Optimal Rotation Periods: An Application of Contract Theory to Forest Regulation

by

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Abstract: In this paper we construct a general principal-agent model to discuss voluntary subsidies to a forest owner to increase the rotation period in a situation with asymmetric information about the owner´s cost type. It is shown that for the forest owner with low cost the voluntary subsidy shall be based on differences in the objective functions between the principal and the agent. However, for an owner with high costs the subsidy shall also include an incentive cost to secure correct revelation of the owner´s cost type. The general model is used to study various forest owner objectives such as maximization of the value of timber, maximization of the social welfare and maximization of a mix between the timber value and the social welfare. With welfare maximization there is no difference in the objective functions between the regulator and the forest owner so no contract is necessary. We also investigate the implications of regulator uncertainty about the forest owner payoff. Both when the regulator perceives a wrong objective function for the forest owner and when regulator is uncertain about the objective function of the owner, uncertainty may imply a lower welfare compared to a situation with full certainty about the forest owners goal.

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1. Introduction

Amenity values (biodiversity, recreational and carbon sequestration values) are often found on privately owned forest areas and capturing these values requires design of policies that influence the decision-making of forest owner´s (see e.g. Hanley et al, 2012). To affect these decisions, payment for eco-system services (PES) has recently been suggested as an important regulatory instrument. PES can be designed to correct the forest owner´s incentive in a way that social optimal value of a regulatory variable is secured (see Engel et al, 2008, Naeem et al, 2015, Polasky et al, 2014 and Wunder, 2005).

Since Hartman (1976) it has been recognized that the amenity values arising from a standing forest may influence the optimal rotation period. Thus, design of PES scheme may require contracts that provide the forest owner with correct incentives to choose a rotation period that generate an optimal mix between the timber profit and the amenity values. Furthermore, the payment to/from the forest owner specified in the contract influence the size of a public budget and a financial burden of raising public funding´s arise. Therefore, an optimal design of PES must also take the effect on public funds into account.

Optimal design of PES must also take heterogeneity of forest owners with respect to the costs of producing eco-system services and the objectives into account. Petucco et al (2015) argue that a significant share of the forest owners in France has other objectives than maximizing the profit from timber with amenity values as an example. It is most likely that forest owners who include amenity values in the objective function will select another rotation period than an owner who solely maximizes the timber profit. In addition, a forest authority (regulator) often has imperfect information about both the costs of producing eco-system service and the forest owner objectives and this represents another important issue influencing the design of PES. The principal-agent approach have been suggested as an appropriate method to use when discussing PES since it takes both heterogeneity of forest owners and imperfect information into account (see e.g. Laffont and Tirole, 1993).[4]

[4] Principal-agent models are useful to discuss PES under agent heterogeneity and different forest owner objectives because optimal contract design is discussed. However, Wilman and Mahendrarajah (2002) study the optimal aggregated level of eco-system services by using optimal control theory under different forest owner objectives. Differences in forest owner objectives have also been investigated by Stenger and Normandia (2003) who use a production function approach.

In this paper we construct a principal-agent model for forestry with a regulator and an owner and to capture heterogeneity among the owners we consider two types of agents with different cost functions. There is asymmetric information about the cost type of the owner and consistent with classical forest economics the rotation period is control and contract variable. An optimal voluntary contract between the regulator and the forest owner is studied and this contract specifies the value of a subsidy to the owner. The regulator is interested in maximizing a weighted a sum of the payoff to the forest owner and the amenity value to other users of a forest. Furthermore, the effect on the public budget of the voluntary subsidy payment is taken into account. For the forest owner we begin with a very general objective and then various combinations of timber value maximization and welfare maximization is studied. Under these different objectives we analyze conditions under which a voluntary subsidy can be offered to a forest owner to increase the rotation period. We show that the optimal voluntary subsidy shall be based on differences in the objective functions between the forest owner and the regulator. Furthermore, an incentive cost shall be imposed on the forest owner with high costs to secure correct revelation of private information. We also investigate regulator uncertainty about the forest owner objectives. Specifically, we consider cases where the regulator has a wrong perception of the owner objective and where there is asymmetric information about the objective function of the owner. Under both assumptions we show that regulator uncertainty may imply that a voluntary subsidy provided to a welfare maximizing (pro-social behavior) forest owner may, in fact, increase the inefficiency.

In practical forest policy there is an increased application of contracts entered with the purpose of involving the forest owner´s in the provision of public goods like biodiversity conservation and carbon storage. One example is Nature 2000 contracts entered with the purpose of increasing biodiversity conservation in Europe (see e.g. Anthon et al, 2010). Other examples is the Danish voluntary subsidies to various biodiversity conservation measures (see Johannsen et al, 2013)[5] and forest owner´s voluntary adherence to management actions that have positive effects on ecosystem services in France. In this paper we will also evaluate these practical forest contracts by using economic theory. Specifically, we identify the properties of optimal forest subsidies.

From a policy perspective two assumptions behind the theoretical analysis in this paper may be criticized. First, the rotation period is used as contract variable. An alternative is to let the payment

[5] Examples of these biodiversity conservation measures are subsidies to take forest stands out of management, subsidies to the introduction of old management practices, subsidies to conversion from coniferous to broadleaf species and subsidies to other near nature management practice.

in the contract depend on an amenity value variable (e.g. the level of biodiversity and carbon sequestration) or, if these variables are difficult to measure, regulatory variables such as setting aside forest area for natural decay (see Jacobsen et al, 2013).[6] However, empirical evidence by Boman et al (2010) and Nghien (2014) show that the rotation period is an important variable affecting the size of amenity values.[7]This fact provides a justification for using the rotation period as contract variable.

Second, we study a long-term contract lasting for a whole rotation period and this assumption may also be criticized. For regulator a selection between a long-term contract and several repeated, short-term contracts must be made. In relation to long-term contracts Horne (2006) argues that that the proportion of agents that refuse a contract is high. However, repeated short-term contracts imply that strategic behavior by forest owner´s may occur due to the dynamic nature of the interaction and to avoid dynamic issues we investigate a long-term contract in this paper. A related issue is whether the payment in the contract shall be permanent in the sense that it shall be based on indefinite rotations as in the Faustman model. However, a permanent subsidy is probably not political feasible so a contract lasting for only one rotation seems to be a realistically option. As a final issue with the voluntary subsidy investigated in this paper the regulator announced two possible contracts at the beginning of the rotation that a forest owner can choose between and pays the subsidy at the end of the rotation period. Here an alternative is to pay the forest owner the subsidy at the beginning of the rotation period and then require that the forest owner commits himself to the policy specified in the contract.[8] However, with the latter requires the behavior by the forest owner is mandatory and from a practical perspective it is better to use voluntary subsidies.

Four strands of existent literature are relevant for the present paper. First, a few papers apply a principal-agent approach to discuss amenity values for a forest represented by Mason and Plantinga (2013) and Anthon et al (2010). Mason and Plantinga (2013) investigate carbon sequestration in trees and asymmetric information about forest owners´ opportunity cost of land is considered. The optimal voluntary subsidy includes both differences in the opportunity costs of land between the

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[6] Another alternative is to let the contracts payment depend upon the share of a forest with trees over a certain age and this will provide an incentive to have older trees in a forest. However, with an initial unequal distribution of year classes in a forest an adjustment period is necessary before this contract generate correct incentives making this policy less useful.

[7] As examples inclusion of biodiversity and carbon sequestration values will increase the rotation period while water protection may favor shorter rotation periods.

[8] Wilman and Mahendrarajah (2002) discuss the timing of the payment in the contracts including payment when a rotation period has been ended and payments before a rotation has period been started.

forest owners and the regulator and an information rent to the most efficient types. Anthon et al (2010) consider the Natura 2000 policy to conserve species in forest areas and, among other things, the regulator lack information about investments in species conservation. The optimal voluntary subsidy is based on differences in the investments levels in species conservation and an information rent is provided to the most efficient forest owners. In this paper we make four contributions to Mason and Plantinga (2013) and Anthon et al (2010). First, we study amenity values in general and not only carbon sequestration values or species conservation values. Second, contrary to both Mason and Plantinga (2013) and Anthon et al (2010) the regulator takes the timber profit into account in the objective function in this paper. Third, the voluntary subsidy in this paper depends on the rotation period and not the opportunity cost of land or the investment in species conservation. Finally, we also analyze a situation where a forest owner maximize a welfare function instead of only the timber profit as in Mason and Plantinga (2013) and Anthon et al (2010).

