Exploring the performance of ambient taxation in local common property exploitation

Abstract

This paper analyses the impact of a group performance incentive mechanism on common property utilisation when cooperation between exploiters is endogenously determined. A livestock-pasture system is considered, where livestock is privately owned while the pasture is utilized as common property. Unless exploiters fully cooperate, the system is characterized by over exploitation. The paper analyses the performance of an ambient taxation mechanism as proposed by Segerson (1988) for regulation of a group non-point source polluters. By using a coalition formation model, we are able to investigate how ambient taxation affect may affect the level of cooperation between exploiters. This is the novelty of the paper. The paper demonstrates that fixed uniform tax rates leads to under-compliance with the ambient targeted level as the incentives to cooperate reduces, while ambient taxation based on fixed heterogeneous tax rates stimulates increased cooperation and therefore over-compliance. The paper also solves for the optimal tax rates and demonstrates how these should be adjusted according to a changing level of cooperation. A numerical analysis based on data from Sámi reindeer herding in northernmost Norway is presented to illustrate the theoretical results.

Thanks to Styret for Forskningsmidler over Reindriftsavtalen (SFR) and the Norwegian Research Council for funding this project.

1. INTRODUCTION

A number of papers have previously addressed the problem of regulating non-point pollution as a problem of moral hazard in groups (e.g., Segerson 1988; Xepapadeas 1991; Cabe and Herriges 1992; Horan et al. 1998). This common social problem is characterized by a divergence between socially and individually optimal behaviours, in combination with non-observability of the individual agent's behaviour. In her pioneering work on non-point pollution, Segerson (1988) proposed a tax/subsidy mechanism based on group performance to promote socially optimal behaviour. She suggested that the regulator should monitor ambient pollution concentrations and tax (subsidise) the polluters when ambient pollution levels are above (below) the optimal level. Hence, the liability of each polluter depends on the abatement effort of all polluters, not just her own. When assuming damage as linear in the ambient pollution level, Segerson demonstrated that the ambient tax/subsidy rule ensures a first-best outcome without observing individual pollution levels. Furthermore, individual monitoring was demonstrated superfluous also in the non-linear case as long as the transport mechanism is identical for all polluters.

Segerson's model assumes that polluters undertake non-cooperative Nash behaviour. Evidence from experimental economics suggests that the ambient tax/subsidy mechanism is likely to be efficient in small group settings of non-cooperating agents, whereas not efficient if agents are allowed to cooperate (Vossler et al. 2006)[1]. The argument is that the ambient tax/subsidy mechanism creates incentives for polluters to cooperate and agree on abatement strategies to reduce their expected tax payment (see Hansen 1998). If cooperation occurs, it therefore tends to render the ambient tax/subsidy mechanism inefficient as agents restrict their behaviour more than what is optimal (Hansen 1998, Vossler et al. 2006).[2] The reason is that this strategy benefits the group as a whole because each unit of abatement reduces the return of only one polluter while all polluters in the group benefit from additional subsidies.

The present paper departs from the literature on non-point pollution problems by focusing on a common property resource setting where harvesting by a group of agents implies reciprocal externalities through a resource constraint. In this setting, cooperation is primarily a way of internalizing harvesting externalities. Unless all herdsmen cooperate and *completely* internalize externalities, regulation is necessary if optimal exploitation is to be ensured. However, if individual harvesting is difficult to observe due to, e.g., costly monitoring or illegal harvesting, the regulator may face the problem of unreported and unobservable harvesting. Following Segerson (1988), an ambient tax/subsidy mechanism may be proposed as a solution to the information problem by specifying a targeted level of aggregate harvest and tax (subsidized) each harvester when the aggregate harvest is above (below) the targeted level. Alternatively, the tax/subsidy mechanism can be defined using the size of the resource stock as target. For the case of ambient tax/subsidy in fisheries with non-cooperative Nash behaviour, see Jensen and Vestergaard (2002) and Hansen et al. (2006).

