1, for example, would imply that a doubling in the size of the investment would also double the amount of good produced. Hence, if enforcement is perfect then scaling up a venture would always be rational as long as the relationship between the investment and the good remains linear.[10] In a contract driven by moral hazard and imperfect enforcement, the contracted upfront investment is determined by (13), which in turn fixes the contracted amount at the level $q(\alpha^*)$. Therefore, the problem of potential opportunism on the part of the agent limits the size of investment even if a scale-up were desirable otherwise.

Note from (13) that if the agent'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 toward zero. Hence, in tendency, our results confirm the importance of contract enforcement for investment levels in various settings. These results also provide further theoretical support for an observed institution-induced comparative advantage, driven by lower rates of breach of contracts for (more valuable) customized inputs in supply chains (Levchenko, 2007; Nunn, 2007; Costinot, 2009). Moreover, they may also help explain the lack of upfront investments in forestry projects contracted in the Clean Development Mechanism (CDM) of the Kyoto Protocol, to which we now turn.

4. Ensuring 'permanence' in carbon sequestration

In this section, we illustrate the model developed in Sections 2 and 3 using the case of investments in carbon sequestration activities in developing countries. International contracts ('carbon offsets') have recently emerged that invest in afforestation or reforestation activities under the CDM of the Kyoto Protocol.[11] Such contracts are made between buyers in industrialized countries looking to offset their greenhouse gas (GHG) emissions (the principal in our model), and project developers or sellers who wish to create tradable emissions credits or certificates (the agent). Thus, the buyer may be a firm (or non-governmental organization) attempting to comply with its environmental obligations, or a national government complying with the Kyoto Protocol. The seller could represent a CDM project developer with limited liability, or a regional or national government that provides for sequestration of carbon dioxide through investment in forestry.

Given the importance of climate benefits from forests, the remainder of this section uses the model to illustrate how incentives could be designed to reduce the risks of carbon reversal from deforestation.[12] In the literature, this problem is

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[10] Note that, for cases where α represents a cash transfer such a linear relationship is not implausible, at least over a restricted range of α. In these cases an increase in the size of the upfront investment 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 remain stable, a linear scale-up might be plausible.

[11] Note that these activities are the only forestry projects eligible within Kyoto's CDM.

[12] Carbon dioxide emissions from deforestation account for up to a fifth of annual global greenhouse gas emissions (Baumert *et al.*, 2005). Forest carbon sinks are vulnerable to wide range of risks from the

often referred to as ensuring permanence in the carbon sink.[13] In particular, we explore the optimal level of (upfront) investment under different liability regimes and when there is also asymmetric information on the agent's opportunity cost. After describing these contracts and the institutional setting, we first investigate alternative liability regimes for invalidated carbon certificates. In doing so, we relate these to the first-best result in which the buyer implements the project alone. We then compare the contract established in Section 3 with the case where the agent's opportunity cost is unobservable to the principal.

4.1 Background: contracting for forest carbon sinks

Under Kyoto, the predominant contractual arrangement is a simple purchase contract known as an 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; Jindal *et al.*, 2008; Weber and Darbellay, 2011). External capital funding is usually unavailable, which can be attributed to the relative lack of experience of many private sector lenders with investment risks in nascent carbon markets (Capoor and Ambrosi, 2008, 2009).[14] Upfront capital is, however, sometimes provided on a non-commercial basis, for example, by the World Bank Forest Carbon Partnership Facility (FCPF) or the United Nations REDD Programme (Wertz-Kanounnikoff and Angelsen, 2009). Larger upfront investments could potentially enable the seller to acquire additional territory for afforestation or reforestation, which, as discussed in Section 3, could help with scaling-up. But overall, the numbers and scale of sequestration schemes have been limited by a lack of upfront financing, alongside constraints on demand formalized under the Kyoto Protocol and the latter's stringent regulatory regime (UNEP, 2004).

As shown in Section 3, imperfect enforcement gives further disincentives to the provision of upfront investments. With carbon sequestration contracts, the upfront investment can also be a frontloaded cash transfer for the acquisition of production inputs, like land, seeds, or machinery. Opportunistic contract breach is then driven by changes in the seller's land-use opportunity cost. This, along with moral hazard in precaution, potentially results in a higher probability of carbon reversal. The latter could arise with respect to precautionary activities, which

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natural (e.g. pests and diseases, climate change) to the political and economic (e.g. weak property rights, exchange rate fluctuations, changing opportunity costs) (see Watson *et al.*, 2000).