Second, a number of papers have constructed dynamic principal-agent models under asymmetric information including Green and Laffont (1979) and Baron and Myerson (1982). Since management of a forest typically involves indefinite rotations (the Faustman case) a dynamic approach seems to be relevant for our paper. One paper conducting a dynamic principal-agent analysis of forest rotation periods is Tatouchoup (2015) who consider asymmetric information about a cost parameter as our analysis. Tatouchoup (2015) investigate the properties of an optimal voluntary subsidy but both the forest owner and the regulator maximize the profit from timber production. However, for our purpose two problems arise with dynamic principal-agent models. First, the results in the dynamic principal-agent models are very sensitive to the basic assumptions including issues like separating equilibria,[9] pooling equilibria,[10] open-loop behavior[11] and feed-back behaviour.[12] Second, very simple objective functions for both the principal and the agent are necessary because of the complicated nature of the dynamic models. However, there are two goals with the present paper: a. to obtain results for the optimal voluntary subsidy that are not sensitive to the assumptions, b. allow for complicated objective functions for both the regulator and the forest owner including amenity values. Thus, it is useful to restrict attention to a static principal-agent approach in this paper and for this reason we only consider one rotation (a single crop case).

[9] In separating equilibria the principals´ and the agents´ do not act as one individual (see e.g. Rothschild and Stiglitz, 1976).
[10] In polling equilibria either the principal or the agent joint together (see e.g. Rothschild and Stiglitz, 1976)
[11] With an open-loop assumption the regulator does not update information about an uncertain variable or function (see e.g. Kreps, 1990).
[12] Feed-back behaviour imply that the principal update information by using a Bayesian rule (see e.g. Kreps, 1990).

Third, a principal-agent literature on extrinsic and intrinsic motivations exists represented by Benabou and Tirole (2003) and Banerjee and Shogren (2012). Extrinsic motivations is an individual´s response to external factors such as economic incentives with standard contract theory as an example while intrinsic motivations is an individual´s internal desire to perform a task. Now monetary rewards (extrinsic motivations) may weaken an individual´s intrinsic motivation to preform pro-social behaviour and this effect is labelled crowding-out. In this paper we reach a similar result as Benabou and Tirole (2003) and Banerjee and Shogren (2012). Specifically, we show that both when the regulator have wrong information about a forest owner´s objective function and when there is asymmetric information about the forest owners objective function, voluntary subsidies to welfare maximizing forest owners (pro-social behaviour) may increase the inefficiencies. However, we model pro-social behavior as a desire to maximize welfare while a parameter in an agent´s profit function captures pro-social behavior in Benabou and Tirole (2003) and Banerjee and Shogren (2012).

Last, a strand of literature has used a principal-agent approach on fisheries[13] and since fisheries are a renewable resource like forest this literature is also important for the present paper. Of particular interest is Jensen and Vestergaard (2002a) who also assume asymmetric information about an exogenous cost parameter and find an optimal subsidy based on the size of an externality. However, there are four important differences between Jensen and Vestergaard (2002a) and the present paper. First, the externality in Jensen and Vestergaard (2002a) arise because of a restriction that is not included while the externality in our model is due to differences in the objective functions. Second, in this paper the rotation period is used as control variable while Jensen and Vestergaard (2002a) use fishing effort (an index for input use). Third, Jensen and Vestergaard (2002a) find an optimal subsidy in a long-run steady-state equilibrium while we consider a voluntary subsidy coving a long time period (one rotation). Finally, as in traditional resource economics the growth of a forest depend on time while the growth is a function of the fish stock size in fisheries.

The rest of the paper is organized as follows. In section 2 we construct a general principal-agent model for a forest and this model is used to discuss different forest owner objectives in section 3. Section 4 investigates regulator uncertainty about the forest owner objective and the paper is concluded in section 5.

2. A general model

[13] See e.g. Jensen and Vestergaard (2002a), Jensen and Vestergaard (2002b) and Aanesen and Armstrong (2013)

2.a. The forest owner

We consider a representative forest owner who is interested in maximizing his own discounted net payoff from managing a forest. However, a number of amenity values for other users arise and a regulator includes these values in a welfare function. Due to differences in objectives of the forest owner and the regulator an externality arise making regulation necessary and in this paper we investigate the conditions under which a voluntary subsidy to increase the rotation period (a contract scheme) can be used as regulatory instrument.

It is assumed that the forest owner can have costs of either type 1 and 2.[14] For the regulator the cost type of the owner is unknown while the owner knows the true costs. T_1 is the rotation period selected by cost type 1 and while the rotation period chosen by cost type 2 is T_2. We let the rotation periods be the control and contract variables and this choice is consistent with traditional forest economics (see Amacher et al, 2009).[15] It is assumed that T_1 and T_2 are perfectly observable to both the forest owner and the regulator.

For the forest owner the discounted gross benefit is labelled $P(T_i)$ for i = 1,2. We assume that $P'(T_i) > 0$ for $T_i < \underline{T}$ while $P'(T_i) < 0$ for $T_i > \underline{T}$ where $\underline{T}$ is the rotation period at which the gross benefit starts to decline. Furthermore, we assume that $P''(T_i) < 0$ for all T_i. It is assumed that the gross benefit function is perfectly observable to both the forest owner and the regulator. Note that, contrary to traditional forest economics, we have not included a discount factor explicitly in $P(T_i)$ because alternative forest owner objectives is discussed in section 3.

We introduce heterogeneity by assuming that the forest owner has either high or low costs. The discounted cost function of type 1 is labelled $C_1(T_1)$ while the discounted costs for type 2 is $C_2(T_2)$. We assume constant marginal costs[16] so that $C_1(T_1)= c_1T_1$ and $C_2(T_2)= c_2T_2$.[17] where c_i is the

[14] In reality a continuum of forest owner (agents) exists and in the principal-agent literature this situation has been extensively studied (see Laffont and Tirole, 1993). However, it is a well-known fact that the results when using two types of agents generalize to a continuum number of agents (see Jensen and Vestergaard, 2002b)

[15] However, for many forest areas additional control values exists with land use and biodiversity conservation measures as examples.

[16] A justification for the assumption about constant marginal costs is three counteracting effects influence the derivatives of a cost function. First, the costs per cubic meter will decrease with the age due to the size of the trees. Second, the growth in volume in cubic meters will increase with the age because $P''(T_i) < 0$. Last, the cost of harvesting trees will decrease with the age because of the age of the trees. To capture these three effects an assumption about constant marginal costs seems reasonable. However, the results in the paper generalize to increasing marginal costs and decreasing marginal costs provided the second-order condition for a maximum is fulfilled.

discounted value of the constant marginal costs. Now to capture the cost difference between the two types we assume that $c_1 < c_2$. Thus, the discounted marginal costs are higher for type 2 than for type 1. Furthermore, it is assumed that the regulator cannot observe exogenous constant marginal costs while the owner knows the true cost parameter leading to an adverse selection problem (see e.g. Hanley et al, 1997).

The regulator offers the forest owner a long-term voluntary subsidy (contract) lasting for one rotation period and this contract cannot be re-negotiated.[18] The conditions in the contract is specified at an initial time period (t = 0) and is based on the length of the rotation period. For type 1 the discounted value of the subsidy is $S_1(T_1)$ while $S_2(T_2)$ is the discounted value of the subsidy for type 2. Note that due to differences in the cost functions the subsidy functions must also differ between the types of forest owners´. Note that since we investigate a subsidy we have that $S_i(T_i) > 0$. As alternative way of expressing this is that if a positive marginal payment ($S_i´(T_i) > 0$) is identical to a marginal subsidy. In traditional forest economics it is common to distinguish between a single-crop case (only one rotation) and an on-going forest (infinite rotations often labelled the Faustman case).[19] In this paper we only consider one rotation due to the fact that a long-term contract is offered. Thus, since the conditions in the contract are specified for one rotation period we can restrict attention to the single crop case in this paper.

Now the representative forest owner is assumed to maximize the discounted payoff defined as the discounted gross benefit minus the discounted costs plus the discounted subsidy payment. Provided the voluntary subsidy is accepted by the forest owner [20] we get the following maximization problem if the owner is of type 1:

$$Max[P(T_1) - c_1 T_1 + S_1(T_1)] \tag{1}$$

With T_1 as control variable we get the following first-order condition:

$$P´(T_1) - c_1 + S_1´(T_1) = 0 \tag{2}$$

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[17] With increasing marginal costs we get that $C_1(T_1) < C_2(T_2)$ for $T_1 = T_2$ and now single-crossing property imply that $C_1´(T_1) < C_2´(T_2)$ for $T_1 = T_2$. Note that with constant marginal costs we do not need to impose single-crossing property because the marginal costs are independent of T_1 and T_2.
[18] A long-term voluntary subsidy makes it possible to use a static model and, thereby, we avoid the restrictive assumptions in dynamic principal-agent models (see the introduction).
[19] See e.g. Neher (1990).
[20] In principal-agent theory the contract is designed such that the agent will enter this due to the participation restrictions (see e.g. Sappington, 1991).