In particular, this paper presents a livestock-grazing system, where livestock is privately owned while the pasture is utilized as common property. Hence, reciprocal externalities between herdsmen work through a vegetation constraint. The current paper explicitly allows for cooperation between agents in internalizing grazing externalities by introducing a collation formation model (e.g., Barrett 1994). An open membership one coalition game is assumed (Johannesen and Skonhoft 2009). That is, membership of the coalition is open to all herdsmen who are willing to abide by its rules. Thus, any herdsman can choose either to join the coalition, or not, and non-members of the single coalition will act independently and in pure self-interest. To what extent harvesting externalities are accounted for, is critically dependent on the level of cooperation between harvesters. In absence of cooperation no externalities are accounted for, in case of partial cooperation a fraction of the externalities is accounted for, whereas full cooperation means that all externalities are internalized.

The paper is motivated by Sámi reindeer herding in northernmost Norway and the on-going changes in the law regulating this industry. In accordance with the traditional Reindeer Management Act of 1978, herd sizes have been regulated through specified group level quotas, but the law of 1978 has been defective when it comes to possibilities to sanction violations (NOU 2001:35). A new Reindeer Management Act established in 2007 proposes a tax on quota violations. However, uncertainty still prevails to whether quota violations are to be taxed on the group level or the individual level. As questioned by the board of one of the reindeer management areas northernmost Norway in a comment to the proposal (January 2011)[3]: "Does it apply … to cases where the aggregate herd size exceeds the [group] quota. Or does it apply when a management unit exceeds an upper [individual] limit." Furthermore: "…[we find] a fine suitable only if upper herd size limits are defined at the [individual] level". Hence, uncertainty still prevails when it comes to final design of the proposed tax-quota system. In order to add insight about possible effects of ambient quota regulations, we therefore aim at analyzing the performance of an ambient tax/subsidy mechanism in a reindeer-pasture setting.

Although observing individual herd sizes can be costly due to huge areas, mixed herds, etc., the law and its related official documents (e.g., NOU 2001:35) make no reference to any such information problems as motivation behind group-level quotas. Instead, group-level quotas are seen as a way of stimulating self-government within Sámi herding communities (NOU 2001:35). However, despite long traditions for cooperation, the industry has been characterized by internal conflicts over pasture utilization over the past decades (e.g., NOU 2001:35). While preparing the new Reindeer Management Act, it has been emphasized that regulations should be based on the social structure and traditions within the herding industry and thereby contribute to reduce conflicts (e.g., NOU 2001:35). Therefore, instead of solving any information problem inherent in observing individual herd sizes, this paper aims at investigating how ambient taxation affects the prospects of cooperation in the reindeer herding industry.

By analysing the impact of an ambient tax/subsidy scheme in a setting where the level of cooperation is endogenously determined, we add new insights on the efficacy of an ambient tax mechanism that have not yet been demonstrated in the literature. Unlike non-point pollution models, cooperating herdsmen will account for the reciprocal externalities within the coalition. An ambient tax/subsidy mechanism as proposed by Segerson (1988) will then work as if coalition members are taxed more heavily on the margin than non-members and hence, reduce the incentive to cooperate. Consequently, and in contrast to Poe et al. (2004) and Vossler et al. (2006), the present paper demonstrates that the ambient tax/subsidy mechanism may stimulate *reduced* cooperation and hence, contribute to *excessive harvesting* of the common property resource as opposed to excessive abatement in non-point pollution models with cooperation.

Although the present paper focuses on a livestock-pasture system, the results are transferable to other kind of common property resources as well. As mentioned above, ambient tax/subsidy mechanisms have been analysed in case of fisheries by Jensen and Vestergaard (2002) and Hansen et al. (2006), but they do not consider fishermen as co-operators in terms of internalising harvesting externalities. Cooperation in harvesting of local common property resources is, however, well known from the literature. Examples from pastures and fisheries are provided by, e.g., Acheson (1987), Ostrom (1990), and Schlager and Ostrom (1992). It is therefore of interest to analyse how cooperation in common property exploitation affects the efficacy of ambient-based regulations.

