”Optimal Afforestation Contracts with Asymmetric Information on Private Environmental Benefits”

Signe Anthon and Bo Jellesmark Thorsen

Affiliations

Signe Anthon is a PhD-student at the Royal Agricultural and Veterinarian University and Bo Jellesmark Thorsen, Ph.D., is Head of Department at the Danish Forest and Landscape Research Institute, a part of *Skov & Landskab*.

Adresses:

Signe Anthon
PhD-student
Skov & Landskab (FSL)
Hørsholm Kongevej 11
2970 Hørsholm, Denmark
Phone: +45 45 17 83 13
E-mail: sia@fsl.dk

Bo Jellesmark Thorsen
Head of Departement
Skov & Landskab (FSL)
Hørsholm Kongevej 11
2970 Hørsholm, Denmark
Phone: +45 45 17 83 45
E-mail: bjt@fsl.dk

"OPTIMAL AFFORESTATION CONTRACTS WITH ASYMMETRIC INFORMATION ON PRIVATE ENVIRONMENTAL BENEFITS"

ABSTRACT: We investigate the problem of subsidising afforestation when private information exists with respect to the level of private utility derived from the project. We develop a simple model that allows for an intelligent design of contracts when information is asymmetric. The model involves the Principal and two groups of agents (landowners): a 'green' group deriving high private utility from the projects and a 'conventional' group deriving lower utility. Afforestation projects may be produced in different environmental quality, and we distinguish between two cases, a high quality and a low quality project. We find that the optimal set of contracts under asymmetric information involves two different contracts. One in which green landowners are somewhat overcompensated for projects of high quality, and one where conventional landowners are offered contracts including lower quality projects, compared to the symmetric case, but with compensation equal to his indifference payment. It is the ability to reduce quality requirements along with subsidies offered that allows for revelation of the private information. Finally, we discus how the results obtained may be used in the implementation of incentive schemes.

KEYWORDS: Principal-agent theory, incentive schemes, revelation principle, environmental economics.

JEL-CODES: D82, H23, Q23

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1. Introduction

The surge of environmental awareness since the late 1960’s has forced environmental policy issues onto the agenda of any government and almost any intergovernmental organisation. It has also caused a sometimes substantial use of public funds for environmental policy issues. These include on the one hand, the fighting of environmental ‘bads’ through control, prevention etc. and on the other hand, the use of subsidies to further the production of environmental goods.

It is now widely accepted that the lack of a market for a number of environmental benefits is likely to result in insufficient production of these benefits. To try to correct for this, artificial markets are some times created, allowing typically a community to encourage the production of environmental benefits by subsidising particular land uses, projects or techniques. This kind of transaction involves two contracting parties: society represented by, e.g. the state on the buyer’s side, and the landowners on the seller’s side. The lack of a market – not to say a perfect one – is likely to have severe consequences for the way prices are set. With no market, the true cost structure on the seller’s side is not easily revealed. It is very likely that landowners possess private information concerning their true opportunity costs or private benefits derived from the different land uses. Therefore prices are likely to be sub-optimal and inefficiently set, the consequence being overcompensation of the landowners.

This dilemma is commonly referred to as a Principal-Agent adverse selection problem. The Principal in the current case is the community and the Agent is the contracting landowner. The problem is a classic one and seminal papers on the theory of adverse selection include Akerlof's (1970) paper on the 'Market for Lemons' – the used cars' market, and Rotschild and Stiglitz (1976) and Stiglitz and Weiss (1981) addressing issues of adverse selection in the insurance and credit markets. For a general introduction to the field, see e.g. Macho-Stadler and Peréz-Castrillo (1997) or Salanié (2000). Adverse selection theory deals with ways to circumvent the existence of private information in order to obtain as efficient prices as possible. Among the means to this end are the use of auctions (see Klemperer (1999) for an excellent overview), yardstick competition and best-practice procedures for payment schedules (e.g. Bogetoft (1997)). Within the field of environmental goods markets, auctions has been investigated theoretically (Baneth (1995), Latacz-Lohmann and van der Hamsvoort, (1997, 1998)), and used and evaluated (Vukina and Marra (2000)). A different approach is to design a number of alternative contract types in a way that forces the different agents to reveal at least part of the private information. Examples are found in Macho-Stadler and Pérez-Castrillo (1997).

This latter approach is taken in the present paper. We investigate the case where private information concerns the level of private utility derived from the environmental good in question. We develop a simple model that allows for an intelligent design of contracts when there is asymmetric information about differences in private utility across agents. The model involves the Principal and two groups of agents, here landowners: a 'green' group deriving high private utility from the projects and a 'conventional' group deriving lower utility. Environmental projects may be produced in different qualities, and we distinguish between two: high quality and low quality projects.