According to (2) the forest owner sets the marginal discounted payoff equal to zero. The marginal discounted payoff consist of the marginal gross benefit ($P'(T_1)$), the marginal discounted costs (c_1) and the discounted marginal voluntary subsidy payment ($S_1'(T_1)$).

Provided a type 2 forest owner also enters the contract, we get the following maximization problem:

$$Max[P(T_2) - c_2 T_2 + S_2(T_2)] \tag{3}$$

With T_2 as control variables we get the following first-order condition:

$$P'(T_2) - c_2 + S_2'(T_2) = 0 \tag{4}$$

Thus, the forest owner also sets the marginal discounted payoff equal to zero if he is type 2 and by comparing (2) and (4) we see that $T_1 > T_2$ because $c_1 < c_2$.

2.b. The regulator

As mentioned above the regulator does not know the cost type of the owner and, therefore, a probability is assigned to the owner being of type 1 (π_1) and type 2 (π_2). Furthermore, apart from the forest owner, other users also obtain benefits from a forest and we label this benefit amenity values. The amenity values is assumed to arise in every time period from the initial time period (t = 0) to the time where the forest is harvested ($t = T$).[21] Labelling $W_{iT_i}(T_i)$ the amenity value at time t the total discounted payoff to other users of a forest is $\int_{t=0}^{T_1} e^{-rt} W_{it}(t)dt$ and we assume that the marginal amenity value is positive but decreasing ($W_{iT_i}'(T_i) > 0$ and $W_{iT_i}''(T_i) < 0$). We include a discount factor explicitly when defining the amenity values because alternative specification of $W_{it}(t)$ is not considered below. Remark that $W_{it}(t)$ captures an externality that arise since the forest owner only includes his own payoff in the objective function while the regulator also includes the amenity value in a welfare function. Due to this externality we consider a voluntary subsidy to forest owners to increase the rotation period as a regulatory mechanism in this paper.

However, the regulator also includes the discounted payoff to the forest owner in the welfare function but when taking this payoff into account the regulator disregard the subsidy payments

[21] See e.g. Hartman (1976).

($S_i(T_i)$) because these are considered as pure transfers.[22] Thus, to capture the forest owner´s payoff only $P(T_i)-c_iT_i$ in included in the welfare function and weight, μ, is attached to the amenity value hile λ is a weight imposed on the payoff to the forest owner.[23] We assume that $\mu, \lambda < 1$ implying that both the forest owner payoff and the amenity value is not attached full weight in the welfare function. Finally, the regulator takes a double-dividend arising when providing subsidies into account.[24] A double-dividend capture that the subsidy payment provided when correcting an externality, as in our model, must be followed by an increase in other distortionary taxes (see e.g. Goulder, 1995). Labelling $\varepsilon < 1$ the marginal cost of collecting the public revenue (the marginal cost of public funds)[25] we therefore include $\varepsilon S_i(T_i)$ in the regulator´s welfare function.

We now get the following expected welfare function for the regulator:

$$\begin{aligned} &Max[\pi_1(\mu\int_{t=0}^{T_1} e^{-t}W_{1t}(t)dt + \lambda(P(T_1)-c_1T_1) - \varepsilon S_1(T_1)) + \\ &\pi_2(\mu\int_{t=0}^{T_1} e^{-t}W_{2t}(t)dt + \lambda(P(T_2)-c_2T_2) - \varepsilon S_2(T_2))] \end{aligned} \tag{5}$$

However, when maximizing (5) we confront the regulator with two sets of restriction. First, we include participation restrictions implying that the regulator wants the owner to accept the contract irrespectively of the cost type. Since a long-term contract is entered we, therefore, require that the discounted payoff from entering the contract is larger than or equal to the discounted payoff of not entering the contract. The payoff of not entering the contract is identical to the payoff the forest owner without regulation (the subsidy) and this payoff is unaffected by the decisions on the size of the rotation periods when entering the contract. Thus, we may use an exogenous reservation payoff in the participation restrictions but this payoff will differ between the forest owner´s type due to differences in the cost functions. Therefore, by letting $\underline{U}_1$ denote the reservation payoff for type 1 and $\underline{U}_2$ the reservation payoff for type 2, the participation restrictions become:[26]

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[22] Treating the subsidy payments as pure transfers is in line with standard welfare economics (see e.g. Boadway and Bruce, 1984).

[23] μ and λ can be interpreted as equity weights in line with Sen and Foster (1997).

[24] It is common to take a double-dividend into account in principal-agent models (see e.g. Holmstrom and Milgrom (1991).

[25] See e.g. Stiglitz and Dasgupta (1971).

[26] The participation restrictions are formulated by using the objective functions of the forest owner. An alternative is to use the forest owner´s first-order conditions (reaction functions) as in e.g. Laffont and Martimort (2001). However,

$$P(T_1) - c_1 T_1 + S_1(T_1) \geq \underline{U}_1 \tag{6}$$

$$P(T_2) - c_2 T_2 + S_2(T_2) \geq \underline{U}_2 \tag{7}$$

From (6) and (7) we see why tax is not considered in this paper. If we impose a tax on the forest owner, the agent will not enter the contract because the payoff is reduced compared to not entering the contract. Thus, a condition for our policy suggestion to work is that $S_2'(T_2) > 0$. From (6) and (7) we can also discuss why voluntary subsidies is enough to reach an optimum According to (6) and (7) a rational forest owner will enter the contract and, therefore, mandatory regulation is not needed.

Second, a set of self-selection restrictions is imposed.[27] These restrictions imply that the regulator wants the forest owner to reveal/report/select the true type and this implies that the regulator want to solve the problem with asymmetric information about the cost function. Thus, for both types we get the following restrictions:[28]

$$P(T_1) - c_1 T_1 + S_1(T_1) \geq P(T_2) - c_1 T_2 + S_2(T_2) \tag{8}$$

$$P(T_2) - c_2 T_2 + S_2(T_2) \geq P(T_1) - c_2 T_1 + S_1(T_1) \tag{9}$$

(8) and (9) imply that provided the forest owner pretends to be of one cost type, he shall also choose the rotation period for this type. Note, also, that (8) and (9) take into account that the owner can hide the cost type for the regulator since an agent of, for example, type 1 pretending to be of type 2 use $c_1 T_2$ on the right hand side of (8).

In appendix it is now shown that the participation restriction for type 2 and the self-selection restriction for type 1 are binding. This implies that:

$$S_2(T_2) = \underline{U}_2 - (P(T_2) - c_2 T_2) \tag{10}$$

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using (6) and (7) provide a more intuitive interpretation of the components of the marginal subsidy as shown in Varian (1992) and Jensen and Vestergaard (2002a).

[27] Many authors, such as Laffont and Tirole (1993), label (8) and (9) incentive-compabability restrictions but using the concept of self-selection restrictions allow for a more straightforward interpretation of the contract (see below).

[28] An alternative is to formulate the self-selection restrictions as a marginal true telling condition derived from the agent´s objective function by using the revelation principle (see e.g. Maskin and Tirole, 1990). However, formulating the self-selection restrictions as a requirement to the total payoffs makes the interpretation of the subsidy payment more straightforward (see below).

$$S_1(T_1) = -(P(T_1) - c_1T_1) + \underline{U}_2 - (c_1 - c_2)T_2 \quad (11)$$

From (10) it is clear that type 2 receives exactly the discounted payoff that makes him enter the contract. However, from section 2.a we have that $c_1 < c_2$ and given this (11) imply that $S_1(T_1) > P(T_1) - c_1T_1 - \underline{U}_2$. Thus, type 1 receives a discounted payoff above the reservation payoff and the size of this payoff is $(c_1 - c_2)T_2$. In the principal-agent literature $(c_1 - c_2)T_2$ is labelled an information rent[29] which is distributed to type 1 to provide him with an incentive to reveal the true cost type. Given asymmetric information about the cost function it is natural that the information rent is based on the cost difference between the two types.