The rest of the paper is organized as follows. The first part of section two provides the ecological part of the livestock-pasture model, while the second part proceeds by introducing herdsman behaviour and coalition formation in a pre ambient-based regulation scenario. The impact of Segerson's (1988) ambient tax/subsidy mechanism on the level of cooperation and pasture utilization is then explored in section three. Section four solves for the optimal tax rates and demonstrates how to adjust the tax rates for changes in the level of cooperation in order to achieve optimal pasture utilization. Section five presents a numerical analysis of the performance of ambient tax/subsidy based on data from reindeer herding in northernmost Norway. Finally, some concluding remarks are provided in section six.

2. THE MODEL

2.1 A livestock-pasture ecological model

This section describes the ecological part of the livestock-pasture model, while herdsman behaviour follows in the next section. It is assumed that a fixed number of N herdsmen utilizes the common property grazing land. The model allows for $0 \le n \le N$ herdsmen to join a coalition of which members cooperate in internalizing grazing externalities. The number of livestock kept by a coalition member and a singleton are denoted y^c and y^{nc}, respectively. The ecological system is then described by equations (1) and (2), where

$$dX/dt = rX(1 - X/K) - bX(ny^c + (N-n)y^{nc}) . \quad [1]$$

represents the vegetation dynamics. The vegetation quantity (i.e., lichen) X grows according to a logistic function $rX(1 - X/K)$ with K as the vegetation carrying capacity, and r as the intrinsic (maximum specific) vegetation growth rate. The vegetation quantity decreases due to consumption by livestock $bX(ny^c + (N-n)y^{nc})$, where the vegetation consumption *per animal* bX is assumed to increase linearly in the amount of vegetation with $b > 0$.[4] For a fixed vegetation quantity $dX/dt = 0$, we see that the equilibrium animal-vegetation relationship is $X = K\left[r - b(ny^{c} + (N-n)y^{nc})\right]/r$. The equilibrium vegetation quantity thus decreases linearly in the number of grazing animals, that is, the marginal vegetation damage caused by grazing is constant.

Equation (2) describes the livestock dynamics for an individual herd and comprises the difference between animal growth $qbXy^{i}$ and slaughtering h^{i}, where $i = c, nc$. The per animal growth is specified as proportional to vegetation consumption, where the parameter $0 < q < 1$ measures the transformation of vegetation biomass into animal growth.

$$\frac{dy^{i}}{dt} = qbXy^{i} - h^{i} \qquad [2]$$

2.2 Herdsman behaviour and coalition formation

We now introduce the economic part of the model and the coalition formation game. First, coalition formation and vegetation utilization is analysed in a pre-tax scenario. An ambient tax/subsidy on is then introduced in the section following below. The profit for herdsman *i*, π^{i}, is:

$$\pi^{i} = ph^{i} - w^{i}y^{i} \qquad [3]$$

where *p* is the per animal slaughtering price (net of slaughtering costs) and w^{i} is the per animal herding cost.[5]

Following Johannesen and Skonhoft (2009) we assume that marginal herding cost of singletons w^{nc} is fixed, whereas the marginal cost of coalition members decreases with the size of the coalition, i.e. $w^{c} = w(n)$ with $w' < 0$ and $w'' \geq 0$ for all $2 \leq n \leq N$, $w(1) = w^{nc}$. Johannesen and Skonhoft (2009) argued that cooperation creates a cost advantage not gained by singletons, the reason being that cooperating herdsmen merge their livestock herds together and look after the flock in shifts, which enables them to spend less time on the pastures than they would have if operating alone. This assumption is essential as it allows for improved prospects of cooperation compared to a situation where no such benefit of cooperation is present.[6] A similar assumption made for cooperating fishermen by Deacon et al. (2010), who argue that cooperation enables fishermen to coordinate the location and timing of fishing by sharing information on stock locations and by providing shared infrastructure.

The coalition formation model is a two step game. In the first step all herdsmen, independently and simultaneously, decide whether or not to join the (potential) coalition. In the second step, coalition members and singletons decide upon their herd sizes, and the accompanying vegetation quantity, through a simultaneously Nash-Cournot game. Coalition members play Nash against singletons by accounting for the reciprocal grazing externalities working within the coalition, while ignoring the externalities imposed on non-members. Singletons, on the other hand, play Nash against all.