To begin, we show formally that in case of transparency and symmetric information, the existence of private utility will decrease the optimal prices of a project of a given quality. Next, we derive the optimal contracts for the case of asymmetric information. We find that the optimal set of contracts involves two contract types. The first is a contract for the ‘green’ group, in which landowners are somewhat overcompensated, and the second a contract where the ‘conventional’ landowners are not overcompensated, but offered contracts including lower quality projects compared to the symmetric case. It is the ability to reduce quality requirements along with subsidies offered that allows for revelation of the private information. Finally, we show that taking into account asymmetric information in the design of contracts will produce a larger welfare gain from the incentive scheme, than will the simple and single flat-rate principle, though not as great a welfare gain as the efficient set obtained under symmetric information. Finally, we illustrate how the results obtained may be used in the implementation of incentive schemes.

The inspiration for our model is the Danish afforestation programme, which we use as our case. The case is described in the following section. Then we turn to the model and present its details. In Section 4, results are derived for the relevant cases. These are discussed in Section 5, along with some perspectives on practical use of the results. Concluding remarks are made in Section 6.

2. The Case

In 1989, the Danish parliament decided to encourage afforestation on agricultural land. The forest cover is only 10 %, and with a high population density the forests are in high demand for a number of uses, from wood production to environmental protection. Danish agricultural land is, however, highly productive and therefore an economically attractive alternative must be presented to the landowner. Hence an incentive scheme was implemented to create an artificial market for afforestation projects. Subsidies were offered for afforestation projects and projects were favoured within certain zones where the benefits were believed to be above average.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	In total
With subsidies	-	-	70	70	70	178	178	212	968	547	3315	5609
Without subsidies, registered 2000	-	510	510	510	510	510	510	510	510	510	510	5100

Table 1. The level of private afforestation efforts 1989-1999 in hectares (Kirkebæk and Thormann 2000, Statistics Denmark *et al.* 2002)

In the early years, subsidies were not attractive enough to encourage much afforestation in itself (Helles and Linddal 1996). However, outside the incentive schemes, awareness (and an increasing area of marginal farmland) caused landowners to establish new forest without receiving subsidies, cf. table 1. The exact amount is as yet unknown, but the observation that a number of landowners are willing to carry the investment in environmental goods, while another group is not, has scientific and empirical support, see e.g. Madsen (2001). Since the value of the forest as a timber-producing crop do not vary much across landowners, the explanation seems to be differences in the way the individual landowners value externalities derived from afforestation. This is the inspiration for the present paper.

3. The Model

The model comprises the Principal, e.g. society, and two types of agents: the ‘green’ landowner and the ‘conventional’ landowner. The ‘green’ landowner derives a larger private utility from any kind of environmental good than does the ‘conventional’ landowner.

Society (the Principal) derives utility W from afforestation projects according to:

$$W(x_i, s_i) = U(x_i) - V(s_i) \qquad (3.1)$$

Where W is the welfare function expressing the total utility of afforestation project i. The utility depends on the quality x of the project and the amount of subsidies s used to induce the project. Common quality parameters are the use of deciduous instead of coniferous species, the inclusion of areas for recreation and outdoor life, the reestablishment of habitats like small ponds and streams among other things. The positive utility derived from the project is expressed through U, while society's disutility of spending s on the project is expressed through V. We assume that $U'(x_i) > 0$ and $U''(x_i) < 0$, reflecting non-satiation and decreasing marginal utility of further increases in quality. Furthermore we assume that $V'(s) > 0$, $V''(s) > 0$ and $V'(0)=0$, implying increasing marginal disutility of spending money on subsidies. This reflects the fact that the shadow cost of additional funds is increasing as more funds are added. Since funds are limited, this is a reasonable assumption.

The landowners face the following profit function for the afforestation decisions and projects i:

$$\Pi_i \quad = \quad -C_e(x_i) - C_{oc} + s_i + ku(x_i) \qquad (3.2)$$

Cost of establishment is C_e, which is assumed increasing in project quality, $C'_e > 0$. C_{oc} gives the landowner's opportunity costs from, e.g. taking the land out of agricultural production. Profit of course also depends on the subsidy itself, s, and finally we include the landowner's private utility, u, expressed in money terms, which is derived from the project undertaken. We assume that u is an increasing function in x, or more precisely $u'(x_i) > 0$, $u''(x_i) < 0$ and $u'(0)=0$. The constant k is introduced to model differences in private utility derived by the landowners, but apart from this difference, landowners are assumed to be identical.

The two types of agents are defined as follows. The conventional landowner has $k = 1$ and the so-called 'green' landowner has $k > 1$. Furthermore, we make the important assumption that society's demand for the afforestation projects is so large that agents from both groups are needed to achieve an optimal production of the good.

