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Incentive Contracts for Natura 2000 Implementation in Forest Areas

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Abstract The implementation of nature conservation policy is often based on contracts between public authorities and landowners. In this article, we model incentive contracts in forest areas in the presence of adverse selection and moral hazard when the conservation outcome is uncertain ex ante but observable ex post. The results show that agents who are likely to achieve a higher level of conservation should be offered a contract where transfers depend on the final outcome, with a bonus for a high ecological level of the forest. When conservation measures are correlated with forest management, we show that the contractual measures involve distorted transfers. We analyse the payment mechanisms used in France and Denmark in the context of the Natura 2000 policy. These mechanisms result in overcompensation and under-performance since they do not take the problem of moral hazard and natural variability into account.

Keywords Adverse selection · Conservation contracts · Forest · Incentives · Limited liability · Moral hazard · Natura 2000 · Uncertain outcome

JEL Classification D82 · Q23 · Q57

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1 Introduction

The European Union (EU) launched the Natura 2000 policy to preserve and restore specific natural habitat types and species. To achieve this goal, areas are designated Natura 2000 sites based on knowledge of their biodiversity and biogeography. The Natura 2000 sites cover both marine and land areas, including forests. Implementation of the Habitats Directive is often based on a contractual relationship between public authorities and landowners, which determines the conservation objectives, active measures and payment mechanisms of the agreement. Several EU countries are in the process of formulating and implementing these contracts. The first objective of our article is to provide theoretical justification for the contractual approach for Natura 2000 implementation in forest areas. The second objective is to compare and discuss the different payment mechanisms used in Natura 2000 contracts in relation to the results of our theoretical model, taking the French and Danish setup as examples.

Using contracts as an implementation mechanism offers a number of advantages. It is in general more acceptable to the landowners who become "producers of biodiversity', a public good. It is also more flexible than one-size-fits-all laws, as it allows for differentiation between habitats and owner types, thereby increasing production of biodiversity where benefits are the greatest and/or costs are minimized. However, the asymmetric distribution of information between the public authority (the 'principal') and the forest landowner (the 'agent') can lead to significant incentive problems, limiting the efficiency of such environmental schemes. First, forest owners are better informed about their ability or their opportunity costs of producing environmental outputs. Second, the forest owner's conservation actions (i.e., investment levels) are observable but not verifiable (i.e., the value of investments cannot be proved) and thus cannot be included in the contract. In the case of Natura 2000 contracts and in many other conservation schemes, the two informational problems (private information and hidden action) seem to be intertwined and have to be handled together. In our article, we model a contract for risk-neutral agents with limited liability that simultaneously deals with both adverse selection and moral hazard (i.e., mixed model), and where the principal can observe and verify the uncertain outcome of the contract after the nature status is attained.

The forest is a multiple-use resource where both economic and ecological goals can be achieved in the same forest area. Protection of some species necessitates strict conservation of the area, but production is often still possible: conservation measures and forest management interact, thus impeding a separate analysis of the conservation measures. Contracts should therefore be designed as multiple-use instruments, allowing the forest owner to continue to profitably manage his land. The conservation contract can have a positive or negative impact on forest management costs, thereby over- or undercompensating for the cost of fulfilling the contract. This can be viewed as a source of (dis)economies of scope.

Several studies deal with the design of incentives with information problems for nature conservation or for the protection of endangered species (Moyle 1998; Polasky and Doremus 1998; Smith and Shogren 2001, 2002; Crépin 2005; Hallwood 2007). Principal-agent models in the case of asymmetric information have also been developed in the context of agri-environmental policy (Bourgeon et al. 1995; Wu and Babcock 1995; Moxey et al. 1999; Ozanne et al. 2001; Fraser 2002, 2004; Gren 2004; Hart and Latacz-Lohmann 2005; among others). However, these studies generally involve either moral hazard *or* adverse selection separately. Analysing models that involve both moral hazard *and* adverse selection is more complicated, and articles developing such incentive-compatible contracts are rare and limited to agri-environmental policy (White 2002; Bontems and Thomas 2006; Ozanne and White 2007).[1] In our model, we consider that adverse selection is followed by moral hazard. In White (2002) and Ozanne and White (2007), even if the moral hazard problem arrives after the adverse selection problem, it differs from ours because induced by imperfect information about the agents' actual compliance to contractual measures. For Bontems and Thomas (2006), moral hazard comes from hidden action and takes place before the adverse selection problem, since effort (in fertilizer application) has an impact on soil productivity (private information of the farmer).

Guesnerie et al. (1989) show that the moral hazard problem does not lead to additional welfare loss compared to the pure adverse-selection case, since risk delegation is without cost when agents are risk-neutral. With risk-averse agents, Theilen (2003) finds that the principal strictly prefers to relax the moral hazard constraints even though this increases the risk premium.

Due to the variability and complexity of biological systems, the relationship between the conservation actions and the outcome is subject to uncertainty. With uncertain outcomes, agents may exert considerable efforts but still achieve poor results. In this case, it is not politically acceptable to severely penalise the agent. Laffont (1995) and then Hiriart and Martimort (2006) analyse mixed models of production that entail environmental hazards when the polluting agent has limited liability. In this case, solving the moral hazard problem is no longer without cost since the principal has to increase the rent to induce safety care.[2]

In our analysis, the contract is based on an outcome that is uncertain, known only after the contract is fulfilled. From an efficiency point of view, basing payments on performance is preferable to basing them only on costs or other observables. Bazzani et al. (2000) found considerable improvements in agri-environmental policies in Italy when switching from flat rate payments per hectare to flat rate payments per unit of environmental improvement. However, making payments dependent on environmental benefits and management is not without problems due to monitoring difficulties and the uncertain correlation between conservation actions and improvements in biodiversity. In our framework, the outcome is clearly observable, either by verifying the presence of a number of species or by using a biological indicator.

In our analysis framework (combination of adverse selection, moral hazard, limited liability, and uncertain ex ante and observable ex post outcome), some important results emerge. The distortions in transfer payment (with respect to the symmetric information case) are mainly due to the problem of moral hazard (i.e., the level of investment is not verifiable). In some cases, depending on the abilities of agents to achieve the higher ecological level of the forest, the problem of moral hazard forces the principal to give up a rent. Agents who are likely to achieve a higher level of conservation should be offered a contract where transfers depend on the final outcome, with a bonus for a high ecological level of the forest. Less efficient agents are reimbursed for the minimal investment, regardless of the ecological level of the forest attained.

The following section presents our theoretical principal-agent model applied to forestry. We then focus on the policy setup in France and Denmark and discuss the contractual setting and the payment mechanisms, before evaluating them in the light of our theoretical results. In France, lump-sum payments are used for standardised operations whereas others are based on estimates of operation costs and investments. The Danish Forest and Nature Agency has

[1] To our knowledge, there is only one study that has analysed conservation contracts in forests with both informational problems but with unlimited liability (see Huennemeyer 2001).

[2] See Laffont and Martimort (2002) for presentation of mixed models with limited liability.

designed payments that cover losses in land value in the form of a lump-sum payment. It is interesting to compare these two systems as the main difference between them is that the Danish one accounts for eventual impacts of conservation on forestry production. Moreover, the reference to the theoretical model gives valuable information on how existing programs can be improved (Crépin 2005), and in our case makes it possible to show the inefficiency of current payment mechanisms.

2 The Model

In this section, we model a theoretical conservation contract with an application to forest areas. We thus introduce the model and basic assumptions, and identify the first-best solutions (with symmetric information) concerning investments for biodiversity made by forest owners and payments granted by public authorities.

2.1 Basic Assumptions

Consider the contractual relationship between a public authority (the principal) and a forest owner (the agent) investing I to improve the conservation value of his forest, independently of his forest activity. Protection of some species necessitates strict conservation of the area, but production is often still possible: conservation measures and forest management interact. In order to simply our model, we exclude in a first step the forest activity of the forest owner. We'll introduce this aspect in the application of the Natura 2000 contracts to France and Denmark. We'll consider later a multiproduct framework where the cost-minimizing forest owner produces both wood and biodiversity.