Now (10) and (11) can be substituted into (5) to obtain:

$$\begin{aligned} &Max[\pi_1((\mu \int_{t=0}^{T_1} e^{-t} W_{1t}(t)dt + \lambda(P(T_1) - c_1T_1) - \varepsilon(-(P(T_1) - c_1T_1) + \\ &\underline{U}_2 - (c_1 - c_2)T_2)) + \pi_2((\mu \int_{t=0}^{T_1} e^{-t} W_{2t}(t)dt + \lambda(P(T_2) - c_2T_2) - \\ &\varepsilon(-(P(T_2) - c_2T_2) + \underline{U}_2))] \end{aligned} \quad (12)$$

By using T_1 and T_2 as control variables we get the following first-order conditions capturing the situation where the forest owner is either of cost type 1 or cost type 2:[30]

$$\mu W_{1T_1} e^{-rT_1} + (\lambda + \varepsilon)(P'(T_1) - c_1) = 0 \quad (13)$$

$$\pi_2(\mu W_{2T_2} e^{-rT_2} + (\lambda + \varepsilon)(P'(T_2) - c_2)) - \pi_1\varepsilon(c_2 - c_1)T_2) = 0 \quad (14)$$

From (13) the marginal amenity value ($\mu W_{1T_1} e^{-rT_1}$) plus the marginal social value of the discounted payoff to the forest owner ($(\lambda + \varepsilon)(P'(T_1) - c_1)$) is set equal to zero for type 1. The marginal social value of the discounted payoff to the forest owner consists of the marginal cost of the subsidy payment to the regulator $(\varepsilon(P'(T_1) - c_1))$ and the marginal value of the owner´s payoff in the welfare function ($\lambda(P'(T_1) - c_1)$. For type 2 an additional term enters in (14) given as $\varepsilon(c_2 - c_1)T_2)$ and because $c_2 > c_1$ this term is labelled the marginal incentive cost (see e.g. Sappington, 1991). The

[29] See e.g. Varian (1992).

[30] Note that if we used marginal truth telling conditions instead of (8) or (9) a second-order derivative of (1) or (3) would enter in (14) instead of the marginal incentive costs (see e.g. Holmstrom and Milgrom, 1991).

marginal incentive cost arises for cost type 2 because cost type 1 must be provided with an incentive to report the true cost type. Finally, note that π_2 and π_1 is included in (14) because these probabilities does not cancel away given that the marginal incentive costs is included.

2.c. The optimal contract

By setting (2) equal to (13) and (4) equal to (14) we get the following optimal marginal subsidies:

$$S_1'(T_1) = -(1-\lambda-\varepsilon)(P'(T_1)-c_1) + \mu W_{1T_1} e^{-rT_1} \tag{15}$$

$$S_2'(T_2) = -(1-\pi_2(\lambda+\varepsilon))(P'(T_1)-c_1) + \pi_2 \mu W_{2T_2} e^{-rT_2} - \pi_1 \varepsilon((c_2-c_1)T_2) \tag{16}$$

Let us start by clarifying how (15) and (16) shall be applied in actual regulation. At the beginning of a rotation period the regulator announces the two voluntary marginal subsidies in (15) and (16) and at the end of the rotation period the subsidy is paid based on the observed behaviour. The forest owner select between the two contracts in (15) and (16) and because of the characteristics of the subsidies a type 1 forest owner will select (15) while an owner of type 2 select (16). Thus, the subsidy scheme in (15) and (16) secure correct self-selection of the owner´s type. Remark that the subsidies in (15) and (16) depend on the rotation period in a way that the forest owner selects an optimal value of either T_1 or T_2. Note also that the two subsidies in (15) and (16) are voluntary but a forest owner who maximizes the discounted payoff will chose to accept one of the contracts.

From (15) we see that the payment in the marginal contract for type 1 will be a marginal subsidy to increase the rotation period if $(1-\lambda-\varepsilon)(P'(T_1)-c_1) < \mu W_{1T_1} e^{-rT_1}$. Thus, a voluntary marginal subsidy can generate correct the forest owner incnetives if the marginal amenity value is large compared to the marginal forest owner payoff. However, if $(1-\lambda-\varepsilon)(P'(T_1)-c_1) > \mu W_{1T_1} e^{-rT_1}$ we have that $S_1'(T_1) < 0$ implying that (15) is a marginal tax and now the forest owner will prefer not to enter the contract so the regulatory mechanism only works if $S_1'(T_1) > 0$. Note that $P'(T_1) - c_1$ and $(\lambda+\varepsilon)(P'(T_1) - c_1) + \mu W_{1T_1} e^{-rT_1}$ represents the first-order conditions for the forest owner and the regulator. Thus, the voluntary marginal subsidy shall be based on the difference in the objective function between the principal and the agent. In this way the marginal subsidy corrects the externality we described in section 2.a. For type 2 the marginal incentive cost ($\pi_1 \varepsilon (c_2 - c_1) T_2)$) shall also be included in the marginal subsidy ((16)). This marginal incentive costs makes it less likely that $S_1´(T_1) > 0$.

From (15) and (16) we obtain that $T_1 > T_2$ due to the facts that $c_1 < c_2$ and the marginal incentive costs is included in (16). Note that (15) and (16) only secure a second-best optimum because the marginal incentive cost is included in the optimal voluntary marginal subsidy for type 2. This result is due to the fact that two goals shall be reached with the subsidy. First, we want to correct an externality arising due to a difference in the objective functions between the owner and the regulator. Second, we want to reveal the forest owners private information about the costs. Given two objectives and only one regulatory mechanism (a subsidy) we can only reach a second-best optimum.

In the introduction we mentioned the Nature 2000 contracts to increase biodiversity conservation, the Danish subsidies to increase biodiversity and the France forest owner´s voluntary adherence to taking eco-system services into account. Based on the voluntary subsidies in (15) and (16) three conclusions can be summarized in relation to actual forest policy. First, forest subsidies shall be corrected for the payoff for the forest owner valued both from the point of view of the regulator and the agent. Second, all amenity values, and not only biodiversity conservation values, shall be include in the subsidy. Last, by proper design of the subsidies, private information can be revealed and, at the same time, externalities can be corrected.

3. Different forest owner objectives

In section 2 the objective of the forest owner is formulated in a very general way by maximizing the discounted payoff. Therefore, we now consider three more specific objectives for the owner given as:

a. Both type 1 and 2 maximize the discounted profit from timber production
b. Both type 1 and 2 maximize the welfare
c. Both type 1 and 2 maximize a mix between the profit from timber production and the welfare

3.a. The profit from timber production

Now consider a forest owner who maximizes the discounted profit from timber production. [31] For indefinite rotations this objective has originally been suggested by Faustman (1849) and has been carefully discussed by Samuelson (1976). However, in this paper only consider one rotation to keep the analysis as simple as possible (the single crop case). We let $G(T_i)$ denote the growth in the volume of timber and consistent with the assumptions in section 2.a. we have that $G'(T_i) > 0$ for $T_i < \underline{T}$, $G'(T_i) < 0$ for $T_i > \underline{T}$ and $G''(T_i) < 0$. The situation where $G'(T_i) < 0$ captures that trees may, for example, start to rotten when they are old enough. Now p_T is a time independent constant price on timber[32] and we have that $p_T G(T_i)$ is the revenue from timber production when trees is harvested at time T_i. We also assume that costs only arise when the trees are harvested and, thus, that no cost arise when the trees are planted or grow. Consistent with the assumptions in section 2.a. we assume constant marginal costs represented by c_i implying that $C_i(T_i) = c_i T_i$ is the total cost of timber production. As above two cost types with cost parameters c_1 and c_2 are assumed to exist and we have that $c_1 < c_2$

Given these assumptions we get that the discounted profit from timber production is:

$$[p_T G(T_i) - c_i T_i]e^{-rT_i} \tag{17}$$

From (17) the discounted payoff to a forest owner is the discounted profit (net revenue minus the costs arising from harvesting trees at time T_i. By differentiating (17) we obtain the marginal profit of timber production as:

$$[p_T G'(T_i) - c_i]e^{-rT_i} - r[p_T G(T_i) - c_i T_i]e^{-rT_i} \tag{18}$$

Thus, the marginal profit of timber consists of two counteracting components effects. The first term in (18) has been labelled the pure profit effect and captures the gain in the net profit from timber of letting the trees stand for one period more. The second term has been denoted the discount effect and captures that if a tree is harvested now the profit can be invested in an alternative way.[33]

Given (17) the marginal incentive costs are:

[31] Recently Boman et al (2010) have shown that the profit from timber production is a reasonable important part of the forest owner´s payoff in the Nordic countries.
[32] A time independent price of timber is a realistic assumption in pulpwood production but the results in the paper generalize straightforward to time dependent prices on timber.
[33] See Neher (1990) for further explanation of the profit and the discount effect.

$$\pi_1\varepsilon[(c_2 - c_1)e^{-rT_2} - r(c_2T_2 - c_1T_2)e^{-rT_2}] \tag{19}$$

From (19) the marginal incentive costs contains a cost effect (the increase in the costs in future periods of not harvesting trees now) and a discount effect (the decrease in the cost of harvesting now).