As there are two types of agents, the Principal offers two different contracts $\{x_G, s_G\}$ and $\{x_C, s_C\}$, to the green and conventional landowners, respectively. The question of interest in the following analysis is: what are the best possible contracts for the Principal under different information regimes? We will look at two information regimes: 1) symmetric information, where the Principal can distinguish between agents and 2) asymmetric information, where the Principal can't. It is important to be able to distinguish between agents, since the indifference incentive, i.e. the payment that makes the agent indifferent to undertaking the project or not, $\tilde{s}_i$, is given from (3.2) as:

$$\tilde{s}_i \quad = \quad C_e(x_i) + C_{oc} - ku(x_i) \tag{3.3}$$

Hence, the indifference payment depends on the private utility derived, and for a given project it will be the cheapest and most efficient solution for the Principal to let a 'green' landowner undertake the project. However, to do that it must be possible to identify the different types of agents. This is difficult in the case of asymmetric information, and to circumvent the problem an intelligent design of contracts is required. In the following analysis we eliminate the opportunity costs, as they are identical across landowners and hence enter only as a constant in the analysis.

4. Results

In this section we present the results of an analysis of the optimal contracts under the above-mentioned two different information regimes. In each case the objective of the Principal is the same: To maximise the utility at society level. The constraints under which this objective must be pursued differ according to the information regime.

4.1 Symmetric information

This is the benchmark case in which we assume that all relevant information is available to both Principal and landowners. The problem to be solved by the Principal is therefore:

$$\begin{aligned} &\underset{x_i, s_i}{Max} \quad W = U(x_G) - V(s_G) + U(x_C) - V(s_C) \\ &st. \\ &s_G = C_e(x_G) - ku(x_G) \\ &s_C = C_e(x_C) - u(x_C) \end{aligned} \qquad (4.1)$$

where index G and C refer to green and conventional project types and incentive levels etc. The two constraints are so-called *participation constraints*. Since the Principal needs agents of both types to enter the contracts, they must be paid (at least) their indifference payment.

To solve the problem, the following Lagrangian is formed:

$$\begin{aligned} L = U(x_G) - V(s_G) + U(x_C) - V(s_C) - \lambda \cdot (C_e(x_G) - ku(x_G) - s_G) \\ - \mu(C_e(x_C) - u(x_C) - s_C) \end{aligned} \qquad (4.2)$$

with the following first-order necessary conditions, here presented only for the controls related to the green contracts:

$$\frac{dL}{dx_G} = U'(x_G) - \lambda \cdot (C'_e(x_G) + ku'(x_G)) = 0$$
$$\Leftrightarrow \quad U'(x_G) = \lambda \cdot (C'_e(x_G) - ku'(x_G)) \tag{4.3}$$

$$\frac{dL}{ds_G} = -V'(s_G) + \lambda = 0$$
$$\Leftrightarrow \quad V'(s_G) = \lambda \tag{4.4}$$

$$\frac{dL}{d\lambda} = C_e(x_G) - ku(x_G) - s_G = 0$$
$$\Leftrightarrow \quad s_G = C_e(x_G) - ku(x_G) \tag{4.5}$$

The first-order necessary conditions related to the conventional agents are quite similar – the only difference being *k=1*. We see from (4.5) that the optimal contracts involve an incentive payment exactly equal to the indifference payment. Thus any net benefits from undertaking the project accrues to society as such. Wee also see, as expected, that the larger *k* the lower the incentive payment for a given project, in the optimal contracts.

Rearranging (4.3) and (4.4) we find that society's marginal rate of substitutions equals the marginal rate of substitution for the agent: $U'(x_i)/V'(s_i) = C'_e(x_i) - ku'(x_i)$. Hence, the solution is Pareto optimal and resources are directed to their best use.

4.2 Asymmetric information

As noted above, the differences in private utility related to the afforestation projects imply that the two types of agents do not have the same indifference payments. For a given project, the indifference payment will be lower for the green landowner than for the conventional landowner. Under symmetric information the authorities can offer a lower incentive payment to the green landowner, ensuring participation *and* efficiency. But under asymmetric information, the Principal cannot discern between the two types and the green landowner has an incentive to pass himself on as a conventional owner. If he succeeds he will collect an information rent. Therefore the problem facing the Principal is to design a set of contracts, $\{x_G, s_G\}$, $\{x_C, s_C\}$, customised to fit the two types of landowners in a way that will make them reveal their type.