The ecological level of the forest S is supposed to be observable and verifiable.[3] We refer to S^I as the initial state of the forest, which is supposed to be the same for all agents. The principal has to create incentives for all agents to participate since the legislation requires that all Natura 2000 sites be protected. Moreover, he also wants to give some agents the incentive to make a higher investment to increase overall biodiversity. These incentives raise the problem of lack of information for the principal to achieve the conservation objective in an efficient way: the agents do not have the same ability to manage their forest and investments for biodiversity are not verifiable.

The heterogeneity of agents is crucial. They manage their forests differently, and their conservation costs are also different. Hence, the ability or the opportunity costs of producing environmental outputs may vary greatly from one forest landowner to another. Within our framework, we consider that this heterogeneity has an effect on the probability of achieving a higher ecological level. This probability is private knowledge held by the agents. The principal only knows that a fraction of the agents ν has a higher probability $\overline{\alpha}$ of achieving a high ecological level, called the "high-prob agent", and a fraction $(1 - \nu)$ has a lower probability $\underline{\alpha}$, the "low-prob agent". The relationship between the principal and the agent is thus subject to the adverse selection problem. Adverse selection occurs because the principal's objective is not only to target the high-prob agents but also the low-prob ones, who cannot so easily achieve a higher ecological level. Indeed, it is more difficult to convince these latter

[3] There are specific habitats and (plant and wildlife) species that are concerned by a specific contractual measure. One way to verify the ecological level of the forest is to check for the presence of a number of species. When conservation of both individual species and habitats is difficult or costly to verify, then the objective defined by the contractual measure is judged to be a good indicator of this ecological level.

to participate in an environmental policy because it is more costly for them to produce the environmental output.

The investment (or the operation) undertaken by the agent is observable for both parties but non-verifiable (by a third party, such as a court of law); in other words, the value of the investment is not observable and cannot be proven. For instance, tree cutting, clearing and mowing can be easily observed by the principal. However, the agent can easily make an erroneous assessment of the quantity or extent of these operations. Hence, the level of invoiced costs does not necessarily reflect the true level of investment. Investment cannot therefore be included in a contract. Also, investment affects the probability of a given ecological level whatever the agent type: a higher investment increases the probability of a high ecological level. Without any loss of generality, we suppose that two levels of investment are possible. All agents have to spend a minimum of $\underline{I}$, so as to commit a minimum set of actions to maintain a minimum ecological level S^L. Furthermore, all forest owners are offered additional measures that cost $\overline{I}$, which are voluntary for both agents and the principal. These additional measures increase the probability of a higher ecological level S^H. It is also possible to achieve this level with the minimum measures, but the probability is lower.

As investment is non-contractible, this leads to the moral hazard problem since the agent can cheat on the level of investment. Moreover, since a low investment can lead to a high ecological level of the forest and thus imply a high payment, agents may have poor incentives to make high investments. Finally, conservation contracts can attract agents who need to undertake forest works that can enter into the category of reimbursable measures.

Therefore, the setup consists of two contracts: a basic contract and one with additional measures. Without a contract, no conservation measure will be undertaken and we consider that the ecological level of forest will tend to be spoiled. The determination of the final ecological level of the forest is a stochastic process with the following probabilities and outcomes:

$$\overline{I} \text{ leads to } \begin{cases} S^H & \text{with probabilities } \overline{\alpha}_1 \text{ and } \underline{\alpha}_1 \text{ according to the type} \\ S^L & \text{with probabilities } (1-\overline{\alpha}_1) \text{ and } \left(1-\underline{\alpha}_1\right) \end{cases}$$

$$\underline{I} \text{ leads to } \begin{cases} S^H & \text{with probabilities } \overline{\alpha}_0 \text{ and } \underline{\alpha}_0 \text{ according to the type} \\ S^L & \text{with probabilities } (1-\overline{\alpha}_0) \text{ and } \left(1-\underline{\alpha}_0\right) \end{cases}$$

where $\overline{\alpha}_i > \underline{\alpha}_i, \forall i = 0, 1$. We use index $i = 0, 1$ to describe the way to achieve a given ecological state with respect to the investment level : "0" for a low investment and "1" for a high one. We have $\overline{\alpha}_1 > \overline{\alpha}_0$ and $\underline{\alpha}_1 > \underline{\alpha}_0$.

In a mixed framework, these two informational problems (private information and hidden action) are considered together. Here, we suppose that the agents are informed about their probabilities before they choose the level of investment. In this case, it has been shown that the introduction of moral hazard exacerbates the adverse selection problem since the (risk-neutral but protected by limited liability) agents need incentives to first reveal themselves before the contract is signed and to then take the appropriate actions (Laffont and Martimort 2002). However, this result is different if moral hazard takes place before adverse selection: mixed models are characterised by fewer allocative distortions (with greater information rents) with respect to the case of pure adverse selection. In our framework, it is not possible to consider that the agent undertakes an investment that affects the distribution of his private information parameter.[4] This case [moral hazard before adverse selection] would have a sense if this private information relied on the ecological level of the forest. But we stated

[4] In our model, the problem of adverse selection is built on the uncertainty of achieving a given ecological level. Therefore, if we suppress uncertainty in outcome, our model results in a pure moral hazard model.

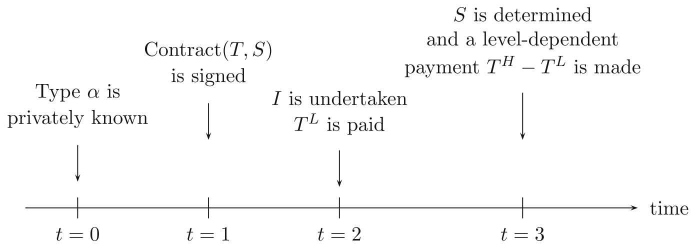

Fig. 1 Contract schedule

that the ecological level of forest was known by all parties. Hence, the ability of the forest owner to produce environmental output is exogenous.

The principal has to offer transfers to the agents in return for their forest investments so that participation and truth-telling are ensured. The principal can use the resulting ecological level of the forest, which is observable and verifiable, to screen the agents. A direct revelation mechanism may thus be a menu of two different contracts, one for each type of agent, which consists of two payments, T^L and T^H, depending on the level of investment, for the ecological level S observed post-contract. The contract schedule is illustrated in Fig. 1. The contractual relationship is a static analysis and thus let the dynamic aspects (repeated contracts) postponed.

We consider contracts between a public authority and a private forest owner. Non-industrial private forest owners are the most common, and forest activity is not the main source of income for them, but rather one investment in a diversified portfolio. Hence, contrary to farmers in the agriculture sector, the assumption of risk aversion is not necessarily well adapted to our application. All agents are therefore assumed to be risk-neutral.[5]

2.2 Optimal Contract with Symmetric Information

In the following model, the principal can perfectly distinguish the types of agents. Investments are observable and verifiable and can thus be included in the contract. Normalising the agent's reservation profit to zero, the participation constraints are such that contracts are accepted if they yield to each type a positive profit:

$$\overline{\alpha}_1\overline{T}^H + (1 - \overline{\alpha}_1)\,\overline{T}^L - \overline{I} \geq 0 \qquad (\overline{PC})$$

$$\underline{\alpha}_0\underline{T}^H + \left(1 - \underline{\alpha}_0\right)\underline{T}^L - \underline{I} \geq 0 \qquad (\underline{\text{PC}})$$

where the high-prob agent receives the transfer $\overline{T}^H$ for a high ecological level of the forest and $\overline{T}^L$ for a low ecological level of the forest. The low-prob agent receives the transfer $\underline{T}^H$ for a high ecological level of the forest and $\underline{T}^L$ for a low ecological level of the forest.

Let V be the social value of the ecological function of the forest. V is not known since it depends on a set of non observable variables (including natural shocks and societal

Footnote 4 continued
Another way to introduce adverse selection would be to consider that the (different) initial ecological state of the forest is hidden information of the owner.