The game is solved by backward induction. Given the choice of non-cooperation, a singleton determines herd size in order to maximize own profit, subject to the ecological constraints [1]-[2] in equilibrium, i.e., when $dX/dt = 0$ and $dy^i/dt = 0$ ($i = nc$), while ignoring the negative impact upon the remaining $(N-1)$ herdsmen. Then, when inserting for the steady state ecological constraints into [3], the profit of a singleton reads $\pi^{nc} = pqbK(r - bny^c - b(N-n)y^{nc})y^{nc}/r - w^{nc}y^{nc}$. The first order condition of this problem is given by:

$$pqbX - pqb^2(K/r)y^{nc} - w^{nc} = 0\,. \qquad [4]$$

The second term in [4] implies that a singleton accounts only for his own impact on the vegetation quantity and ignores the externality imposed on the $N-1$ remaining herdsmen. Hence, a singleton will increase his herd size up to the point where the marginal private rent equals zero.

The coalition determines individual herd sizes so as to maximize total coalition profit. Hence, the coalition accounts for the grazing externalities working between the n coalition members, while ignoring the impact on the $(N-n)$ singletons. When inserting for the steady state ecological constraints into [3] the joint profit reads $n\pi^n = pqbK(r - bny^c - b(N-n)y^{nc})ny^c/r - w(n)ny^c$. The first order condition of this problem is:

$$pqbX - pqb^2 (K/r)ny^c - w(n) = 0 . \qquad [5]$$

The second term in [5] equals the aggregate marginal cost of the coalition of an additional animal in the individual herd and implies that the vegetation quantity impact upon the other coalition members is taken into account. The optimal number of animals kept by a coalition member is thus determined by the equity between the private marginal rent and the *within* coalition social marginal cost.

When inserting for X from [1] (with $dX/dt = 0$) into the first order conditions [4]-[5] and solving for y^c and y^{nc}, the profit maximizing number of animals kept by a member of the coalition and a non-cooperator is found as:

$$y^c(n) = \frac{r}{bn(N-n+2)}\left[1 - \frac{(N-n+1)w(n)}{pqbK} + \frac{(N-n)w^{nc}}{pqbK}\right] \qquad [6]$$

and

$$y^{nc}(n) = \frac{r}{b(N-n+2)}\left[1 - \frac{2w^{nc}}{pqbK} + \frac{w(n)}{pqbK}\right], \qquad [7]$$

respectively.

In the first stage of the game each individual herdsman decides whether to join the potential coalition or not. A stable coalition must fulfil the following two conditions of internal and external stability (e.g., Barrett 1994):

$$\pi^c(n) \geq \pi^{nc}(n-1) \qquad \forall cooperators \qquad [8]$$

and

$$\pi^{nc}(n) \geq \pi^c(n+1) \qquad \forall non-cooperators . \qquad [9]$$

That is, every coalition member should not be worse off by staying within the coalition with n herders than to become a non-cooperator with $n-1$ cooperators left. By the same token, no non-cooperator should be worse off by staying outside the coalition with n herders than joining it so that the coalition size becomes $n+1$. A coalition of $n = n^* \leq N$ cooperators that simultaneously satisfies conditions [8] and [9] is stable.

Equations [6] and [7] demonstrate that coalition members may restrict their herd sizes below that of singletons or they may keep more livestock than singletons. The terms before the brackets indicate that coalition members account for the grazing externalities within the coalition, while singletons ignore the grazing externalities imposed on others. This works hence in the direction of coalition members keeping fewer animals than singletons. On the other hand, cooperation implies reduced marginal herding cost which works in the direction of cooperators keeping more animals than singletons. The external stable coalition condition states, however, that singletons should benefit more from free riding on the coalition than they would gain from joining in. Partial cooperation stability hence means that coalition members restrict their herd sizes compared to that of singletons, otherwise there would be nothing to gain from free riding on the coalition. Grand coalition stability may, however, result in increased herd sizes compared to a situation with no cooperation. See also Johannesen and Skonhoft (2009).