Now the same restrictions as in section 2.b is binding and we can find first-order conditions for the forest owner and the regulator. Given these conditions we can reach the following voluntary marginal subsidies:

$$\begin{aligned} &S_1{'}(T_1) = -(1-\lambda-\varepsilon)([p_TG'(T_1) - c_1]e^{-rT_1} - \\ &r[p_TG(T_1) - c_1T_1]e^{-rT_1}) + \mu W_{1T_1}e^{-rT_1} \end{aligned} \tag{20}$$

$$\begin{aligned} &S_2{'}(T_2) = -(1-\pi_2(\lambda-\varepsilon))([p_TG'(T_2) - c_2]e^{-rT_2} - \\ &r[p_TG(T_2) - c_2T_2]e^{-rT_2}) + \mu W_{2T_2}e^{-rT_2} - \pi_1\varepsilon[(c_2 - c_1)e^{-rT_2} - \\ &r(c_2T_2 - c_1T_2)e^{-rT_2}] \end{aligned} \tag{21}$$

As in section 2.c the regulator announce (20) and (21) at the beginning of a rotation period and pays the subsidy at the end of the rotation period. Furthermore, we let the forest owner select between (20) and (21) and thereby the cost type of the agent is revealed. Note that (20) and (21) is voluntary subsidies because a rational forest owner will benefit from entering the contract. From (20) the payment in the marginal contract to type 1 is based on the difference between the forest owner´s discounted profit from timber production and the welfare. For type 2 an incentive cost is included in (21) because type 1 must be given an incentive to reveal the correct type. (20) and (21) represents a second-best optimum because both differences in the objective functions and asymmetric information must be accounted for in the subsidies. Note that (20) and (21) will only work provided the equations represents a subsidy to increase the rotation period. $S_i{'}(T_i) > 0$ will require that the forest owner´s marginal timber profit is lower than the marginal social welfare. Remark, also, that we must expect that $T_1 > T_2$ because $c_1 < c_2$ and the marginal incentive costs is included in (21). Finally, the major contribution of the subsidies in (20) and (21) to actual forest policy is that the voluntary subsidies shall be corrected for the discounted profit from timber production.

3.b. Welfare

Now we assume that the forest owner maximize exactly the same welfare function as the regulator[34] and that both the forest owner and the regulator use the discounted profit from timber production for the forest owner payoff in the welfare function. In this way the objective function for both the forest owner and the regulator is:

$$\mu \int_{t=0}^{T_i} e^{-t} W_{it}(t)dt + \lambda([p_T G(T_i) - c_i T_i]e^{-rT_i}) - \varepsilon S_i(T_i)) \tag{22}$$

Thus, according to (22) the forest owner include the amenity value with a weight on μ, the profit from timber production with a weight on λ and the double dividend arising from correcting a externality with a weight on ε.

Let us now discuss the implications of having a forest owner that maximize welfare as defined in (22). The only difference between the forest owners and the regulators maximization problems is that the latter include participation and self-selection restrictions. However, these restrictions are non-binding or, alternatively, non-existing for the following reasons when the forest owner maximize welfare. According to the self-selection and participation restrictions the regulator knows the objective function of the forest owner and because the owner maximizes welfare there is no incentive to misreport the cost type. Thus, the self-selection restriction in (8) and (9) is non-binding. Furthermore, provided the forest owner is interested in maximizing welfare the agent will only accept the contract if this is optimal. Consequently, the participation restrictions in (6) and (7) is also non-binding or non-existing with a welfare maximizing forest owner. Therefore, the maximization problems for both the regulator and the forest owner are identical and therefore no externality has to be corrected. Thus, we get that $S_1'(T_1) = S_2'(T_2) = 0$ and the main policy implication of this result is that when a forest owner include amenity values and forest owner payoff in an optimal way no voluntary subsidies shall be offered to the agent.

3.c. A mixed between the profit from timber production and the welfare

Now we consider the situation where the forest owner maximizes a mix between the discounted profit from timber production and the welfare. To capture this situation we introduce a weight, α, in front of the profit from timber production in (17) and a weight, 1-α, in front of the welfare in (22). With this formulation the profit from timber production is included both separately and as a

[34] In relation to this objective Boman et al (2010) find that amenity values is very important for many forest owners in the Nordic countries.

component in the welfare function. However, even though this can be criticized it turns out to be convenient for the analysis in section 4.1. Now the objective function for the forest owner becomes:

$$\alpha[p_T G(T_i) - c_i T_i]e^{-rT_i} + (1-\alpha)(\mu \int_{t=0}^{T_i} e^{-t} W_{it}(t)dt + \lambda[p_T G(T_i) - c_i T_i]e^{-rT_i} - \varepsilon S_i(T_i)) \tag{23}$$

The first term in (23) captures that the forest owner include discounted profit from timber production while the second term is the social welfare.

Since the regulator´s and forest owner´s objective function differ the agent has no incentive to reveal the true cost type. Thus, the regulator wants to offer the forest owner a voluntary subsidy that secures correct revelation of the cost type and correct the externality arising from differences in the objective function. As in section 2.b the self-selection restriction for type 1 and the participation restriction for type 2 are binding. By using the same procedure as in section 2 we arrive at the following marginal subsidies:

$$S_1{}'(T_1) = \frac{-(\alpha(\lambda-1)+\varepsilon)([p_T G'(T_1) - c_1]e^{-rT_1} - r[p_T G(T_1) - c_1 T_1]e^{-rT_1}) + \alpha\mu W_{1T_1} e^{-rT_1}}{(1-\alpha)\varepsilon} \tag{24}$$

$$S_2{}'(T_2) = \frac{-\pi_2((\alpha(\lambda-1)+\varepsilon)([p_T G'(T_2) - c_2]e^{-rT_2} - r[p_T G(T_2) - c_2 T_2]e^{-rT_2}) + \alpha\mu W_{2T_2} e^{-rT_2}) - \pi_1\varepsilon[(c_2 - c_1)e^{-rT_2} - r(c_2 T_2 - c_1 T_2)e^{-rT_2}]}{(1-\alpha)\varepsilon} \tag{25}$$

The regulator announces the two contracts in (24) and (25) to the forest owner at the beginning of a rotation and pays the subsidy at the end of the rotation period. By selection of a marginal subsidy the forest owner reveals the private information about the cost type and due to the inclusion of participation restrictions it is profitable for the forest owner to enter the contract.

Now we consider the case where the forest owner is of type 1 in (24) and we begin with the term given by $\alpha\mu W_{1T_1} e^{-rT_1}$. Here we observe that the forest owner with a mixed objective impose a weight on the size of $(1-\alpha)$ on the marginal amenity value while the regulator attach full weight on this marginal value. Thus, the regulator only needs to correct a share on α of the marginal amenity value and the second term in the nominator of (24) captures this correction. For the marginal profit from timber production we note that the welfare effect of this profit differ because the forest owner only impose a weight of $(1-\alpha)$ on this component of welfare. However, the forest owner also impose a separate weight of α on the profit from timber production and this profit also generate a double dividend which is attached a weight on ε. These facts explain why the marginal profit from timber production is corrected with $\alpha(\lambda-1)+\varepsilon)$ in (24). Note that if $-\alpha(\lambda-1)>\varepsilon$ the marginal profit from timber production enters with a negative sign because the forest owner attach a high weight to this component of welfare (α is large). However, provided $-\alpha(\lambda-1)<\varepsilon$ the marginal profit of timber production enters with a positive sign because a high weight is attached to the double-dividend (ε is large). Next we observe from (24) that a denominator on the size of $(1-\alpha)\varepsilon$ enters because the forest owner imposes a weight of $(1-\alpha)$ on the double-dividend (ε). Finally, from (25) we observe that the only difference between a type 1 and a type 2 forest owner is that the marginal incentive costs enter in (25).