To ensure that the green landowner chooses the project designed for him, he must be compensated for the net utility he would derive from choosing the project and contract meant for the conventional landowner. Thus, his incentive constraint becomes:

$$s_G \geq +C_e(x_G) - k \cdot u(x_G) \underbrace{- C_e(x_C) + k \cdot u(x_C) + s_C}_{\text{Net utility of choosing the conventional contract.}} \tag{4.6}$$

The corresponding constraint for the conventional landowner becomes:

$$s_C \geq C_e(x_C) - u(x_C) \underbrace{- C_e(x_G) + u(x_G) + s_G}_{\text{Net utility of choosing the green contract}} \tag{4.7}$$

Thus, the problem to be solved by the Principal involves four different constraints, the two participation constraints from (4.1) and two incentive constraints (4.6) and (4.7). However, due to the structure of the problem, one can prove that two of them are redundant: the participation constraint for the green agent and the incentive constraint for the conventional agent. This is done in the appendix, cf. Propositions 7.1 and 7.2, and hence we are left with the problem:

$$\begin{aligned}
&\underset{s,x}{Max} \quad W = U(x_G) - V(s_G) + U(x_C) - V(s_C) \\
&st. \\
&\qquad s_C = C_e(x_C) - u(x_C) \\
&\qquad s_G = -C_e(x_C) + k \cdot u(x_C) + s_C + C_e(x_G) - k \cdot u(x_G)
\end{aligned} \tag{4.8}$$

To solve this problem, we form the Lagrangian:

$$\begin{aligned}
L = {} & U(x_G) - V(s_G) + U(x_C) - V(s_C) - \lambda \cdot (C_e(x_C) - u(x_C) - s_C) \\
& - \mu(-C_e(x_C) + k \cdot u(x_C) + s_C + C_e(x_G) - k \cdot u(x_G) - s_G)
\end{aligned}. \tag{4.9}$$

The first-order necessary conditions become:

$$\begin{aligned}
&\frac{dL}{dx_G} = U'(x_G) - \mu \cdot (C'_e(x_G) - k \cdot u'(x_G)) = 0 \\
&\Leftrightarrow \quad U'(x_G) = \mu \cdot (C'_e(x_G) - k \cdot u'(x_G))
\end{aligned} \tag{4.10}$$

$$\begin{aligned}
&\frac{dL}{ds_G} = -V'(s_G) + \mu = 0 \\
&\Leftrightarrow \quad V'(s_G) = \mu
\end{aligned} \tag{4.11}$$

$$\begin{aligned}
&\frac{dL}{dx_C} = U'(x_C) - \lambda \cdot (C'_e(x_C) - u'(x_C)) - \mu \cdot (-C'_e(x_C) + k \cdot u'(x_C)) = 0 \\
&\Leftrightarrow \quad U'(x_C) = \lambda \cdot (C'_e(x_C) - u'(x_C)) + \mu \cdot (-C'_e(x_C) + k \cdot u'(x_C))
\end{aligned} \tag{4.12}$$

$$\frac{dL}{ds_C} = -V'(s_C) - \mu + \lambda = 0$$
$$\Leftrightarrow \quad V'(s_C) = \lambda - \mu \tag{4.13}$$

$$\frac{dL}{d\lambda} = -(C_e(x_C) - u(x_C) - s_C) = 0$$
$$\Leftrightarrow \quad s_C = C_e(x_C) - u(x_C) \tag{4.14}$$

$$\frac{dL}{d\mu} = C_e(x_C) - k \cdot u(x_C) - s_C - C_e(x_G) + k \cdot u(x_G) + s_G = 0$$
$$\Leftrightarrow \quad s_G = -C_e(x_C) + k \cdot u(x_C) + s_C + C_e(x_G) - k \cdot u(x_G) \tag{4.15}$$
$$\Leftrightarrow \quad s_G = C_e(x_G) - k \cdot u(x_G) + (k-1) \cdot u(x_C)$$

In (4.15) we find the incentive payment for the green landowner using (4.14) to substitute for s_C. We note that since $k > 1$, the incentive payment exceeds the indifference payment, cf. (4.2). The incentive payment for the conventional landowner is exactly the indifference payment.

Combining (4.10) and (4.11) we obtain:

$$\frac{U'(x_G)}{V'(s_G)} = C'_e(x_G) - k \cdot u'(x_G) \tag{4.16}$$

Thus, society's marginal rate of substitution equals that of the individual green landowner. For the contract offered the conventional landowner, the corresponding result combining (4.12) and (4.13) is:

$$\frac{U'(x_C)}{V'(s_C)} = C'_e(x_C) - u'(x_C) + \frac{(k-1)\cdot\mu}{\lambda-\mu}\cdot u'(x_C) \qquad (4.17)$$

Since $k > 1$ and $\lambda > \mu > 0$, the last term is positive, and hence society's marginal rate of substitution is larger than that of the individual conventional landowner.

This establishes the formal properties of the optimal contracts under symmetric as well as asymmetric information. Next we turn to the interpretation and perspectives.

5. Discussion

Taking the presence of private utility into account implies that, for a given project, subsidies will be smaller and hence the net utility gain to society will be larger, cf. (3.3) and (3.1) respectively. Thus, in equilibrium society will buy more and/or better projects from the landowners compared to a situation without private utility derived from the afforestation project.