5 Several studies assume risk neutrality for private forest owners in incentive problems (e.g., Polasky and Doremus 1998; Langpap 2006).

preferences) summarized by X, added to the known ecological level S. We assume that V is increasing with respect to S.[6] For the purpose of simplification, we write $V^H = V(S^H, X)$ and $V^L = V(S^L, X)$. Moreover, let $\lambda > 0$ denote the social cost of public funds. For the definition of the expected social value of conservation and later for the derivation of optimal separating contracts, we need the following Lemma:

Lemma 1 *Pooling contracts do no exist in equilibrium.*

Proof See Appendix A. □

We can state that the principal prefers that a high-prob agent undertakes a high investment, and that the low-prob agent makes a low investment.[7] Hence, the risk-neutral principal considers the following expected social value of conservation:

$$W = \nu\left[\overline{\alpha}_1\left(V^H - \lambda\overline{T}^H\right) + (1-\overline{\alpha}_1)\left(V^L - \lambda\overline{T}^L\right) - \overline{I}\right] + (1-\nu)\left[\underline{\alpha}_0\left(V^H - \lambda\underline{T}^H\right) + \left(1-\underline{\alpha}_0\right)\left(V^L - \lambda\underline{T}^L\right) - \underline{I}\right] \quad (1)$$

In the case of symmetric information, the problem of the principal is to maximize Eq. 1 subject to the participation constraints ($\overline{PC}$) and ($\underline{PC}$). The optimisation solution is quite standard.[8] The symmetric information transfer $\overline{T}^0$ paid by the principal to the high-prob agent is the same, regardless of the ecological level of the forest attained. The transfer $\underline{T}^0$ paid to the low-prob agent is also the same, regardless of the ecological level of the forest attained:

$$\overline{T}^0 = \overline{T}^H = \overline{T}^L \quad \text{and} \quad \underline{T}^0 = \underline{T}^H = \underline{T}^L \quad (2)$$

These payments cover the investment[9]:

$$\underline{T}^0 = \underline{I} \quad \text{and} \quad \overline{T}^0 = \overline{I} \quad (3)$$

Table 1 summarizes the notation.

[6] A way to estimate the social value of the ecological function of the forest V would be to carry out contingent valuation studies for all the Natura 2000 sites, which would be prohibitively costly. If V was perfectly known, a simple incentive scheme that makes payments conditional on ecological improvements would be the first-best. More specifically, the principal should sign "futures" contracts with landowners who can provide highest ratios of $[V(S_1) - V(S_0)]/payment$ at the end of the contract period, just like in a futures market, where S_1 and S_0 are the ecological levels before and after the contract period. Therefore, in this case, there would be no need to use the complicated contract scheme developed in this article.

[7] This result has important implications with asymmetric information since it imposes separating contracts between the types of agents.

[8] It is easy to verify that differentiating the Lagrangian of the principal's problem by $\overline{T}^H$ and $\overline{T}^L$ leads to the following results. The multiplier of the constraint ($\overline{PC}$)—the cost of rents—is positive and the same for the two derivatives. We obtain the same result when differentiating by $\underline{T}^H$ and $\underline{T}^L$. This implies that the transfer for the high-prob agent is the same, regardless of the ecological level of the forest attained. Idem for the low-prob agent. Moreover, this means that rents are costly. Hence the principal gives no rents to the agents and thus the two participation constraints are binding.

[9] If the assumption of risk neutrality is removed, that is, if T is replaced by $u(T)$ in the participation constraints ($\overline{PC}$) and ($\underline{PC}$), then the result is the same as with the risk-neutral assumption. The multipliers of the participation constraints now depend on $u'(T)$ but are still positive and equal, still implying the same transfer, regardless of the ecological level of the forest attained, but depending on the type of agent. Since the participation constraints are binding, we also obtain that the transfer covers the investment.

Table 1 Summary of notation

Low-prob agent	High-prob agent	Definition
S^I		Initial ecological state of the forest
S^L		Minimal ecological (final) state of the forest
S^H		High ecological (final) state of the forest
V^L		Social value of the ecological function of the forest with state S^L
V^H		Social value of the ecological function of the forest with state S^H
$\underline{I}$		Minimal investment
$\overline{I}$		High investment (with additional measures)
λ		Social cost of public funds
W		Expected social value of conservation
ν	$1-\nu$	Proportions of forest owners according to their type
$\underline{\alpha}_0$	$\overline{\alpha}_0$	Agents' probabilities to achieve S^H with $\underline{I}$
$\underline{\alpha}_1$	$\overline{\alpha}_1$	Agents' probabilities to achieve S^H with $\overline{I}$
$\underline{T}^L$	$\overline{T}^L$	Monetary transfer to the agent if S^L is attained
$\underline{T}^H$	$\overline{T}^H$	Monetary transfer to the agent if S^H is attained

3 The Optimal Contract with Adverse Selection and Moral Hazard

We now develop the optimal contracts in the presence of asymmetric information. The principal cannot determine the types of agent, and the actual investments cannot be verified after the contracts have been signed. Recall our assumption that the principal prefers a high-prob agent to undertake a high investment and a low-prob agent to make the low investment. This implicitly involves separation between the types of agents in the optimal contract. We first show that pooling contracts do not exist (in Appendix A) and then the existence of separating equilibrium (in Appendix C).

The agent's adverse selection incentive constraints are written as:

$$\overline{\alpha}_1\overline{T}^H + (1-\overline{\alpha}_1)\overline{T}^L - \overline{I} \geq \overline{\alpha}_0\underline{T}^H + (1-\overline{\alpha}_0)\underline{T}^L - \underline{I} \tag{4}$$

$$\underline{\alpha}_0\underline{T}^H + (1-\underline{\alpha}_0)\underline{T}^L - \underline{I} \geq \underline{\alpha}_1\overline{T}^H + (1-\underline{\alpha}_1)\overline{T}^L - \overline{I} \tag{5}$$

Constraints (4) and (5) ensure that each agent type prefers to accept the contract designed for his type rather than the one designed for the other type. Recalling that the principal wants the high-prob agent to undertake $\overline{I}$ and the low-prob agent $\underline{I}$, this also means that each agent must have no interest in undertaking the other's investment. We first consider the incentives for the low-prob agent. It can easily be argued that this agent should not be rewarded for a high ecological level of the forest: he should make the lowest possible investment $\underline{I}$ and should not be given any reward for a high ecological level since this would give the high-prob agent the incentive to pass himself off as the low-prob agent. Therefore, $\underline{T}^H \leq \underline{T}^L$. At the same time, when a low ecological level is achieved, the payment cannot be higher than the payment for the high ecological level, since this would give the high-prob agent the perverse incentive to actually ensure the low ecological level. Therefore, the transfer for the low-prob agent is the same, regardless of the ecological level of the forest attained: $\underline{T} = \underline{T}^H = \underline{T}^L$. Furthermore, the participation constraint ($\underline{\text{PC}}$) has to be binding. Therefore, the optimal transfer for the low-prob agent is:

$$\underline{T} = \underline{I} \tag{6}$$

Reporting results from Eq. 6 in Eqs. 4 and 5 allows us to rewrite the adverse selection incentive constraints as:

$$\overline{\alpha}_1 \overline{T}^H + (1 - \overline{\alpha}_1)\overline{T}^L - \overline{I} \geq 0 \tag{$\overline{AD}$}$$

$$\underline{\alpha}_1 \overline{T}^H + (1 - \underline{\alpha}_1)\overline{T}^L - \overline{I} \leq 0 \tag{$\underline{\text{AD}}$}$$

This means that the expected payment of the high-prob agent has to be larger than the investment $\overline{I}$, and that the expected payment of the low-prob agent passing himself off as the other agent also has to be smaller than $\overline{I}$. Note that the participation constraint ($\overline{PC}$) and the incentive constraint ($\overline{AD}$) for the high-prob agent are the same.