3. A SEGERSON AMBIENT TAX/SUBSIDY MECHANISM

Unless all herdsmen cooperate, only a fraction, if any, of the grazing externalities is accounted for and hence, common property exploitation implies excess herd sizes and economic overgrazing. Segerson (1998) proposes the following fixed tax-rate mechanism to compensate for inefficiency in the unregulated scenario:

$$T(Y) = t(Y - \hat{Y}) \qquad [10]$$

where $\hat{Y}$ is the *targeted* vegetation quantity and $Y = ny^c + (N-n)y^{nc}$ is the actual total number. Equation [10] indicates that if the targeted aggregate herd size is below the actual level, each herdsmen pay a tax, while the herdsmen receive a subsidy ($T(Y) > 0$) if $Y < \hat{Y}$. Given this mechanism, the group of herdsmen is jointly held liable for an individual herdsman's contribution to overgrazing. This section considers an ambient tax mechanism based on fixed uniform tax rates. We solve for the optimal tax rates in section five below.

When including the ambient tax mechanism the first order conditions of a singleton and coalition member read $pqbX - pqb^2(K/r)y^{nc} - w - t = 0$ and $pqbX - pqb^2(K/r)ny^c - w - nt = 0$, respectively. The last terms on the right hand sides reflect that a singleton accounts for own impact on the tax payment, while a cooperator accounts the impact on the tax payment of all coalition members. Hence, although the tax rate t is identical across herdsmen, the ambient tax/subsidy mechanism hits a coalition member harder on the margin than a singleton. It follows that, for a fixed level of cooperation, coalition members restrict their herd sizes even more relatively to that of singletons. When inserting $X = K(r - b(ny^c + (N-n)y^{nc}))/r$ (section two above) into the first order conditions, the profit maximizing number of animals kept by each member of the coalition and singleton is found as:

$$y^c(n) = \frac{r}{bn(N-n+2)}\left[1 - \frac{(N-n+1)w(n)}{pqbK} + \frac{(N-n)w^{nc}}{pqbK} - \frac{(N-n+1)nt}{pqbK} + \frac{(N-n)t}{pqbK}\right] \qquad [6']$$

and

$$y^{nc}(n) = \frac{r}{b(N-n+2)}\left[1 - \frac{2w^{nc}}{pqbK} + \frac{w(n)}{pqbK} + \frac{(n-2)t}{pqbK}\right], \qquad [7']$$

respectively.

From equation [7'] it is seen that the ambient tax stimulates singletons to *increase* their herd size for all $2 < n < N$. This result is quite surprising, but occurs because the marginal cost of livestock keeping increases more for coalition members than for singletons. Hence, coalition members have the incentive to collectively reduce herd sizes below the target of the ambient tax which, in turn, allows for singletons to increase their herd sizes. Still, when keeping the size of the coalition fixed, the vegetation quantity increases. The latter is seen by inserting [6'] and [7'] into [1] (with $dX/dt = 0$. Then the vegetation quantity reads:

$$X(n) = \frac{K}{(N-n+2)}\left[1 + \frac{w(n)}{pqbK} + \frac{(N-n)w^{nc}}{pqbK} + \frac{Nt}{pqbK}\right] \qquad [11]$$

Imposing the tax mechanism also influences the coalition size which, in turn, affects the aggregate herd size and corresponding vegetation quantity. We now take a brief look at this while numerical examples add more insight in section five below. As demonstrated above, the direct effect (i.e., for a fixed coalition size *n*) of the ambient tax/subsidy stimulates a reduction in the aggregate herd size and increased vegetation quantity. The new equilibrium is, however, associated with less cooperation because of improved free rider benefits due to the excessive herd size reductions made by the coalition members. This indirect effect means that a smaller share of the grazing externalities is accounted for and works in the direction of an increase in the aggregate herd size. The total effects on livestock numbers and grazing pressure are thus ambiguous. A uniform ambient tax mechanism may therefore reduce the vegetation quantity, even though the marginal cost of livestock maintenance increases for all. See section five.

To sum up, ambient taxation based on fixed uniform tax rates has a negative impact on the level of cooperation which reverses the direct reduced grazing-intensity effect and may even enhance the aggregate herd size. Regulators should be aware that internal institutions may vary due to changing economic conditions and aim to account for this by adjusting the tax rates properly. In the next section we therefore solve for the optimal tax rates and demonstrate how these vary with the level of cooperation in the herding community.