[13] Ensuring the permanence of forest carbon sinks has mainly been investigated using risk management (see Bayon *et al.*, 2007, for a review), pricing, and accounting approaches (Dutschke, 2002; Kim *et al.*, 2008). While risk management in forestry carbon contracts has been considered both at the national and individual level (Eliasch, 2008), relatively little research has been undertaken on how individual contracts could be efficiently designed to ensure permanence (Dutschke and Angelsen, 2008).

[14] For the same reasons the insurance market for default risks on the carbon market is still underdeveloped (Kossoy and Ambrosi, 2010; Weber and Darbellay, 2011).

minimize the risk of forest fires, parasites, or illegal logging.[15] Consequently, any carbon dioxide sequestered is at constant risk of being returned through deforestation, whether by accident or intentional breach of contract. Hence, both constraints in our contract framework are likely to hold if the buyer has an interest in the permanence of the carbon sink.

Within the current international climate policy regime, the buyer has indeed a strong incentive to ensure permanence. The current practice is to issue 'temporary' credits for forestry projects, which must be renewed or replaced by permanent credits, either when the carbon sink ceases to exist or after their expiry. The responsibility 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). Hence, *de facto* liability for forest carbon losses under Kyoto is transferred to those purchasing credits from project developers. Yet, while sellers cannot be held liable for losses they may maintain control over the forest via ownership and use rights. Therefore, the current system of buyer liability ensures that the contract is prone both to moral hazard in precaution and opportunistic contract breach.

Note that the (implicit) system of buyer liability is a direct result of the Kyoto architecture in which only buyer countries face credible sanctions.[16] As this precludes the use of Kyoto-level sanctions in those cases where the carbon sink is reversed, incentives guaranteeing permanence have to be established at the level of the individual contract.[17] We hence assume in the following that the buyer's need to ensure enforcement-proofness and incentive compatibility within these contracts is driven by the system of buyer liability currently in place.

4.2 Contracts under different liability regimes

In this sub-section, we compare contract incentives under different liability regimes. Under buyer liability, we assume that the principal is interested in the permanence of the carbon sink. The optimal contract is hence subject to the

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[15] Regarding moral hazard, it could be argued that with a very low $\underline{\sigma}$, the amount of carbon sequestered is too small for the 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.

[16] The Kyoto compliance regime features sanctions such as punitive additional emissions cuts or exclusion from trading mechanisms. These obviously require emissions reductions commitments, which exist only for industrialized, i.e. Annex I countries (see UNFCCC, 2005, Decision 27). The principle of 'common but differentiated responsibilities' implies that the burden for climate change mitigation falls on these countries (Vanderheiden, 2008). Therefore, developing (i.e. non-Annex I) countries, being CDM host countries cannot be held liable within the Kyoto system.

[17] In principle, the Kyoto provisions attribute liability to the buyer country. It is, however, plausible that this country could subrogate against private sector buyers situated within its borders. Hence transferring liability to the primary private-sector buyer is possible while subrogating against the seller is subject to the same problems of imperfect enforcement that drive our results. See Ohndorf (2009) for a more extensive analysis on the interaction of liability and contractual incentives in this context.

enforcement-proofness constraints (2) and (3), and the incentive compatibility constraint for moral hazard (6). We compare the investment levels derived under the the status quo of buyer liability with two alternative regimes: seller liability and no liability. While the former is currently on the table as an option in a future, post-2012 climate agreement, the latter is being implemented in bilateral agreements among countries.

4.2.1 *Buyer liability* 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 the seller's outside option. For simplicity, we assume the following specifications for the remainder of this section:

$$q(\alpha) = \alpha^{1/2}, \tag{18}$$

$$z(\alpha) = d \cdot \alpha^{1/2}, \tag{19}$$

where we assume $d \leqslant 1$ to reflect that α is at least as productive in its intended use as in the seller's outside option. 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. The contracting environment depicted in Sections 2 and 3 can be directly applied to carbon sequestration contracts. Since the seller retains physical control over the forest, the contract is vulnerable to both opportunistic contract breach as well as moral hazard. For (18) and (19), the corresponding transfers within the contract determined by (13) to (15) are given by:

$$\alpha^{*}_{O} = \left(\frac{\underline{\sigma}}{d(1-\gamma\theta)(\pi t_l + (1-\pi)t_h)} \cdot \frac{C}{\Delta_\rho \Delta_\sigma} \right)^2, \tag{20}$$

$$\beta_l = \frac{t_l(1-\gamma\theta)d}{\underline{\sigma}}, \tag{21}$$

$$\beta_h = \frac{t_h(1-\gamma\theta)d}{\underline{\sigma}}. \tag{22}$$

Unsurprisingly, α^{*}_{O} decreases in the seller'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 cost is 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 $\left(\text{i.e.} \frac{C}{\Delta_\rho \Delta_\sigma}\right)$ is only a determinant of α but not 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 deter opportunistic contract breach. Both specifications of the backloaded transfer increase in the seller's incentive to breach the contract in order to counteract the corresponding decrease in upfront investment.[18]