Consider now the conditions under which (24) represents a voluntary marginal subsidy to the forest owner to increase the rotation period ($S_1\acute{}(T_1)>0$). First, we note that $0<(1-\alpha)\varepsilon<1$ and that $\alpha\mu W_{1T_1}e^{-rT_1}>0$. From this it follows that $S_1\acute{}(T_1)>0$ if $-\alpha(\lambda-1)>\varepsilon$ capturing that the marginal profit from timber production enters with a positive sign. Furthermore, provided $-\alpha(\lambda-1)<\varepsilon$ $S_1\acute{}(T_1)>0$ if $(\alpha(\lambda-1)+\varepsilon)([p_T G\acute{}(T_1)-c_1]e^{-rT_1}-r[p_T G(T_1)-c_1T_1]e^{-rT_1})<\alpha\mu W_{1T_1}e^{-rT_1}$. For type 2 the marginal incentive costs makes it less likely that a voluntary marginal subsidy is reached in (25).

Note, also, that by comparing (24) and (25) it seems likely that $T_1 > T_2$ and the marginal incentive costs imply that only a second-best optimum is reached. Finally one policy implications of (24) and (25) is that when the owner and the regulator attach different weights to the timber profit and the amenity value, the voluntary subsidy shall only include the part of these values not taken into account by the forest owner.

4. Regulator uncertainty

In this section we consider two kinds of uncertainties for regulator about the forest owner objective function:

a. Regulator perceives a wrong forest owner objective function.
b. Regulator has asymmetric information about the forest owner objective function.

4.a. A wrong objective function

As in section 2 and 3 we assume that the regulator has asymmetric information about the cost parameter of the forest owner but now a wrong forest owner objective function is used when determining the voluntary marginal subsidy. Specifically, regulator believes that the forest owner is interested in maximizing the profit from timber production but, in reality, the owner maximizes a mix between the profit from timber production and the welfare. Now it is important to be clear about the formulation of the self-selection and participation restrictions. Since the regulator believes the forest owner maximize the profit from timber production this objective is also used in the two sets of restrictions. Thus, the expectations of the regulator are reflected in (6)-(9) and, therefore, we get that type 1´s self-selection restriction and type 2´s participating restriction is binding.

Now it is useful to treat the two cost types separately and we begin with type 1. Because the regulator believes the forest owner maximize the profit from timber production, the actual voluntary marginal subsidy, $S_{1A}'(T_1)$, is given by:

$$\begin{aligned} S_{1A}'(T_1) &= -(1-\lambda-\varepsilon)([p_T G'(T_1) - c_1]e^{-rT_1} - \\ & r[p_T G(T_1) - c_1 T_1]e^{-rT_1}) + \mu W_{1T_1} e^{-rT_1} \end{aligned} \tag{26}$$

However, in reality the forest owner maximize a mix between the profit from timber production and the welfare and from (24) the optimal voluntary marginal subsidy, $S_{1O}'(T_1)$, is:

$$S_{1O}'(T_1) = \frac{\begin{array}{c} -(\alpha(\lambda-1)+\varepsilon)([p_T G'(T_1) - c_1]e^{-rT_1} - \\ r[p_T G(T_1) - c_1 T_1]e^{-rT_1}) + \alpha\mu W_{1T_1} e^{-rT_1} \end{array}}{(1-\alpha)\varepsilon} \tag{27}$$

First, we compare (26) and (27) and we assume that from above we assume that $S_{1A}'(T_1) > 0$ and $S_{1O}'(T_1) > 0$ indicating that the forest owner receives a voluntary marginal subsidy to increase the rotation period. Now we investigate conditions under which we have that $S_{1O}'(T_1) > S_{1A}'(T_1)$. Here we note that the denominator in (27) tend to lead to this result because $(1-\alpha)\varepsilon < 1$. The opposite conclusion holds for the marginal amenity value in the nominator because $\alpha\mu W_{1T_1} e^{-rT_1}$ enters in (27) while only $\mu W_{1T_1} e^{-rT_1}$ is included in (26). However, the timber profit part also tend to imply that $S_{1O}\acute{}(T_1) > S_{1A}\acute{}(T_1)$ because $\alpha > 1$.[35] Thus, based on the timber profit part of the nominator in (26) and (27) and the denominator in (27) we will expect that $S_{1O}\acute{}(T_1) > S_{1A}\acute{}(T_1)$. The explanation for this result is that the cost of the externality is larger when maximizing the profit from timber production than with a mixed objective because a positive weight is attached to welfare by the forest owner in the latter situation.

Now let us consider the implications of this result for the rotation periods. Since the forest owner makes the actual decisions we must use the first-order conditions for the owner and here we use the condition from section 2.a implying that:

$$P\acute{}(T_i) - c_i + S_i\acute{}(T_i) = 0 \qquad (28)$$

Note, first, that if the optimal voluntary subsidy in (27) is inserted in (28), the forest owner´s first-order condition is reduced to the regulator´s optimal condition and we label the rotation period in this case T_1*. However, the actual voluntary marginal subsidy in (26) is smaller than the optimal marginal subsidy and now we get that the actual rotation period, T_1, is higher than T_1*. Thus, the fact that the regulator perceives that the forest owner maximize the timber value while the owner attach a positive weight to the welfare imply that $T_1 > T_1$*. If we interpret the case where the forest owner attach a positive weight to the welfare as pro-social behavior, this kind of behavior may generate inefficiencies because a wrong subsidy is used by the regulator. One policy implication is that it is important for regulator to know the true objective function of the forest owner. If a regulator perceives a wrong objective function economic inefficiencies may arise.

Next we investigate type 2 and if regulator believes the forest owner maximize the profit from timber production the actual marginal subsidy, $S_{2A}\acute{}(T_2)$, is equal to:

$$\begin{aligned} S_{2A}\acute{}(T_2) &= -(1-\pi_2(\lambda+\varepsilon))([p_T G\acute{}(T_2) - c_2]e^{-rT_2} - \\ & r[p_T G(T_2) - c_2 T_2]e^{-rT_2}) + \pi_2 \mu W_{2T_2} e^{-rT_2} - \pi_1 \varepsilon[(c_2 - c_1)e^{-rT_2} - \\ & r(c_2 T_2 - c_1 T_2)e^{-rT_2}] \end{aligned} \qquad (29)$$

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[35] For the timber profit part of (26) and (27) we must have that $\alpha(\lambda-1) - \varepsilon < 1 - \lambda - \varepsilon$ from which it follows that $\alpha(\lambda-1) < 1-\lambda$ and $\alpha < 1$. Thus, the timber profit part of (26) and (27) tend to lead to the result that $S_{1O}\acute{}(T_1) >$ $S_{1A}\acute{}(T_1)$

However, for a forest owner with a mixed objective the following optimal subsidy, $S_{2O}´(T_2)$, is obtained:

$$S_{2O}´(T_2)=\frac{\begin{array}{l}\pi_2((\alpha(\lambda-1)+\varepsilon)([p_T G´(T_2)-HC_2´(T_2)]e^{-rT_2}-\\-r[p_T G(T_2)-HC_2(T_2)]e^{-rT_2})+\alpha\mu W_{2T_2}e^{-rT_2})-\\\pi_1\varepsilon[(HC_2´(T_2)-HC_1´(T_2))e^{-rT_2}-r(HC_2(T_2)-HC_1(T_2))e^{-rT_2}]\end{array}}{(1-\alpha)\varepsilon} \tag{30}$$

When investigating the rotation periods for a forest owner of type 2 we note that the only difference between (29) and (30) and (26) and (27) is the marginal incentive costs is included in both $S_{2O}´(T_2)$ and $S_{2A}´(T_2)$. Thus, provided (29) and (30) is a marginal subsidy it is likely that $T_2 > T_2*$ because the marginal incentive costs is included in both equations. Therefore, for type 2 the existence of pro-social behavior may also reduce the welfare when regulator uncertainty about the forest owner objective function exists.

However, due to the inclusion of the marginal incentive costs in (29) and (30) we can reach an additional result. Remember that the marginal incentive cost is included for cost type 2 to provide cost type 1 with an incentive to reveal the true cost parameter. Within the notation from section 2.b the marginal incentive costs is given by $\pi_1\varepsilon(c_2-c_1)$ and this cost exactly secure that type 2´s participation restriction and type 1´s self-selection restriction is binding if the forest owner maximize the timber profit. However, even though $T_2 > T_2*$ the rotation age does not influence the marginal incentive cost. Thus, despite the fact that regulator uses a wrong subsidy, a type 1 forest owner has the same incentive to report the correct type.[36]

4.b. Asymmetric information about the forest owner objective

Now we discuss the implications of regulator asymmetric information about the forest owner´s objective function for the regulator and here the general model from section 2 is used. Specifically, we assume that the regulator assigns a probability, π_1, to the case where the owner maximize the discounted payoff and a probability, π_2, to an owner objective of maximizing the welfare.