There is no moral hazard problem for the low-prob agent since this agent has no incentive to make a higher investment when the low investment is covered. However, the principal wants the high-prob agent to undertake the high investment level. His expected profit has to be greater than the one he would obtain with a low investment level (not desired for the high-prob agent by the principal). This is ensured by the following moral hazard incentive constraint:

$$\overline{\alpha}_1 \overline{T}^H + (1 - \overline{\alpha}_1)\,\overline{T}^L - \overline{I} \geq \overline{\alpha}_0 \overline{T}^H + (1 - \overline{\alpha}_0)\,\overline{T}^L - \underline{I} \tag{$\overline{MH}$}$$

Combinations of both problems also exist (leading to mixed constraints). Mixed constraints insure that each type prefers to accept the contract designed for his type rather than the one designed for the other type in which he would *not undertake* the desired investment *either*:

$$\overline{\alpha}_1 \overline{T}^H + (1 - \overline{\alpha}_1)\overline{T}^L - \overline{I} \geq \overline{\alpha}_1 \underline{T}^H + (1 - \overline{\alpha}_1)\underline{T}^L - \overline{I} \tag{7}$$

$$\underline{\alpha}_0 \underline{T}^H + (1 - \underline{\alpha}_0)\underline{T}^L - \underline{I} \geq \underline{\alpha}_0 \overline{T}^H + (1 - \underline{\alpha}_0)\overline{T}^L - \underline{I} \tag{8}$$

Since the optimal transfer for the low-prob agent is $\underline{T} = \underline{I}$, we can rewrite the mixed constraints (MX) as following:

$$\overline{\alpha}_1 \overline{T}^H + (1 - \overline{\alpha}_1)\overline{T}^L - \overline{I} \geq \underline{T} - \overline{I} \tag{$\overline{MX}$}$$

$$\underline{T} - \underline{I} \geq \underline{\alpha}_0 \overline{T}^H + (1 - \underline{\alpha}_0)\overline{T}^L - \underline{I} \tag{$\underline{\text{MX}}$}$$

Comparing Eq. $\overline{MX}$ with constraint ($\overline{AD}$) leads us to ignore the high-prob agent's mixed constraint since $\underline{T} - \overline{I} < 0$.

Finally, we impose limited liability constraints so that the agents do not have to pay for participation:

$$T^L \geq 0, \quad T^H \geq 0 \tag{9}$$

To sum up, in addition to the limited liability constraints and by rearranging the constraints, the principal's program is subject to the following four constraints:

$$\overline{\alpha}_1 \overline{T}^H + (1 - \overline{\alpha}_1)\overline{T}^L - \overline{I} \geq 0 \tag{$\overline{PC}$}$$

$$\underline{\alpha}_1 \overline{T}^H + (1 - \underline{\alpha}_1)\overline{T}^L - \overline{I} \leq 0 \tag{$\underline{\text{AD}}$}$$

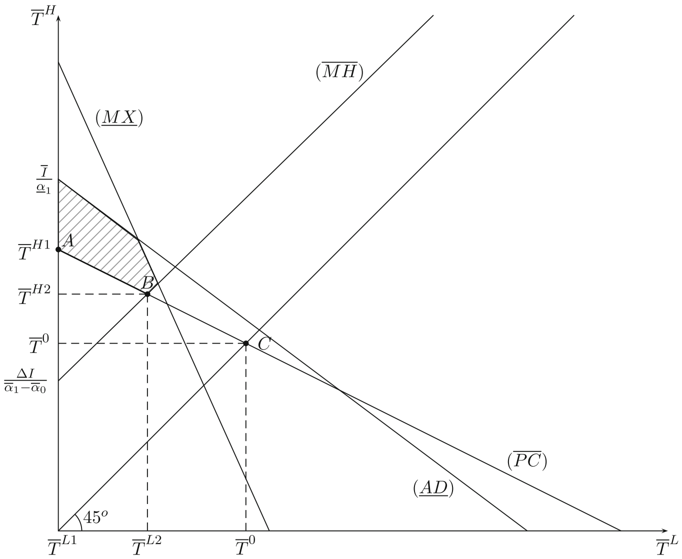

Fig. 2 Incentive feasible contracts in the case of a mixed model (1st case)

$$(\overline{\alpha}_1 - \overline{\alpha}_0)(\overline{T}^H - \overline{T}^L) - \Delta I \geq 0 \qquad (\overline{MH})$$

$$\underline{\alpha}_0\overline{T}^H + (1 - \underline{\alpha}_0)\overline{T}^L - \underline{I} \leq 0 \qquad (\underline{\text{MX}})$$

where $\Delta I = \overline{I} - \underline{I}$. This set of constraints defines the incentive feasible solutions.

In Fig. 2, we plot the constraints as a function of $\overline{T}^L$ and $\overline{T}^H$, and we obtain the set of incentive feasible solutions indicated by the shaded area.[10] We illustrate a first case where the moral hazard constraint $(\overline{MH})$ is not above the participation constraint $(\overline{PC})$. Note that the two constraints ($\underline{\text{AD}}$) and ($\underline{\text{MX}}$) are always overruled by $(\overline{MH})$ (see Appendix B). The optimal contract in the case of symmetric information for the high-prob agent is represented by C, even if this contract respects as well the adverse selection constraint. In an asymmetric information framework, the principal's objective is to minimise costs in view of the different participation and incentive constraints. Therefore, as seen on Fig. 2, the participation constraint $(\overline{PC})$ is always binding. Defining the indifference curve of the principal from Eq. 1 in which the result from Eq. 6 is reported, we can easily check that the slope of this indifference curve is the same as the slope of $(\overline{PC})$. The second-best contracts for the high-prob agent are thus represented by the segment between A and B according to the binding constraints. This simply means that compared to the symmetric-information case (C), the high-prob agent is given less payment for a low ecological level (less than his investment) but more if he manages to achieve the high ecological level, due to the problem of moral hazard. There is no contract more likely than another one: it is sufficient that the difference between $\overline{T}^L$ and

[10] We do not need to take $\underline{T}$ into account since it is constant. As explained above, because of the principal's preferences, the low-prob agent is incited to make the low investment and is exactly cost-reimbursed, regardless of the ecological level of the forest attained. Note also that Fig. 2 is only an example of what the set of incentive feasible contracts could look like.

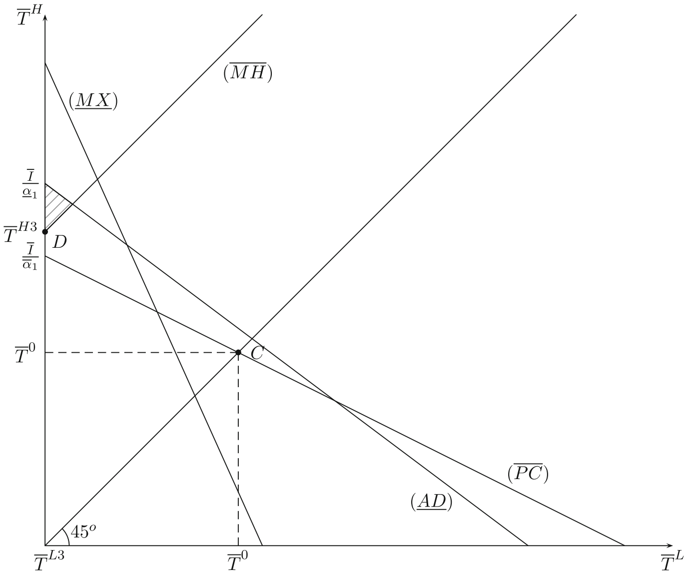

Fig. 3 Incentive feasible contracts in the case of a mixed model (2nd case)

$\overline{T}^H$ be at least equal to the ratio between the differential ΔI and the differential $(\overline{\alpha}_1 - \overline{\alpha}_0)$, as given by $(\overline{MH})$. In this first case, the expected profit remains zero.

A second case, illustrated by Fig. 3, occurs when $(\overline{PC})$ is decreased or $(\overline{MH})$ is increased. In this case, $(\overline{PC})$ is no longer binding and the optimal contract should only solve the moral hazard problem while respecting the limited liability constraints. When the moral hazard constraint $(\overline{MH})$ is above the participation constraint $(\overline{PC})$, then: $\frac{\Delta I}{\overline{\alpha}_1-\overline{\alpha}_0} > \frac{\overline{I}}{\overline{\alpha}_1}$ or equivalently $\frac{\Delta I}{\overline{I}} > \frac{\overline{\alpha}_1-\overline{\alpha}_0}{\overline{\alpha}_1}$. The shaded area is the new set of incentive feasible solutions, and D represents the optimal contract for the high-prob agent. A main reason for this result would be the low differential between $\overline{\alpha}_0$ and $\overline{\alpha}_1$, that is the low and high investments have close probabilities to achieve the higher ecological level. In this case, to avoid cheating from the high-prob agent, the principal has to clearly indicate to him not to undertake the low investment, otherwise no reimbursement will be made (but the agent is still protected by limited liability). In return, inducing the high ecological level requires the principal to compensate for this difference by giving up an informational rent. Hence, the agent has a strictly positive expected profit:[11] $E(\pi) = \frac{\overline{\alpha}_0\overline{I}-\overline{\alpha}_1\underline{I}}{\overline{\alpha}_1-\overline{\alpha}_0}$. Finally, the likelihood of the contract D relative to the contract A is directly related to the low differential between the probabilities to achieve the high ecological level of forest.