5.1 Symmetric information

With symmetric information, this effect can be used entirely in the design of contracts, and whatever the projects' quality subsidies will be equal to the indifference payment needed, cf. (4.5). The implications for the optimal set of contracts can be illustrated by considering the equality relation between marginal rates of substitution: $U'(x)/V'(s) = C'_e(x) - k\cdot u'(x)$ in the (*x*, *s*)-space as in Figure 1.

Figure 1 shows the iso-curves of marginal rates of substitution for society $U'(x)/V'(s)$ and for the landowner $C'_e(x) - k\cdot u'(x)$ [1]. In the case of symmetric information, compensation will be equal to

[1] The appendix contains proofs of the form of the curves and the relative position of iso-levels.

the cost of the project net of private utility, cf. (4.5). Point *A* represents an optimal contract for the green landowner. For the conventional landowner to undertake the same project, a larger incentive payment is required. However, from Proposition 7.3 (Appendix) and *u*'< *ku*', the optimality condition will only be satisfied if he undertakes a project of lower quality. Depending on the actual form of the functions, he may receive a larger or smaller incentive payment than the green landowner, – as illustrated by the points *B* and *C*. Thus, with symmetric information, compensation is equal to the marginal cost perceived by the landowner, cf. (4.5), the allocation of funds is Pareto optimal as implied by (4.3) and (4.4), and the conventional landowner will be asked to undertake projects of lower environmental quality than will the green landowner.

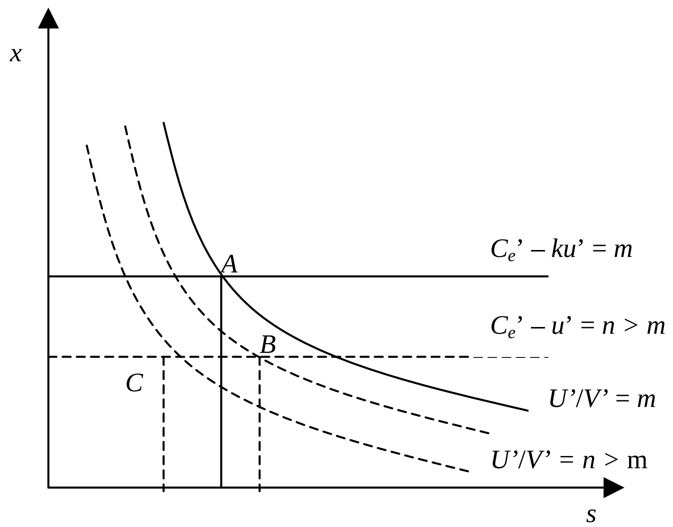

Figure 1. The optimal contracts for the case of symmetric information. Point *A* is the optimal contract for the green landowner, points *B* and *C* may be so for the conventional landowner.

5.2 Asymmetric information

Under an asymmetric information regime the optimal contract somewhat overcompensates the green landowner, the reason being that he needs compensation for the option to pass himself on as a conventional landowner and hence increase his signalled level of needed compensation for any type of project. We note that the overcompensation depends on the differences in private utility functions *and* on the project undertaken by the conventional landowner, cf. (4.15).

We also find that in the optimal contract society's marginal rate of substitution equals the green landowner's net cost of increasing the project quality. Hence, the optimal contract is Pareto optimal – but not efficient.

The type of green project x_G also changes. The incentive s_G paid for a given project x_G is now larger, and hence society's marginal rate of substitution is lower, everything else equal. The marginal cost of a given project remains the same, and hence (4.16) implies that a project of lower quality will be undertaken. The situation is illustrated in Figure 2, where point *A* is the optimal contract in the case of symmetric information, whereas point *B* is the optimal contract with asymmetric information. The project has lower quality and is purchased at a price larger than the indifference payment – in the example even larger than the price of the better project under symmetric information.

The effect of asymmetric information on the batch of projects undertaken by green landowners is thus a welfare loss in the double sense of the Principal having to accept projects of lower environmental quality – and hence lower benefits to society - at a relatively higher cost and hence disbenefit to society. This in spite of an optimal contract design somewhat mitigating the effects of asymmetric information.

For the conventional landowner's contract under asymmetric information, we find that compensation equals the net cost of the project to him, cf. (4.14). The equilibrium is, however, attained at a higher marginal rate of substitution for society than in the case of symmetric information. This is due to the last term of (4.17), which can be interpreted as the additional social marginal cost of improving x_C, arising from the effect this will have on the green contract x_G – larger subsidies for poorer projects. Thus, while the conventional contract is efficient in the sense of only compensating the landowner for his indifference payment, it is not Pareto optimal.