4.2.2 *Seller liability* In the future, post-2012 climate agreement liability for carbon reversals from forests is unlikely to remain with buyers, i.e. those Annex I countries with GHG emissions targets that are currently participating in Kyoto's trading mechanisms (Palmer, 2011). Instead, there are a number of policy options being explored that could result in host countries such as Brazil and Indonesia taking on liability, including the possibility of such countries taking on emissions cuts of their own (Dutschke and Angelsen, 2008; Eliasch, 2008). Thus, liability for carbon reversals could be contracted in the form of sanctions and penalties for sellers. In this case the seller would have to replace certificates cancelled due to carbon reversal.[19] If we maintain our assumption of a sufficiently large replacement value v of a certificate the seller will never choose his outside option. Under these circumstances the buyer would simply optimize as if contract enforcement were complete. As there is no need for discriminating for differences in opportunity costs, we denote the backloaded transfer in this case simply as β. To compare explicit levels of α we specify the function $q(\alpha)$ as in (18). His objective function is then

$$EV_{SL} = (v - \beta)(\rho(1)\,\overline{\sigma} + (1 - \rho(1))\underline{\sigma})q(\alpha) - \alpha, \tag{23}$$

which is optimized subject to

$$\beta \cdot q(\alpha) - \frac{C}{\Delta_\sigma \Delta_\rho} \geq 0, \tag{24}$$

as the buyer would still want to incentivize due care. The buyer chooses β such that (24) holds with equality. Substitution of this β into (23) and an unconstrained optimization over α yields the optimal investment level for seller liability:

$$\alpha_{SL} = \left(\frac{1}{2} v(\rho\overline{\sigma} + (1 - \rho)\underline{\sigma})\right)^2. \tag{25}$$

A comparison of (25) with (20) yields that α_{SL} is larger than α_O^* as defined in (20) if:

$$v(\rho\overline{\sigma} + (1 - \rho)\underline{\sigma}) > \frac{2\underline{\sigma}}{d(1 - \gamma\theta)(\pi t_l + (1 - \pi)t_h)} \cdot \frac{C}{\Delta_\rho \Delta_\sigma}. \tag{26}$$

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[18] Even in the absence of moral hazard, the buyer's desire to secure permanence leads to a reduction in upfront investment and therefore in project size (see MacKenzie *et al.*, 2010).

[19] Within an international treaty, this liability would be attributed to the seller country. In the event of subnational activities such as projects being utilized in a post-2012 framework, it will not necessarily be identical to the entity implementing the project (see Palmer, 2011). 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.

Given specifications (18) and (19), this is the condition for which the Lagrange multipliers for the enforcement-proofness 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 with seller liability. Seller liability will always be preferred as the amount of carbon sequestered is unambiguously larger.

Interestingly, α_{SL} corresponds to the same investment level as if the buyer implemented the forestry project himself. To see this note that upfront investment would not be affected by opportunistic behaviour since the buyer can be conceived of as a single entity, or being in a highly integrated relationship. Hence, the objective function of the integrated relationship would be:

$$EV_{FB} = v \cdot (\rho\overline{\sigma} + (1-\rho)\underline{\sigma})q(\alpha) - \alpha - C. \tag{27}$$

Since 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 optimizes (27) without constraints. Hence, the investment level would again be α_{SL}. In the real world, however, an integrated contract relationship is rare for a number of reasons, including high search costs for buyers, fears over sovereignty and 'carbon colonialism', and the fact that the CDM rules insist on the participation of local people who in turn are supposed to benefit from implemented projects (Olsen and Fenhann, 2008; Lövbrand *et al.*, 2009). In a future climate arrangement that incorporates forest carbon sinks, the latter are likely to be retained in the form of so-called 'social safeguards' (see UNFCCC, 2010).