[36] However, this result will change with increasing marginal costs. With $T_2 > T_2*$ we obtain that the actual incentive cost is larger than the optimal incentive costs. The optimal incentive costs would generate correct incentive for type 1 to reveal the correct cost type so $T_2 > T_2*$ imply that a too “large” incentive to reveal the true cost type exist. The opposite conclusion holds with decreasing marginal costs. Because $T_2 > T_2*$ the incentive for type 1 to reveal the cost type is too “low”.

Furthermore, to simplify the analysis we disregard asymmetric information about the cost function and let cT_i be the cost function with both objectives where c is an exogenous cost parameter that is identical for both types of forest owners.

The forest owner is assumed to know the true objective function. If the owner maximize the discounted payoff we get the following problem:

$$Max[P(T_1) - cT_1 + S_1(T_1)] \tag{31}$$

Now the first-order condition is:

$$P'(T_1) - c + S_1{}'(T_1) = 0 \tag{32}$$

From (32) we may find an optimal rotation period when the objective is to maximize the discounted payoff, T_1, and given the assumption about the derivatives of $P(T_1)$, T_1 is unique.

Turning to the case where the forest owner maximizes the welfare we argued in section 3.b that when the welfare function is the same as for regulator and the owner the voluntary marginal subsidy shall be zero. Thus case seems uninterested and, therefore, we introduce two differences in the welfare functions between the forest owner and the regulator. First, the welfare of the forest owner´s is increased with the subsidy payment while the regulator treats this payment as a pure transfer. Second, the forest owner does not include a double-dividend of the subsidy payment in the welfare function. Given these assumptions the forest owner´s objective function can be formulated as:

$$\mu \int_{t=0}^{T_1} e^{-t} W_{2t}(t) + \lambda(P(T_2) - cT_2) + S_2(T_2) \tag{33}$$

In maximizing (33) we assume that the forest owner does not include the participation and the self-selection restrictions. This seems to be a natural assumption since the participation and self-selection restrictions is formulated as requirements to the forest owner´s payoff functions that an optimal subsidy must fulfil.

From (33) we get the following first-order condition:

$$\mu W_{2T_2} e^{-rT_2} + \lambda(P'(T_2) - c) + S_2{}'(T_2) = 0 \tag{34}$$

From (34) the forest owner sets the marginal welfare, as perceived by the agent, equal to zero. The marginal welfare consist of the marginal amenity value ($\mu W_{2T_2} e^{-rT_2}$), the marginal value of the payoff to the owner ($\lambda(P'(T_2)-c)$) and the voluntary marginal subsidy ($S_2'(T_2)$). By solving (34) we may find an optimal value of T_2 and, given the assumptions about the derivatives of W_{2t} and $P(T_1)$, this rotation period is unique. However, because welfare is defined differently by the principal and the agent we do not know whether T_1 or T_2 yield the highest welfare from the point of view of regulator.

Turning to the regulator we introduce asymmetric information about the forest owner objective function by introducing π_1 and π_2 defined above. Furthermore, the welfare function as defined by the regulator and a forest owner differ since the former treat the subsidy payment as a pure transfer and take a double-dividend into account. Thus, the expected welfare for regulator is:

$$\begin{aligned} &Max[\pi_1(\mu \int_{t=0}^{T_1} e^{-t} W_{1t}(t)dt + \lambda(P(T_1)-cT_1) - \varepsilon S_1(T_1)) + \\ &\pi_2(\mu \int_{t=0}^{T_2} e^{-t} W_{2t}(t)dt + \lambda(P(T_2)-cT_2) - \varepsilon S_2(T_2))] \end{aligned} \tag{35}$$

Note that (35) captures an externality that arise for both types of the forest owners. For a forest owner that maximizes the discounted payoff (type 1) the same difference in objectives functions as in section 2 arise. For a type 2 forest owner there is a difference in the way the principal and the agent value the subsidy payment and this also generate a difference in the objective functions.

Another difference between the maximization problems of the forest owner and the regulator is that the latter include participation restrictions and self-selection restrictions. For the participation restrictions we let $\underline{U}_1$ denote the reservation payoff when the discounted payoff is maximized while $\underline{U}_2$ is the reservation payoff when maximizing welfare. Given this the participation restrictions for both forest owner objectives can be stated as:

$$P(T_1) - cT_1 + S_1(T_1) \geq \underline{U}_1 \tag{36}$$

$$\mu \int_{t=0}^{T_2} e^{-t} W_{2t}(t)dt + \lambda(P(T_2)-cT_2) + S_2(T_2) \geq \underline{U}_2 \tag{37}$$

According to (36) and (37) the regulator wants the forest owner to enter the contract both when the discounted payoff and the welfare are maximized. Thus, both type 1 (36)) and type 2 in (37)) must not receive less than the reservation payoffs ($\underline{U}_1$ and $\underline{U}_2$). One implication of this is that voluntary subsidies to solve the externality problems arising due to differences in the objective functions between the forest owner and the regulator.

We must also include self-selection restrictions for both type 1 and type 2 and these are given as:

$$P(T_1) - cT_1 + S_1(T_1) \geq P(T_2) - cT_2 + S_2(T_2) \tag{38}$$

$$\begin{aligned} &\mu \int_{t=0}^{T_2} e^{-t} W_{2t}(t)dt + \lambda(P(T_2) - cT_2) + S_2(T_2) \geq \\ &\mu \int_{t=0}^{T_1} e^{-t} W_{1t}(t)dt + \lambda(P(T_1) - cT_1) + S_1(T_1) \end{aligned} \tag{39}$$

For type 1 it follows from (38) that the discounted payoff of choosing T_1 must not be lower than the discounted payoff of choosing T_2. (39) state that the welfare as perceived by the forest owner of selecting T_2 must be larger than or equal to the welfare of choosing T_1.

In appendix we now argue that type 1´s participation restriction is binding while the only interesting situation arise when type 2´s self-selection restriction is binding. This implies that:

$$S_1(T_1) = \underline{U}_1 - (P(T_1) - cT_1) \tag{40}$$

$$\begin{aligned} &S_2(T_2) = -\mu \int_{t=0}^{T_2} e^{-t} W_{2t}(t)dt - \lambda(P(T_2) - cT_2) + \\ &(\mu \int_{t=0}^{T_1} e^{-t} W_{1t}(t)dt + (1-\lambda)(P(T_1) - cT_1)) - \underline{U}_1) \end{aligned} \tag{41}$$

From (40) the forest owner just receives the discounted payoff that makes him enter the contract provided the discounted payoff is maximized. However, a welfare maximizing forest owner obtains an information rent to reveal the correct objective function. The information rent is based on the welfare of being type 1 ($\mu \int_{t=0}^{T_1} e^{-t} W_{1t}(t)dt + (1-\lambda)(P(T_1) - cT_1)) - \underline{U}_1$).

Now (40) and (41) can be substituted into (35) and this gives the following problem:

$$Max[\pi_1(\mu\int_{t=0}^{T_1} e^{-t}W_{1t}(t)dt + (\varepsilon+\lambda)(P(T_1)-cT_1)-\varepsilon\underline{U}_1) +$$
$$\pi_2((1+\varepsilon)(\mu\int_{t=0}^{T_2} e^{-t}W_{2t}(t)dt + (\varepsilon+\lambda)(P(T_2)-cT_2))-\varepsilon\underline{U}_1 - \tag{42}$$

$$\varepsilon(\mu\int_{t=0}^{T_1} e^{-t}W_{1t}(t)dt + (1+\lambda)(P(T_1)-cT_1))$$

The first-order conditions are given by:

$$\begin{aligned}&\pi_1(\mu W_{1T_1}e^{-rT_1} + (\lambda+\varepsilon)(P'(T_1)-c)) - \\ &\pi_2(\mu W_{1T_1}e^{-rT_1} + \varepsilon(1+\lambda)(P'(T_1)-c)) = 0\end{aligned} \tag{43}$$

$$(1+\varepsilon)\mu W_{2T_2}e^{-rT_2} + (\lambda+\varepsilon)(P'(T_2)-c) = 0 \tag{44}$$

For type 2 (44) capture that the marginal welfare is set equal to zero. The marginal welfare consists of the marginal amenity value corrected with $(1+\varepsilon)$ and the social value of the marginal payoff to the forest owner ($(\lambda+\varepsilon)(P'(T_2)-c)$). For type 1 a marginal incentive cost given by $\pi_2(\mu W_{1T_1}e^{-rT_1} +$ $\varepsilon(1+\lambda)(P'(T_1)-c))$ is also imposed to make type 2 reveal the true objective function and this incentive cost represents the marginal welfare of being type 1. This expression for the marginal incentive cost seems natural since there is asymmetric information about the objective function in this section.