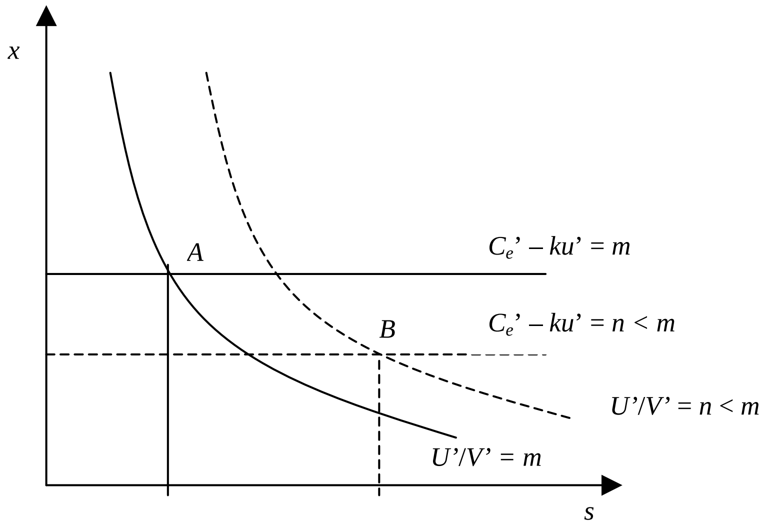

Figure 2. An illustration of the change in the optimal contract for the green landowner caused by asymmetric information.

These results have consequences for the type of x_C projects undertaken compared to the case of symmetric information. In this case, the landowner also received exact compensation, but did so in a situation with a lower marginal rate of substitution for society. Thus, by Proposition 7.3 (cf. Appendix), the project undertaken under asymmetric information has to be of lower quality to obtain higher marginal utility, *U'*(*x*), and, since compensation is exact, at the same time lower marginal cost to society, *V'*(s). Both effects increase the marginal rate of substitution and imply that the optimal contract involves a project where quality is inefficiently low.

It can be concluded that society spends too little on this type of projects and/or buys projects of too low quality from these landowners. The situation is illustrated in Figure 3.

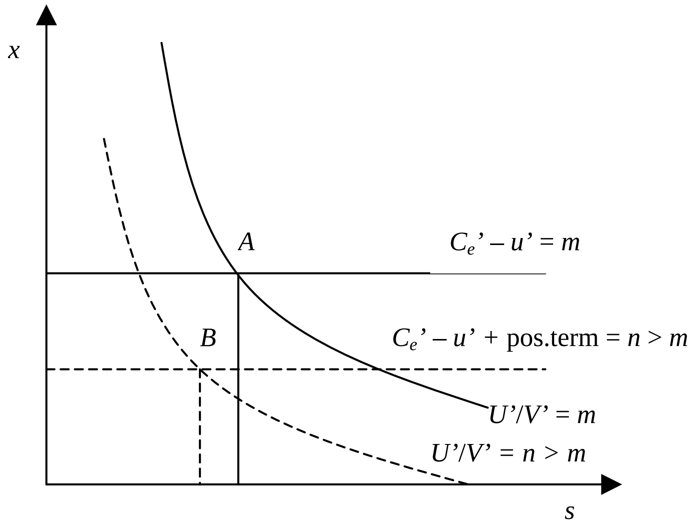

Figure 3. The conventional landowner: The case of symmetry with optimal contract at point *A* and the asymmetric case with optimal contract at point *B*. The

A final point of the results under asymmetric information is the relation between the welfare economic loss resulting from overcompensation of the green landowner, and that resulting from asking too little of the conventional landowner. We see from (4.15) that as x_C is reduced to nothing, overcompensation vanishes too. Reducing x_C at the same time increases the distortion present in (4.17), thereby increasing the welfare loss from asking too little of the conventional landowners. If we extrapolate the result to a situation with many landowners of each type, this suggests the following considerations. If society can fulfil most of its demand for afforestation projects by contracting with the green landowners, it will be wise to design fairly poor contracts for the conventional landowners – thereby reducing welfare loss on the majority of the projects. If conventional landowners are likely to be the primary suppliers of afforestation projects, the difference between the projects should be smaller and society can limit the welfare loss to being primarily a relatively large overcompensation on few projects only.

5.3 Assessing the gains from optimal contract designs

From the above it is clear that compared to the case of information symmetry the existence of asymmetric information implies welfare reductions – even in the optimal contract set. It may be worthwhile to recapitulate the benefits relative to the case where the asymmetric information is not taken into account and the Principal is offering a single flat-rate non-differentiated subsidy regardless of the landowner's type. Denote this situation Case I, the case where asymmetry is accounted for Case II, and let Case III denote the symmetric case. Cases II and III are those treated above.