The menu of second-best contracts is thus defined by the following proposition:

Proposition 1 *In the mixed model, the menu of optimal separating contracts consists in:*

1. *For the low-prob agent, an optimal transfer of:*

$$\underline{T} = \underline{I} \tag{10}$$

[11] In the case where agents are supposed to be risk-averse but still maintaining that the principal is risk-neutral, the optimal contract will have to involve some insurance of the agent by the principal (Laffont and Rochet 1998; Bontems and Thomas 2006). In this case, a solution as given by Eq. 11 or Eq. 14 is no longer possible. Moreover, risk aversion implies that information rents are socially more costly and, therefore, have to be diminished by the principal.

2. *For the high-prob agent:*

   (a) *when both participation and limited liability constraints are binding (i.e., the agent carries all the risk), the optimal contract is to pay zero if a low ecological level occurs and a payment higher than the cost of investment if a high ecological level occurs (Contract A in Fig. 2):*

$$\overline{T}^{L1} = 0$$
$$\overline{T}^{H1} = \frac{\overline{I}}{\overline{\alpha}_1} \tag{11}$$

   (b) *If both participation and moral hazard constraints are binding (leading to risk sharing between the parties), the optimal contract covers part of the cost of investment in the low ecological level and gives the agent a bonus in the high ecological level (Contract B in Fig. 2):*

$$\overline{T}^{L2} = \overline{I} - \frac{\overline{\alpha}_1}{(\overline{\alpha}_1 - \overline{\alpha}_0)}\Delta I$$
$$\overline{T}^{H2} = \overline{I} + \frac{1 - \overline{\alpha}_1}{(\overline{\alpha}_1 - \overline{\alpha}_0)}\Delta I \tag{12}$$

   (c) *If only the participation constraint is binding, the optimal contract is on the segment* $]AB[$ *(Fig. 2):*

$$\overline{T}^{L} < \overline{T}^{L2}, \quad \overline{T}^{H} > \overline{T}^{H2} \tag{13}$$

   (d) *If only the moral hazard constraint is binding, the high-prob agent is paid zero if the low ecological level occurs, and more than in the 1st case (binding participation constraint) if the high ecological level occurs (contract D in Fig. 3):*

$$\overline{T}^{L3} = 0$$
$$\overline{T}^{H3} = \frac{\Delta I}{(\overline{\alpha}_1 - \overline{\alpha}_0)} \tag{14}$$

We show in Appendix C the conditions of existence of separating contracts.

4 Study of Natura 2000 Implementation in France and Denmark

4.1 Biodiversity Conservation and Forest Management

The Natura 2000 contracts are not strict conservation contracts where the forest owner needs to cease his forest management altogether. Therefore, it is essential to analyse participation in Natura 2000 schemes as an integrated forest management decision. Many of the investments or measures of the Natura 2000 contracts affect forest operations (e.g., removal of intruding species, natural regeneration or cessation of drainage). Some can have a positive effect on the economy of forest management, either by saving the cost of operations that would otherwise have been undertaken (e.g., some cases of natural regeneration) or by making otherwise economically unfeasible activities feasible (e.g., removal of intruding species), thereby increasing wood quality or production. Others have a negative impact on the economy of forest management, either by having a negative effect on productivity (e.g., stopping drainage) or by increasing operating costs (e.g., no fertilisers). The cost of investment I for producing biodiversity comes along with an extra fixed cost ($A(I) > 0$) or a fixed benefit ($A(I) < 0$) on wood production in addition to his variable costs. The multiproduct framework where the cost-minimizing forest owner produces both wood and biodiversity is more relevant in understanding the correlation between the Natura 2000 contracts and general forest management. The relationship between wood and biodiversity can be examined in terms of cost complementarities. Hence $A(I) < 0$ can be viewed as a source of economies of scope (i.e., the cost of producing two or more goods jointly is less than the sum of costs of producing each good separately).[12]

Considering that the contract has an impact on the forest activities modifies the optimal contract of the mixed model. It implies replacing I by $I + A(I)$ in the optimal solutions derived in the previous section. In the case of a positive correlation between conservation measures and forest management, the moral hazard problem is exacerbated as the gap between payments for high and low ecological levels is increased, and the participation and incentive compatible constraints are increased, which makes higher expected payments necessary. The reverse is true if the correlation is negative.

4.2 Implementation and Payment Mechanisms

Our analysis suggests that the implementation of the nature conservation scheme is reduced to the following menu of contracts:

- A basic contract: Agents are asked to invest $\underline{I}$ and are paid $\underline{T} = \underline{I} + A(\underline{I})$
- A contract with additional measures: Agents are asked to invest $\overline{I}$ and are given a prepayment equal to $\overline{T}^L < \overline{I} + A\left(\overline{I}\right)$ to ensure incentive compatibility. After termination of the contract, if S^H is achieved, agents are given a bonus equal to $\overline{T}^H - \overline{T}^L$.

This payment mechanism corresponds to the time line in Fig. 1. The first contract has a low investment, and the entire transfer $\underline{T}$ corresponding to the cost of investment is made in period 2, as there is no problem of moral hazard (see Prop. 1 1). The second contract involves a high investment, and the transfer is divided into two periods: before and after the ecological level is achieved. The first transfer $\overline{T}^L$ could be equal to zero (Prop. 1 2. (a)). However, unless it is only the moral hazard constraint that is binding (Prop. 1 2. (d)), it is not necessary to choose a zero payment since the risk can be shared between the principal and the agent (Prop. 1 2. (b)). In this case, since the participation constraint is binding, $\overline{T}^L$ is also positive. Once the ecological level is achieved (in period 3), a bonus can be given, depending on the ecological level. If an ecological level S^H is achieved, the agent receives $\overline{T}^H - \overline{T}^L$; otherwise he receives nothing. It may be preferable not to retain the entire transfer until the final ecological level has been achieved, as the time lapse between finalising the contract and achieving the outcome can be long. Therefore, an initial transfer is preferable, whenever possible, while maintaining the right incentives.

[12] Without loss of generality, consider a producer of (only) wood, requested to also produce biodiversity. He accepts to sign the conservation contract in the case where the cost of producing both wood and biodiversity (including $A(I)$) is less than the sum of the two separate and independent costs without interaction between the two goods (and so without $A(I)$). The likelihood of economies of scope is greater with $A(I) < 0$. We note that economies of scope may exist even in the case of $A(I) > 0$ because of other sources of cost complementarities between wood and biodiversity (the spreading of fixed costs over the two goods).

4.3 France

In France, only 359 contracts have been signed, including 64 forest contracts corresponding to 1.2 million euros (figures from 2006). Natura 2000 contracts are rare in forest areas because the signing of a Natura 2000 charter is less much constraining and the forest owner benefits from a monetary deduction. In the case of a charter, the management of a specific site only requires actions classified as non-compensated commitments (corresponding to the "good practices" identified in the site plan). No financial subsidies are expected contrary to contracts, but a land tax exemption is included. "Good practices" in the Natura 2000 charter do not necessitate investments. It is possible that they are not sufficient to reach the minimum ecological level required in a Natura 2000 contract. Due to this reason, we choose not to take them into account in this application.

Another reason explaining the lack of signed contracts could be that they ignore forest management costs correlated to conservation investments. If the monetary transfer does not cover these additional costs, then the forest owner will reject the contract. However, the compensated conservation actions could benefit the forest management in some cases and over-compensate the landowner. For instance, in the Limousin region, a contract was signed in which the forest owner is committed to opening passageways for bats. Modification and maintenance work is 100% financed over five years. However, at the same time, this work totally benefits the landowner since the trails can be used for the forest machines needed for felling and pruning.