4.2.3 *No liability* Another interesting case that has been observed is one in which no liability for replacing invalidated offsets exists. Recent voluntary bilateral forest carbon contracts between Norway, and respectively, Brazil and Guyana, perhaps best illustrate this case.[20] 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 enforcement-proofness 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, which occurs with probability $(1-\pi)$. In this case, payment of contract damages is enforced with probability γ. The buyer's objective function for the case without liability is hence:

$$EV_{NL} = \pi(v-\beta)q(\alpha)(\rho(1)\overline{\sigma} + (1-\rho(1))\underline{\sigma}) - \alpha + (1-\pi)\gamma\theta t_h z(\alpha). \tag{28}$$

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[20] The contract between Norway and Guyana, for example, can be seen in the form of a Memorandum of Understanding at: http://www.forestry.gov.gy.

Note that we assume the timing of the contract to be still the same as laid down in Section 2, which implies that the buyer is still interested in incentivizing due care. 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 (28) and optimizing with respect to α. Note that this optimization 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 optimization yields:

$$\alpha_{NL} = \frac{1}{4}(d(1-\pi)\gamma\theta t_\mathrm{h} + \pi v(\rho\overline{\sigma} + (1-\rho)\underline{\sigma}))^2 = \left(\pi \cdot \sqrt{\alpha_{SL}} + (1-\pi)\frac{1}{2}\gamma\theta t_h d\right)^2. \tag{29}$$

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 (29) with (20) 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_{NL} 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 regime.

Interestingly, if t_h is large enough α_{NL} could in principle be larger than the first-best level determined by (25). 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 and yielded larger returns than sequestration, equation (27) would have to be altered accordingly. A subsequent optimization would then yield levels of upfront investments that are strictly larger than α_{NL}.

4.2.4 *Choosing among liability regimes* In light of our analysis, the current liability regime within Kyoto seems, at first sight, to be an unfortunate choice. Buyer liability for forestry offsets is likely to yield lower levels of investment in sequestration than a situation in which the seller is held accountable for replacing emissions credits lost through carbon reversal. From (20), this inefficiency is larger where host country contract enforcement is weaker. But this is not to say that the current liability regime for CDM forestry projects resulted from careless design. The Kyoto Protocol implements seller liability within the inter-country cap-and-trade system, which indicates that the negotiators were aware of the underlying incentive problems.[21] It is therefore likely that the implementation of buyer liability within the CDM emerged as a result of institutional restrictions. Indeed, establishing seller liability within this mechanism 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 Kyoto-level sanctions, which effectively precluded seller liability.

This left two choices for the Kyoto negotiators, either a system with no liability 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). Concerns about the high risks of carbon reversal in host countries meant that a system of no liability gave way to the sole remaining choice of buyer liability. While imperfect, 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 realizing the high-level opportunity cost remains relatively small.

Beyond Kyoto, a variety of different setups have been discussed to foster REDD activities. Potential financing schemes range from marketable credits to a non-offset fund (Isenberg and Potvin, 2010). Since all of these involve financial transfers, there are obvious implications for the attribution of liability and incentives for ensuring permanence. Within the outline of an agreement on REDD, adopted by the UNFCCC conference of the parties in Cancun, the responsibility for monitoring and enforcement is attributed to host countries (UNFCCC, 2010). While there is, as of yet, no final decision on the accountability of host countries, this may not be sufficient to incentivize a higher level of permanence in the absence of a global climate treaty that includes the participation of both developed and developing countries. Another Kyoto-type agreement with mandated emissions reductions may again result in a regime of buyer liability, particularly if developing countries are excluded from commitments to reduce emissions. A voluntary global arrangement such as a Global Refunding System outlined by Gersbach and Winkler (2011) could, potentially, provide the necessary incentives for developing country participation (Gersbach, 2008), and draw these countries into a regime of seller liability. If such a scheme is complemented by conditional side payments to foster

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[21] Within Kyoto emissions trading for Annex I-countries, potential shortfalls of Assigned Amount Units are to be replaced by the overselling country (UNFCCC, 2005, Decision 27).

abatement in developing countries then seller liability could induce a greater transfer of finance for REDD activities.[22]

4.3 On indexing contracted transfers

In Sections 2 and 3, we assumed that backloaded transfers are made contingent on the the agent's opportunity cost that is fully observable to the principal. For example, for already-generated CDM certificates the seller's opportunity cost is only driven by third-party offers, which explains why contracted prices are often pegged to the spot market price for such certificates (Capoor and Ambrosi, 2009). Yet, in application to forestry, opportunity costs in a given area are also 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 have been key factors driving deforestation (see, for example, Andersen *et al.*, 2002; Soares-Filho *et al.*, 2006). The policy implication of this is to index payments for REDD to agricultural prices (Benitez *et al.*, 2006; Dutschke and Angelsen, 2008). We investigate this possibility using our contracting framework.