In Case I, in order to induce the conventional landowner to participate, the Principal must supply contracts that fulfil:

$$\begin{aligned} &U'(x^I)/V(s^I) = C_e'(x^I) - u'(x^I) \\ &s = C_e(x^I) - u(x^I), \end{aligned} \qquad (5.1)$$

This condition is the solution for the conventional contract with symmetric information, see (4.3)-(4.5). Note that this subsidy will also be offered to the green landowner. He will be overcompensated *and* undertake a project of lower quality than optimal.

$$\begin{aligned} \Pi_G &= -C_e(x) + ku(x) + s = -C_e(x) + ku(x) + C_e(x) - u(x) \\ &= (k-1)u(x) > 0 \end{aligned} \qquad (5.2)$$

This observation and the analyses of Cases II and III allows us to make the following conclusions:

$$\begin{aligned} x_C^{II} &< x_C^{III} = x_C^{I} \\ s_C^{II} &< s_C^{III} = s_C^{I} \\ x_G^{III} &> x_G^{II} > x_G^{I} \end{aligned} \tag{5.3}$$

The first row follows from the result that the conventional project in Case II is reduced in quality due to its effect on the information rent needed for the green landowner. The second row follows from the first and (4.14), and the third follows from the analysis of the asymmetric case presented above: as the price of the green quality project increases due to information rents, less quality is demanded. It is not possible to say how s_G in the different cases relates to each other, as this depends on the exact form of the functions involved. Even if green landowners generally need less compensation for a given project, society may ask them to undertake projects so much better than the conventional alternative that the incentive payment s_G is larger than the alternative s_C.

Nevertheless, when comparing Case I and Case II, we know that society will only ask more of the green landowner if it is optimal, and hence - even if he needs a bigger incentive to undertake the projects of higher quality - overall benefits will still be larger. The overall welfare gain from acknowledging the asymmetric information and designing two optimal contracts instead of a single one, can be expressed as:

$$W^{II} - W^{I} = \underbrace{[U(x_G^{II}) - V(s_G^{II}) - U(x_G^{I}) + V(s_G^{I})]}_{>0,\, by\ proposition\ 8.3,\ (4.15),\ (4.16)\ and\ (5.1)} + \underbrace{[U(x_C^{II}) - V(s_C^{II}) - U(x_C^{I}) + V(s_C^{I})]}_{<0\ by\ proposition\ 8.3,\ (4.14),\ (4.17)\ and\ (5.1)} > 0 \tag{5.4}$$

where the expression in the first square bracket is known to be numerically larger than the second expression, due to the fact that the optimisation in the asymmetric case, with two resulting and different contracts, is less restricted than the optimisation with only one possible contract. The welfare gain is created through better use of the green landowner's willingness to undertake projects at a lower cost in terms of subsidies. Due to private information, the increased use of the green landowners has a cost in terms of overcompensation of the green agents and reduced quality of the projects offered to the conventional landowners.

6. Concluding Remarks and Perspectives

The long-term political objective of the Danish afforestation efforts is a doubling of the forest area from 450,000 ha to 900,000 ha within a century. The efforts of a decade of afforestation programmes involving subsidies for afforestation project has resulted in less than 20,000 ha of new forest, and hence there is still a long way to go. Interestingly, empirical studies (Madsen 2001) and observations (Statistics Denmark *et al*. 2002) indicate that a number of landowners are willing to undertake afforestation without compensation. Whatever the reasons for this, the observation indicates that landowners may differ significantly with respect to the private benefits they derive from the environmental goods produced by afforestation. Finally, the afforestation projects differ substantially with respect to quality of the environmental goods they supply. Common quality parameters are the use of deciduous instead of coniferous species, the inclusion of areas for recreation and outdoor life, the reestablishment of habitats like small ponds and streams, and other things usually preferred by the public (Jensen 1999). According to Statistics Denmark *et al*. (2002), the amount of coniferous species used in private afforestation projects is still very large, approximately 60%, and hence not likely to produce environmental goods of sufficient quality.

These observations show the obvious need for efficient design of incentive schemes for more private afforestation projects, involving incentives to enhance the environmental quality. Furthermore, the observation points out one possible way to improve the efficiency of incentive schemes, i.e. to make use of the variations among landowners with respect to their private benefits from afforestation projects. An evident obstacle here is that one cannot simply tell which landowners derive what level of benefits: Information is asymmetric.

The contribution of the present study is to show how this obstacle may be solved and gains in incentive scheme efficiency may be made. We show that, in a simple framework, it is optimal to form different contracts with different groups of landowners. Furthermore, we show how one should mitigate the adverse effects of private information by reducing the demands on landowners with little appreciation of environmental goods, and increasing the demands on and gains to landowners with more appreciation of such goods.

The model is, of course, overtly simple as it involves only two agents and assumes that society's utility of projects and disutility of incentive payments are additive. Nevertheless, while some of these simplifications and assumptions may be relaxed in a more technical study, e.g. by assuming a known distribution for the landowners' *k*, we prefer the simple set-up in this paper. While maintaining a reasonably simple notation, the model points out the important characteristics of the optimal contracts and the differences between situations with symmetric and asymmetric information, respectively.