A management plan is developed for each Natura 2000 site. Assessment of the actual ecological level of the site provides general guidance for the stakeholders involved in the site management. It defines management and conservation objectives together with their implementation, in terms of regulation and contractual measures, as well as financing. These objectives can be either maintaining or improving the biodiversity in the forest. Legal terms and conditions are proposed for future contracts, and monitoring and evaluation procedures are defined. The contracts signed between the government representative and a public or private landowner are voluntary. The Natura 2000 contract consists of a number of elements: a list of operations or commitments (eligible or not for financial compensation), financial conditions (amount, time and means of payment), and the documents necessary to control contractual commitments.[13]

For forested areas, 13 measures are listed in which the conditions of eligibility for specific operations/commitments are described.[14] These contractual measures include: creation or restoration of clearings, moors, forest ponds and riparian forest, suppression or limitation of undesirable species, specific directed (and natural) regeneration, preservation of senescent trees (i.e., beyond economic maturity, or even decaying). In order to satisfy contractual measures, different commitments or operations eligible for financing are defined: tree cutting, clearing, mowing, warping, planting, etc.

The type of payment depends on the contractual measure: either a regionally regulated amount for standardised measures and measure K, or estimated operation costs and investments, with a maximum amount per hectare. The first type of payment is built on the principle

[13] The government representative monitors the compliance with the commitments that were set out in the contract. In case of non-compliance, subsidies are totally or partially cut.

[14] See Annex V of the circular of 24th December 2004. The term of the contract is five years (renewable) for all measures except for one concerning senescent wood—the so-called "measure K"—for which the term is 30 years. In the case where some contracts concern production, the output must be left in situ (revenues from measures covered by Natura 2000 contracts are not permitted). The financial and technical conditions are established in each region.

of a lump-sum payment based on a legal scale. This system makes it possible to rapidly determine the level of transfer and, at the same time, facilitates the financial forecasts made by the government agencies. In other cases where the principle of a lump-sum payment cannot be applied—typically, for the majority of the operations because of their complexity—the government representative has to approve the estimates. They both lead to the same payment in our model:

$$\underline{T}^F = \underline{I} \quad \text{and} \quad \overline{T}^F = \overline{I} \tag{15}$$

The payment mechanism is independent of outcomes and does not take private information into account. It does not take related forest management into account either. Therefore, there will be a difference between the actual cost of implementing the contract and the transfer, even if agents are truthful and do not hide their actions. Furthermore, in the real world, if we assume asymmetric information, then the agents have incentives to choose the high-investment contract over the low-investment contract and then make the low investment. Indeed, as discussed in the setup of our theoretical model, it is clear that investment cannot be included in the contract: even if the operation (e.g., tree cutting, clearing) could be observed by the principal, its value can be easily overestimated by the agent without the principal being able to verify it because of the uncertainty about the quantity or the extent of the operation. The agent's profits are:

$$\overline{\pi}^F = \overline{\alpha}_0\overline{T}^H + (1-\overline{\alpha}_0)\,\overline{T}^L - \underline{I} - A\left(\underline{I}\right)$$
$$\underline{\pi}^F = \underline{\alpha}_0\overline{T}^H + \left(1-\underline{\alpha}_0\right)\overline{T}^L - \underline{I} - A\left(\underline{I}\right)$$

Hence, the profits are identical, regardless of the type, and equal to: $\pi^F = \Delta I - A\left(\underline{I}\right)$.

The agents participate only if $\Delta I \geq A(\underline{I})$; otherwise they reject the contract. In the latter case, the social value of the Natura 2000 scheme is $W^F = 0$. If they participate, all agents are overcompensated by $\Delta I - A(\underline{I})$. We have calculated the loss in social value from this payment mechanism when the agents are accepting the contract (see Appendix D). One can show that the loss in social value is affected in three ways. First, the expected benefits decrease as the probability of the high ecological level decreases. Second, the tax distortion increases due to the information rent of both agent types. Third, the direct cost for the high-prob agents decreases since they no longer make the high investment. The benefit loss is: $-\nu\left[(\overline{\alpha}_1 - \overline{\alpha}_0)\left(V^H - V^L\right)\right]$. The loss due to overcompensation of the low-prob agent is $-(1-\nu)\left[\lambda\left(\Delta I + A\left(\underline{I}\right)\right)\right]$, and the loss due to the high-prob agent is $-\nu\left[\overline{I}\lambda - \lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1 - \overline{\alpha}_0}(\Delta I + A(\overline{I}))\right]$. The gain from the decreased cost of the high-prob agent is $\nu[\Delta I + \Delta A(I)]$. Hence, the French payment mechanism leads to an overcompensation of agents and a loss in social benefits of the scheme. Moreover, the agents may not participate at all because the principal ignores the correlated cost in forest management.

4.4 Denmark

In Denmark, the procedure for achieving an agreement on Natura 2000 sites is as follows. The initial state of the forest type and its conservation status concerning protected species are first described. A forest plan is then prepared, determining the conservation objectives and the actions necessary to obtain or conserve the desired status of the area. The public authorities negotiate a voluntary agreement with the forest owner based on the forest plan. The contract is permanent for all current and future owners and users. It can be renegotiated if the changes comply with the forest plan and if both parties agree. If it is not possible to achieve a reasonable agreement, forest owners are obligated to accept a set of requirements and restrictions to secure the basic forest plan.

The contract describes the measures and payment. The basic requirement of the Natura 2000 agreements is to maintain the forest at a specific level of nature conservation in the future. Implementation is based on a set of restrictions related to forest management rather than to specific active conservation measures. In addition to this, the two parties can agree on additional restrictions for the purpose of increasing general biodiversity in Danish forests. These additional measures are always voluntary and should lead to improvements that are beyond the goals of the forest plan. A non-exhaustive list of restrictions that can be implemented as basic or additional measures rewarded by a payment includes: natural forest regeneration (not planting), prohibition of "bad" practices (e.g., pesticides, fertilisers, soil preparation, drainage), absolute conservation (no forest management).

Whether these restrictions in forest management result in additional cost to the forest owner depends on his or her previous management of the area. Economic loss that can be proved by the owner to stem from the Natura 2000 regulation is compensated for as net present value. The compensation is in principle a lump-sum payment calculated from the decrease in the market value of the forest. The net-present-value approach solves a number of problems. First, it takes into account the fact that the Natura 2000 contracts are part of general forest management by taking both direct costs and opportunity costs into account, thereby covering a larger proportion of the costs. Second, it takes into account the fact that the conservation costs are continuous rather than a one-time investment, since the forest plan's restrictions are permanent. However, this type of payment mechanism does not address the problem of moral hazard. The individual forest plan specifies the conservation goals of the agreement, but since there is no possible bonus, the forest owner has the incentive to make the lowest possible investment to achieve the goals and then claim that he could not fulfill the goals due to biological variation.

The net-present-value-approach is equivalent to compensating the investment after making up for the correlation with forest management:

$$\underline{T}^D = \underline{I} + A\left(\underline{I}\right) \quad \text{and} \quad \overline{T}^D = \overline{I} + A\left(\overline{I}\right) \tag{16}$$

None of the agents are given any incentive to make the high investment. Instead, they will claim to be the high-probability agent and make the low investment, thereby decreasing the probability of achieving a high ecological level. As in the French case, the agent's profits are the same, regardless of the type: $\pi^D = \overline{\pi}^D = \underline{\pi}^D$. However, the level of profits is different from the French case: $\pi^D = \Delta I + \Delta A(I)$.

As before, social value is affected in three ways, and the calculation is given in the Appendix D. The benefit loss is equal to: $-\nu\left[(\overline{\alpha}_1 - \overline{\alpha}_0)\left(V^H - V^L\right)\right]$. The loss due to overcompensation of the low-prob agent is $-(1-\nu)\left[\lambda\left(\Delta I + A\left(\underline{I}\right)\right)\right]$, and the loss due to the high-prob agent is $-\nu\left[\lambda\left(\overline{I} + A\left(\overline{I}\right)\right) - \lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1 - \overline{\alpha}_0}\left(\Delta I + A\left(\overline{I}\right)\right)\right]$. The gain from the decreased cost of the high-prob agent is $\nu\left[\Delta I + \Delta A(I)\right]$.

Whether the loss in social value and the overcompensation is bigger or smaller for the Danish payment mechanism compared to the French depends on two things: the correlation with forest management and the participation of the agents in the French system. The French system leads to less overcompensation if the investment increases costs ($A(I) > 0$), even though it does so by ignoring the related cost of forest management, unless $\Delta I < A\left(\underline{I}\right)$. In this case there is no participation at all. On the other hand, if the investment actually decreases forest management costs, the Danish mechanism is more efficient. Nevertheless, they have one thing in common: none of the payment mechanisms addresses either the adverse selection or the moral hazard problem, thereby leading to lower social value than necessary.