In order to highlight the advantage of indexing, first assume that the seller's opportunity cost is unobservable to the buyer and hence, cannot be used for discriminatory transfers. As a consequence, there exists only one contracted per unit price β , and the buyer's contract design is altered as follows.

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

$$(\rho(1)\cdot\overline{\sigma}+(1-\rho(1))\cdot\underline{\sigma})\cdot\beta q(\alpha)-C\geq(\rho(0)\cdot\overline{\sigma}+(1-\rho(0))\cdot\underline{\sigma})\cdot\beta q(\alpha). \quad (30)$$

Furthermore, there exists only one relevant enforcement-proofness constraint, which is:

$$\beta\cdot\underline{\sigma}q(\alpha)-(1-\gamma\theta)t_h\cdot z(\alpha)\geq 0. \quad (31)$$

The buyer's objective function becomes:

$$EV_U=(v-\beta)\cdot(\rho(1)\cdot\overline{\sigma}+(1-\rho(1))\cdot\underline{\sigma})\cdot q(\alpha)-\alpha. \quad (32)$$

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

$$\max_{\alpha,\beta}\ (32),\ \text{subject to (31) and (30).}$$

We denote the Lagrange multiplier for the enforcement-proofness constraint λ_1', and λ_2' for the moral hazard incentive constraint. The solution for the

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[22] In this scheme, the contract would be signed between developed and developing countries with the latter held liable for contract breach. To induce participation from developing countries, Gersbach's (2008) 'no lose' assumption would need to hold: the amount retributed in case of contract breach cannot exceed previous contract transfers from the buyer to the seller and any transfers from the fund.

first multiplier is:

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

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

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

which is, given large v, again positive for $\underline{\sigma}$ low enough.

Solving (31) and (30) each holding with equality, the contracted transfers are given by:

$$\alpha_U^* = z^{-1}\left(\frac{C\underline{\sigma}}{(1-\gamma\theta)t_h \cdot \Delta_\rho\Delta_\sigma}\right), \tag{33}$$

$$\beta_U^* = \frac{C}{\Delta_\rho\Delta_\sigma q(\alpha_U^*)}. \tag{34}$$

A comparison of this contract with one defined by (13) to (15) reveals that coupling contracted per unit prices to the observed opportunity cost will always be (at least weakly) preferred by the buyer and the seller. To see this, note that the contract defined by (33) and (34) 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 incentivize the same level of precaution. At the time of contracting, the seller would be indifferent between both contracts. Furthermore, a comparison of (13) with (33) 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 backloaded payments are not made contingent on the seller's opportunity cost.

For those cases where changes in opportunity cost are unobservable to the buyer, this result simply indicates the cost arising from the information asymmetry. In a converse argument, the above comparison provides support for indexing contract transfers to agricultural prices. Given that the buyer's rent and the level of sequestration are always larger under indexing, the inclusion of such clauses is advisable where contract enforcement is highly imperfect.[23]

5. Conclusion

Opportunistic behaviour due to imperfect contract enforcement is a risk in many economic transactions. This is particularly problematic for transactions necessitating upfront investments, which could be considered as partially specific or customized to the transaction. Such transactions are often international in nature

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

and include outsourcing contracts, natural resource contracts, and environmental service contracts. These contracts need to be designed in a way that not only minimizes moral hazard in precaution, but also deters opportunistic contract breach under imperfect contract enforcement. In this paper, an enforcement-proof incentive contract is developed in which a principal 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 first determined the optimal contract that ensures both due care in precaution and delivery of the good. We showed that the agent'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 limit in the quantity of good up to a specific level, even if an infinite scale-up would be beneficial in a situation without opportunism. A more severe moral hazard problem, that is the more expensive it is to induce effort, results in a smaller distortion. This unexpected result is due to the fact that by increasing the upfront payment, the principal also increases the agent's payoff at the end of the contract.

One direct application is the optimal contract design that ensures delivery ('permanence') in forestry carbon offsets—something crucial to any future international climate agreement. 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 carbon sequestration will be reversed if a higher level of opportunity cost is realized. By contrast, under a system of seller liability, the carbon sink will persist and the upfront investment corresponds to the first best. Hence, seller liability is likely to be the most efficient system of all. While such a liability regime does not exist under the current international climate policy framework, it should be a feature of a post-2012 framework with a greater role for forest carbon sinks than at present. A global climate treaty that voluntarily induces emissions reductions could, potentially, enable a shift to seller liability.

Further investigation may involve explicit modelling of indexing through the dynamic extension of our contracting problem, which would enable an analysis of the optimal contract to manage volatile changes in the agent's opportunity cost over multiple periods.

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