In reality the implementation of incentive scheme variation as described will have to deal with a finite number of contract variants, most likely rather few. The results of this paper suggest that this type of schemes should include afforestation alternatives, which differs in quality: 1) Alternatives with low establishing costs and little focus on environmental goods. Incentive payments for this type of projects should be equal to the indifference payment needed by landowners not very keen on environmental goods. And 2) another type of afforestation projects, with considerable focus on environmental goods and higher establishing costs. These projects take into account that green landowners are willing to undertake them at a discount - reflecting their higher private benefit as well as their required information rent. With a limited number of contracts possible, inefficiencies will still prevail, but the associated welfare losses may be reduced and the afforestation process benefit.

7. Appendix

7.1. Reducing the asymmetric problem

Under asymmetric information the maximisation problem with all constraints becomes:

$$\begin{aligned}
&\underset{s,x}{Max} \quad W = U(x_G) - V(s_G) + U(x_C) - V(s_C) \\
&st. \\
&\qquad s_G = C_e(x_G) - ku(x_G) \\
&\qquad s_C = C_e(x_C) - u(x_C) \\
&\qquad s_G = -C_e(x_C) + k \cdot u(x_C) + s_C + C_e(x_G) - k \cdot u(x_G) \\
&\qquad s_C = -C_e(x_G) + u(x_G) + s_G + C_e(x_C) - u(x_C)
\end{aligned} \tag{7.1}$$

However, two constraints are redundant as shown by the following two simple propositions:

Proposition 7.1

The participation constraint of the green landowner is superfluous, as he will have a positive profit from any of the contracts offered.

Proof: The optimal contract offered to the conventional landowner must satisfy his participation constraint. Since, for any project, the green landowner derives a larger private utility from undertaking the project (k>1), he will always participate if the conventional landowner will. Formally stated:

$$\begin{aligned}
&If \qquad s_C - C_e(x_C) + u(x_C) \geq 0 \\
&then \quad s_C - C_e(x_C) + k \cdot u(x_C) > 0.
\end{aligned} \tag{7.2}$$

Proposition 7.2

The incentive constraint for the conventional landowner cannot be binding because he will always choose the contract designed for him, provided it satisfies the participation constraint.

Proof: The contract designed for the green landowner is customised to his higher private utility. Therefore, to the conventional landowner it implies a lower profit than choosing the contract designed for him. This follows from the participation constraint for the conventional landowner and the incentive constraint for the green agent which are both binding:

$$\begin{aligned} s_C &\geq -C_e(x_G) + u(x_G) + s_G + C_e(x_C) - u(x_C) \\ &\geq u(x_G) + ku(x_C) + s_C - ku(x_G) - u(x_C) \\ &\geq u(x_G) + ku(x_C) - ku(x_G) - u(x_C) + C_e(x_C) - u(x_C) \\ &= (1-k)\cdot(u(x_G) - u(x_C)) + C_e(x_C) - u(x_C) \end{aligned} \tag{7.3}$$

Since $k > 1$ and the project x_G will be of better quality than the project x_C, the first term is negative and hence the right-hand-side of the incentive constraint is smaller than the right-hand-side of the participation constraint, hence the former is redundant.□

Proposition 7.3

In (x, s)-space iso-curves of the U'/V'-measure are convex towards origo. Iso-curves of the $C'_e(x)$-$u'(x)$-measure in the (x, s)-plane are linear and have a zero slope.

Proof

The proposition follows from the properties of the functions *U* and *V*, and C_e and *u*, respectively. To see this for the *U'/V'*-measure, consider a point $y = (x', s')$ in the (*x*, s)-space where *U'/V'* = *m*. Letting *s* go towards zero implies that *V'* approaches 0 (V'(0)=0). To keep the measure *U'/V'* steady, *U'* must approach zero too, implying that the iso-curves must pass through points where *x* approaches infinity. Thus, from the point *y* the iso-curve bends upward in a convex fashion. Similar observations can be made if we from the point *y* decrease the value of *x* towards zero. This implies that *U*' increases and hence the iso-curve must stretch out along the *s*-axis in order to increase the value of *V*' appropriately. Obviously, iso-curves of the measure $C'_e(x)$-$u'(x)$ are lines along the *s*-axis, as *s* is not an argument in this measure. The observations follow directly from the derivatives:

$$\partial\left[U'(x)/V'(s)\right]/\partial s = -V''(s)U'(x)/[V'(s)]^2 < 0$$
$$\partial\left[U'(x)/V'(s)\right]/\partial x = U''(x)/V'(s) < 0$$
$$d[C_e^{'}(x) - u'(x)]/ds = 0$$
$$d[C_e^{'}(x) - u'(x)]/dx = C_e^{''}(x) - u''(x) > 0$$

Thus, *U*'/*V*' is convex towards origo and C'_e *u*' is linear along the *s*-axis. It also follows from these observations that the iso-levels of *U*'/*V*' increase towards origo, whereas the iso-levels of C'_e - *u*' increase along the *x*-axis.□

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