5 Concluding Comments

This article is motivated by the ongoing implementation of the Natura 2000 policy in the EU. We wanted to analyse the way contracts were drawn up to provide nature conservation in forest areas. Our objective was twofold. First, optimal contract design was developed in a mixed model where adverse selection takes place before moral hazard. We used a two-type model where investments are not contractible and influence the probability of biodiversity improvement. The forest landowners also differ in the probability that their forests achieve a high ecological level; this probability is the private information of the landowners. Moreover, the impact of the contract on forest management was introduced to take the multi-functionality of forests (i.e., production aspects together with conservation goals) into account. Second, we discussed the application of Natura 2000 in France and Denmark with special emphasis on their payment mechanisms.

The main results characterising the optimal incentive contracts are:

(1) the low-probability agent should be offered a low-investment contract with a payment that is independent of the final ecological level of the forest;
(2) the high-probability agent should be offered a contract where transfers depend on the final ecological level of the forest, thereby sharing risk with the principal. Because investment is not verifiable, a level-dependent payment is necessary to ensure compliance with the nature conservation goals. This is done by introducing a bonus when a high ecological level is attained;
(3) for this contract, the moral hazard constraint always overrules the other constraints; and
(4) the high-probability agent (who undertakes high investment) is overcompensated in some cases.

Moreover, by including the effect of these contracts on forest management, we find that it either increases or decreases the transfer, depending on whether the correlation is negative or positive. It does not change the overall structure of the model, but neglecting related forest management costs has a strong implication in terms of participation and efficiency.

These results were used to analyse the specific payment mechanisms in France and Denmark. We showed that in both cases, neither the adverse selection nor the moral hazard problem is solved. This leads to a loss in benefits and overcompensation of agents. The French mechanism only covers implementation costs, whereas the Danish mechanism also takes related forest management costs into account. This means that the French mechanisms may not fulfill the participation constraint and explains why few forest contracts have been signed in France until now.

One of the main policy implications that can be deduced from our analysis is the importance of linking the Natura 2000 contracts to the observed outcomes (for instance, by counting some of the threatened species protected on a specific site) rather than to the cost of measures. It is an efficient incentive mechanism to ensure optimal behaviour in forests where it is difficult to verify the conservation investments of the forest owners. It is particularly evident as the Natura 2000 setup ensures that a vast amount of information is gathered both before and after the implementation of the contracts. This means that the biodiversity goals can be included in the contracts without considerable extra transaction costs, since most of the necessary information already exists.

Further research is needed to explore some possible extensions of this model. Some significant parameters have not been included in the model, such as the temporal aspects and term of contract in particular (no limit in Denmark, five years in France). With respect to the latter, a one-shot payment could be revised to include conditional payment, spread out over time. Moreover, the problem of heterogeneity (considered only by way of different types of landowners in our article) is also linked to different initial ecological levels of forest areas. This issue could be included in a more complex model by taking a form of spatial differentiation by forest habitats and/or species into account.

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Appendix

A Proof of Lemma 1: Non Existence of Pooling Equilibria

Consider that all agents are asked to invest $\overline{I}$. We want to show that only one contract—the pooling contract—which is accepted by both agent types, does not exist.

Let $q_1 = \nu\overline{\alpha}_1 + (1-\nu)\underline{\alpha}_1$ be the probability to achieve the high ecological level when the principal does not know the agent type. The expected social value of conservation for the principal can thus be written:

$$W_1 = q_1(V^H - \lambda T^H) + (1-q_1)(V^L - \lambda T^L) - \overline{I}.$$

The indifference curve of the principal when $W_1 = 0$ is:

$$T^H = \frac{q_1 V^H + (1-q_1)V^L - \overline{I}}{q_1\lambda} - \frac{(1-q_1)}{q_1}T^L.$$

In Fig. 4, we also draw the indifference curves of agents, derived from their participation constraints (PC). The indifference curve of a high-prob agent (denoted $\overline{PC}$) for a utility level $\overline{K}_1$ is:

$$T^H = \frac{\overline{K}_1 + \overline{I}}{\overline{\alpha}_1} - \frac{(1-\overline{\alpha}_1)}{\overline{\alpha}_1}T^L.$$

For the low-prob agent, the indifference curve ($\underline{PC} = \underline{K}_1$) is:

$$T^H = \frac{\underline{K}_1 + \overline{I}}{\underline{\alpha}_1} - \frac{(1-\underline{\alpha}_1)}{\underline{\alpha}_1}T^L.$$

Since $\overline{\alpha}_1 > \underline{\alpha}_1$, the indifference curves of the low-prob agent have a greater negative slope than those of the high-prob agent. This implies that the indifference curves verify the single-crossing property.

We define a pooling contract P as a contract anywhere on the indifference curve $W_1 = 0$ and where the indifference curves of the low-prob and high-prob agents pass through P. If the principal offers a contract C_1, it will be preferred to the pooling contract P by low-prob agents but not by high-prob agents.

Moreover, let $\underline{W}$ be the expected social value when only low-prob agents accept to contract: $\underline{W} = \underline{\alpha}_1(V^H - \lambda T^H) + (1-\underline{\alpha}_1)(V^L - \lambda T^L) - \overline{I}$. The indifference curve $\underline{W} = 0$ has a greater (negative) slope than the indifference curve $W_1 = 0$. It is easy to check that this latter

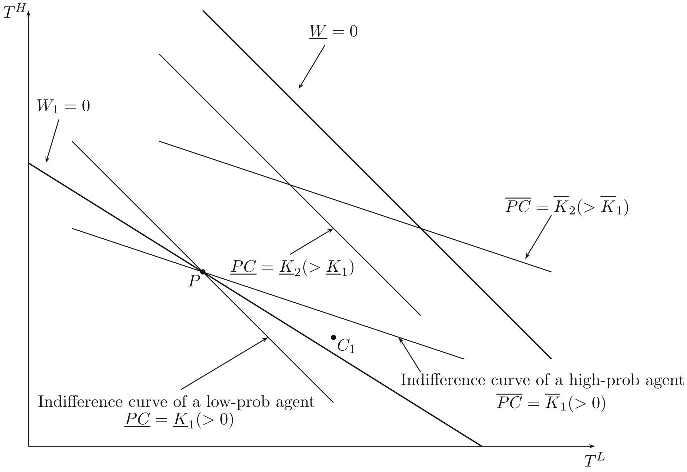

Fig. 4 No pooling equilibria

indifference curve is below the former one. Hence, when only low-prob agents accept the contract C_1, this contract is profitable to the principal (because C_1 is below the indifference curve of the principal $\underline{W} = 0$). Therefore, the pooling contract P is not a Nash equilibrium, and these arguments hold for any pooling contract.

A similar demonstration could be done when all agents are required to invest $\underline{I}$.

B The Moral Hazard Constraint of the High-prob Agent

To see that the constraints for the low-prob agent ($\underline{\text{AD}}$) and ($\underline{\text{MX}}$) are always overruled by the moral hazard constraint ($\overline{MH}$), we must look at the optimal contract when ($\overline{MH}$) is not binding.

- If ($\underline{\text{AD}}$) is binding, the optimal contract is the pure adverse selection solution, where the principal takes the entire risk and where the difference between payments according to the final ecological level of the forest is only marginal.[15] This solution cannot solve the moral hazard problem.
- If ($\underline{\text{MX}}$) is binding, we have a new solution. The optimal contract for the high-prob agent is:

$$\left\{ \left(\overline{T}^L = \frac{\overline{\alpha}_1 \underline{I} - \underline{\alpha}_0 \overline{I}}{\overline{\alpha}_1 - \underline{\alpha}_0} \right), \left(\overline{T}^H = \frac{(1 - \underline{\alpha}_0)\overline{I} - (1 - \overline{\alpha}_1)\underline{I}}{\overline{\alpha}_1 - \underline{\alpha}_0} \right) \right\}.$$

  This solution involves some risk-sharing, $\overline{T}^H > \overline{T}^L$, but not enough to ensure the right investment under hidden action.

Therefore, the moral hazard constraint always overrules the constraints of the low-prob agent.

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15 The derivation of the pure adverse selection problem and of the pure moral hazard problem is available from the authors upon request.