By combining (32) with (43) and (34) with (44) we get that:

$$\begin{aligned}&S_1'(T_1) = \pi_1(\mu W_{1T_1}e^{-rT_1} + (\lambda+\varepsilon)(P'(T_1)-c)) - P'(T_1) - c - \\ &\pi_2(\varepsilon(1+\lambda)(\mu W_{1T_1}e^{-rT_1} + P'(T_1)-c)\end{aligned} \tag{45}$$

$$S_2'(T_2) = \varepsilon(\mu W_{2T_1}e^{-rT_2} + (P'(T_2)-c)) \tag{46}$$

First, note that the regulator let the forest owner select between (45) and (46) and the chosen marginal subsidy will reveal information about the owner´s objective function. Furthermore, the subsidies in (45) and (46) can be made voluntary because the owner will accept the subsidies in (45) and (46) irrespectively of the objective function. From above we have that provided the forest owner maximizes welfare the regulator and the forest owner value the subsidy differently.

Regulator imposes a negative weight, ε, on the subsidy payment while the forest owner imposes a full positive weight of getting a subsidy. The marginal subsidy in (46) must reflect this difference in objectives and since $\mu W_{2T_2} e^{-rT_2} + (P'(T_2) - c)$ is a measure for the marginal payment in the contract, (46) reflects this externality. For type 1 ((45)) we have that the forest owner maximizes the discounted payoff while the regulator maximize welfare and the cost of this externality is equal to the two first terms in $S_1'(T_1)(\pi_1(\mu W_{1T_1} e^{-rT_1} + (\lambda + \varepsilon)(P'(T_1) - c))$ and $P'(T_1) - c$). However, the marginal incentive costs are also included in (45) to secure that a welfare maximizing forest owner will report the true objective. Furthermore, (45) will only work if $S_1'(T_1) > 0$ implying that the marginal amenity value shall be large and the forest owner payoff shall be small. Note, also, that (45) and (46) only represents a second-best optimum because of the inclusion of the marginal incentive costs.

A problem with pro-social behaviour also arises in this section. To see this let us compare the above model with the model where the regulator know that the forest owner maximize the discounted payoff (section 2). By using the same arguments as in section 4.1 this implies that the rotation period is distorted away from a social optimum in (42). Thus, the existence of a welfare maximizing forest owner will decrease the welfare with regulator have asymmetric information about the forest owner´s objective function. Note from (45) and (46) that we get that $T_2 > T_1$ because (46) is based on welfare maximization while (45) is based on maximizing the discounted payoff. Finally, there are two main policy implications of (46) and (47). First, the regulator must take into account that the principal and the agent may attach different weights to the subsidy payment. Second, by designing the voluntary subsidy properly information about the forest owner objective function may be revealed.

5. Conclusion

In this paper we have constructed a general principal-agent model to discuss voluntary subsidies provided to a forest owner to increase the rotation period. To capture heterogeneity among forest owner´s we consider two types of agents with different cost functions and there is asymmetric information about an exogenous cost parameter. Consistent with traditional forest economics the rotation period is used as control and contract variable and the characteristics of a long-term contract lasting for one rotation is investigated. The regulator is interested in maximizing a weighted sum of forest owners discounted payoff and the amenity values. Contrary, the forest owner only maximizes the discounted payoff and this difference in objective functions generates an externality which an optimal voluntary subsidy can correct. Furthermore, a forest owner with high costs must be imposed an extra marginal cost to secure correct revelation of the low cost owner´s private information.

The general model is used to conduct two kinds of analysis in the paper. First, we consider the implications of different forest owner objectives represented by maximization of the profit from timber production, maximization of the welfare and maximization of a mix between the profit from timber production and welfare. In all these three cases the optimal voluntary subsidy shall correct for the externality that arise due to difference in objectives between the principal and the agent. One implication of this result is that when forest owner maximize the welfare no voluntary subsidy is necessary since there is no difference in the maximization problems of the regulator and the forest owner. Second, the implications of regulator uncertainty about the forest owner´s objective function are considered. Specifically, we investigate situations where the regulator perceives a wrong forest owner objective function and where the regulator has asymmetric information about the forest owner objective. We show that in both of these cases regulator uncertainty may lead to a distortion away from an optimum and, therefore, pro-social behavior may, in fact, reduce the welfare.

From the point of view of practical forest contracts that take the amenity values into account has become increasingly popular. Examples are Nature 2000 contracts to increase biodiversity conservation, the Danish support biodiversity conservation measures by voluntary subsidies and the forest owner´s voluntary adherence to eco-system services in France. We make five major contributions to the practical discussion of forest contracts. First, the payment in the forest contracts shall be corrected for the payoff to the owner valued both from the point of view of the regulator and the agent. The present value of the profit from timber production is an example of a forest owner payoff. Second, all amenity values, and not only biodiversity values, shall be incorporated in the forest contracts. Third, by proper design of the subsidies, these can be used to reveal private information including information about the owner´s objective function. Forth, it is important to clarify the objective function of the forest owner when designing voluntary subsidies. Specifically, no subsidy is necessary if the owner already maximizes welfare and if the subsidy payment is valued different by the forest owner and the regulator, this must be taken into account in the subsidy. Last, in the case where the forest owner attach different weights to the profit from timber production and the amenity values the voluntary subsidy shall only correct for the parts of these values not taken into account by the forest owner.

The analysis in the paper is based on three simplifying assumptions. First, we only include two types of forest owners. Second, we use a static model since only one rotation is considered. Third, we study a long-term contract lasting for the whole rotation period. Relaxing these assumptions by studying a continuum of forest owners, several rotations or short-term contracts is important areas for future research.

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Appendix

A. Section 2, 3 and 4.1.

For type 1 the two restrictions are:

$$S_1(T_1) \geq P(T_1) - c_1 T_1 - \underline{U}_1 \tag{A.1}$$

$$S_1(T_1) \geq P(T_1) - c_1 T_1 - (P(T_2) - c_1 T_2 - S_2(T_2)) \tag{A.2}$$

Since $S_1(T_1)$ enters with a negative sign in the regulators objective function, one these restrictions must be binding. Thus, we must analyze which restriction that is binding and here we consider if this can be the self-selection restriction. According to the participation restriction for type 2 we have that:

$$P(T_2) - c_2 T_2 + S_2(T_2) \geq \underline{U}_2 \tag{A.3}$$

From single-crossing property we have that:

$$-c_2 T_2 \leq -c_1 T_2 \tag{A.4}$$

By adding $P(T_2)$ and $S_2(T_2)$ in (A.4) and using (A.3) we get that:

$$P(T_2) - c_1 T_2 + S_2(T_2) \geq P(T_2) - c_2 T_2 + S_2(T_2) \geq \underline{U}_2 \tag{A.5}$$

Thus, the expression in the bracket of (A.2) is larger than the reservation payoff and since the term is subtracted it must be the self-selection restriction for type 1 that is binding.

One of type 2´s restriction must also be binding and now we consider whether can be the self-selection restriction. If this restriction is binding we have that:

$$P(T_2) - c_2 T_2 + S_2(T_2) = P(T_1) - c_2 T_1 + S_1(T_1) \tag{A.6}$$

Substituting the binding self-selection restriction for type 1 into (A.6) gives:

$$c_1 T_2 - c_1 T_1 = c_2 T_2 - c_2 T_1 \tag{A.7}$$

However, (A.7) violates single-crossing property so the self-selection restriction for type 2 cannot be binding and instead the participation restriction is binding. Finally, note that these results are the same in section 3 since the forest owner objective functions have the same properties as in section 2.

B. Section 4.2.

First, we consider the restrictions for a forest owner that maximize the timber value. Since $S_1(T_1)$ enters with a negative sign in the welfare function and a positive sign in the restrictions, one of the restrictions for type 1 must be binding. Can this be the self-selection restriction? From the main text we have that T_1 is a unique optimal value. Thus, the self-selection restriction of type 1 cannot be binding and therefore the participation restriction is binding.

Now we turn to a forest owner that maximizes the welfare. As for type 1 one of the restrictions must be binding. From the main text the relative welfare properties of T_1 and T_2 cannot be determined because of a difference in the objective functions between the forest owner and the regulator. Thus, we have two possibilities we must consider. The first possibility is that the participation restriction for type 2 is binding this case is uninteresting because we have no problem with asymmetric information. The second possibility is that the self-selection restriction for type 2 is binding and this is the case we consider in the main text.