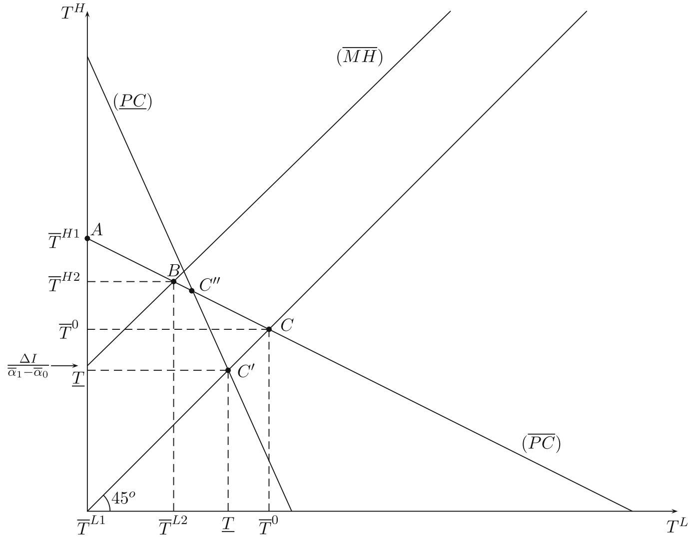

Fig. 5 Existence of a separating equilibrium

C Conditions for Separating Contracts

Figure 5 illustrates the existence of a separating equilibrium. Since low-prob agents must not be rewarded for a high ecological level, contract C' is offered to low-prob agents so that transfers are the same whatever the outcome and that their participation constraint is binding. The binding participation constraint of the low-prob agents and the binding adverse selection constraint of the high-prob agents (that is also their participation constraint) imply that the high-prob agents are not tempted to take C'. But as C'' is the intersection between the participation constraints of each agent type, high-prob agents will only be interested in contracts located on the segment $[AC'']$. Therefore, depending on the binding constraint, both contracts A and B are candidate to be a part of the separating equilibrium with contract C'.

However, contract B might not be an equilibrium. This the case when B is to the right of C''. In particular, the moral hazard constraint $(\overline{MH})$ could move to the south-east of the diagram for two reasons (see Fig. 5): (i) a lower differential between low and high investments ΔI, or (ii) a higher differential between the probabilities of achieving a high ecological state linked to the investment level for the high-prob agents $(\overline{\alpha}_1 - \overline{\alpha}_0)$. In this case, B is preferred to C' by low-prob agents and the separating pair (B, C') is not an equilibrium anymore.

D Difference in Social Value of Conservation

The French payment mechanism results in the following social value of conservation:

$$W^F = \nu \left[\overline{\alpha}_0 V^H + (1 - \overline{\alpha}_0)\, V^L\right] + (1 - \nu)\left[\underline{\alpha}_0 V^H + \left(1 - \underline{\alpha}_0\right) V^L\right] - \lambda \overline{I} - \underline{I} - A(\underline{I})$$

Comparing this with the social value of the mixed model including forest management, we obtain:

$$W^F - W^{MX} = \nu \left[\overline{\alpha}_0 V^H + (1 - \overline{\alpha}_0)\, V^L\right]$$

$$
\begin{aligned}
&+(1-\nu)\left[\underline{\alpha}_0 V^H+\left(1-\underline{\alpha}_0\right)V^L\right]-\lambda\overline{I}-\underline{I}-A\left(\underline{I}\right)\\
&-\nu\left[\overline{\alpha}_1 V^H+(1-\overline{\alpha}_1)V^L-\lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1-\overline{\alpha}_0}(\Delta I+A(\overline{I}))-\overline{I}-A(\overline{I}))\right]\\
&-(1-\nu)\left[\underline{\alpha}_0 V^H+\left(1-\underline{\alpha}_0\right)V^L-\left(\underline{I}+A\left(\underline{I}\right)\right)(1+\lambda)\right]\\
=&-\nu\left[(\overline{\alpha}_1-\overline{\alpha}_0)\left(V^H-V^L\right)\right]-\nu\left[\lambda\overline{I}-\lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1-\overline{\alpha}_0}\left(\Delta I+A\left(\overline{I}\right)\right)\right]\\
&+\nu\left[\Delta I+\Delta A(I)\right]-(1-\nu)\lambda\left(\Delta I+A\left(\underline{I}\right)\right)
\end{aligned}
$$

We know that W^{MX} is the maximum social value under the constraints of the mixed model when forest management is taken into account. Therefore, there has to be a loss in social value. The benefit loss is $-\nu\left[(\overline{\alpha}_1-\overline{\alpha}_0)\left(V^H-V^L\right)\right]$, the loss due to overcompensation of the low-prob agent is $-(1-\nu)\left[\lambda\left(\Delta I+A\left(\underline{I}\right)\right)\right]$ and to the high-prob agent $-\nu\left[\lambda\overline{I}-\lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1-\overline{\alpha}_0}\left(\Delta I+A\left(\overline{I}\right)\right)\right]$. The gain from the decreased cost of the high-prob agent is $\nu\left[\Delta I+\Delta A(I)\right]$.

The Danish payment mechanism gives a social value of:

$$
\begin{aligned}
W^D=&\ \nu\left[\overline{\alpha}_0\left(V^H-\lambda\overline{T^H}\right)+(1-\overline{\alpha}_0)\left(V^L-\lambda\overline{T^L}\right)-\underline{I}-A\left(\underline{I}\right))\right]\\
&+(1-\nu)\left[\underline{\alpha}_0\left(V^H-\lambda\overline{T^H}\right)+\left(1-\underline{\alpha}_0\right)\left(V^L-\lambda\overline{T^L}\right)-\underline{I}-A\left(\underline{I}\right)\right]\\
=&\ \nu\left[\overline{\alpha}_0 V^H+(1-\overline{\alpha}_0)V^L\right]+(1-\nu)\left[\underline{\alpha}_0 V^H+\left(1-\underline{\alpha}_0\right)V^L\right]\\
&-\lambda\left(\overline{I}+A\left(\overline{I}\right)\right)-\underline{I}-A\left(\underline{I}\right)
\end{aligned}
$$

The loss in social value compared to the mixed model is:

$$
\begin{aligned}
W^D-W^{MX}=&\ \nu\left[\overline{\alpha}_0 V^H+(1-\overline{\alpha}_0)V^L\right]+(1-\nu)\left[\underline{\alpha}_0 V^H+\left(1-\underline{\alpha}_0\right)V^L\right]\\
&-\lambda\left(\overline{I}+A\left(\overline{I}\right)\right)-\underline{I}-A\left(\underline{I}\right)\\
&-\nu\left[\overline{\alpha}_1 V^H+(1-\overline{\alpha}_1)V^L-\lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1-\overline{\alpha}_0}\left(\Delta I+A\left(\overline{I}\right)\right)-\overline{I}-A\left(\overline{I}\right))\right]\\
&-(1-\nu)\left[\underline{\alpha}_0 V^H+\left(1-\underline{\alpha}_0\right)V^L-\left(\underline{I}+A\left(\underline{I}\right)\right)(1+\lambda)\right]\\
=&-\nu\left[(\overline{\alpha}_1-\overline{\alpha}_0)\left(V^H-V^L\right)\right]-(1-\nu)\lambda\left(\Delta I+\Delta A(I)\right)\\
&-\nu\left[\lambda\left(\overline{I}+A\left(\overline{I}\right)\right)-\lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1-\overline{\alpha}_0}\left(\Delta I+A\left(\overline{I}\right)\right)\right]+\nu\left[\Delta I+\Delta A(I)\right]
\end{aligned}
$$

The benefit loss is $-\nu\left[(\overline{\alpha}_1-\overline{\alpha}_0)\left(V^H-V^L\right)\right]$, the loss due to overcompensation of the low-prob agent is $-(1-\nu)\left[\lambda\left(\Delta I+A\left(\underline{I}\right)\right)\right]$, and to the high-prob agent is $-\nu\left[\lambda\left(\overline{I}+A\left(\overline{I}\right)\right)-\lambda\frac{\overline{\alpha}_1}{\overline{\alpha}_1-\overline{\alpha}_0}\left(\Delta I+A\left(\overline{I}\right)\right)\right]$. The gain from the decreased cost of the high-prob agent is $\nu\left[\Delta I+\Delta A(I)\right]$.

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