4. OPTIMAL TAX RATES

The socially optimal herd sizes y^c and y^{nc} are determined so as to maximize the aggregate profit in the herding community given the ecological constraints [1]-[2] in equilibrium, i.e., when $dX/dt = 0$ and $dy^i/dt = 0$. The first order conditions are given as

$$pqbX - pqb^2(K/r)(ny^c + (N-n)y^{nc}) - w = 0 \qquad [12]$$

The first term in this condition represents the private marginal income of adding another animal to the individual herd, for a given vegetation quantity. The second and third terms are the marginal cost components, where the second term reflects the total social marginal cost which implies that the vegetation quantity impact upon all other herdsmen is taken into account. The latter reflects the loss of future slaughtering income for all due to an individual herd size increase. This is the external effect that herdsmen may fail to fully take into account, unless they fully cooperate, under the private profit maximization demonstrated in section three above.

This section solves for the optimal tax rates in two scenarios. First, we allow for tax rates to differ between cooperators and non-cooperaters, while the second scenario considers uniform tax rates.

4.1 Heterogeneous tax rates

The individual tax payment is now given as $T^i(Y) = t^i(Y - \hat{Y})$, where the tax rate imposed on coalition members t^c may differ from that imposed on singletons t^{nc}. Efficiency is achieved when all grazing externalities are internalized and the cost advantages of cooperation are fully exploited, i.e., $n = N$. The corresponding first order efficiency condition then reads $pqbX - pqb^2(K/r)Ny - w(N) = 0$ (subscript denoting cooperator is omitted) and defines the efficient individual herd size y^*, where X is found in equation [1] (with $dX/dt = 0$). That is, efficiency is ensured when all herdsmen keep y^* animals. By equating this condition with the corresponding private first order conditions, the optimal tax rates are found as:

$$t^c = \left[\frac{pqb^2K}{r}(N-n)y^c + w(N) - w(n)\right]\frac{1}{n} \qquad [13]$$

$$t^{nc} = \frac{pqb^2K}{r}(N-1)y^{nc} + w(N) - w^{nc} \qquad [14]$$

The optimal tax rates are set equal to the marginal net social cost of exceeding the social optimal herd size and hence, ensure compliance with the targeted aggregate herd size Ny^*. As argued above, the pre-tax stable equilibrium of partial cooperation is characterized by cooperators keeping smaller herds than singletons. Hence, in order to ensure both cooperators and singletons to comply with the individual efficient herd size y^*, the optimal tax rate on coalition members is below that of singletons, i.e. $t^c < t^{nc}$.

Some differences compared to ambient pollution problems are worth mentioning. In the present, the marginal vegetation loss caused by grazing animals is constant. The optimal tax rates still vary across coalition members and singletons, which contrasts the finding in ambient pollution problems where constant marginal damage implies *uniform* tax rates (Segerson 1988). This contrast is due to some fundamental differences in the systems studied. First, grazing externalities already accounted for are deducted in the present. Because coalition members individually accounts for a larger share of the grazing externalities than a singleton they hence obtain a larger tax rate deduction. Second, deviations from the minimum marginal herding cost $w(N)$ stimulate individual herds below the efficient individual level. This is deducted in the present in favour of singletons because they operate with a relatively high marginal herding cost compared to coalition members. Third, as opposed to singletons, coalition members account for the reciprocal impact on tax payments within the coalition. This stimulates herd size reductions below the efficient level in the coalition and is hence deducted by charging coalition members by a share of the marginal net social cost only.

Equation [14] demonstrates that the optimal tax rate levied on singletons is set independently of the realized coalition size n. To see this, recall that the optimal tax rates ensure that all herds are adjusted to the efficient individual herd size, i.e., $y^c = y^{nc} = y^*$, where efficiency is defined as full cooperation. y^* is therefore determined independently of the actual level of cooperation. It follows that the tax rate imposed on singletons is set irrespective of the level of cooperation in the pre-tax scenario. In contrast, even though individual efficiency (y^*) is defined independently of n, equation [13] shows that the optimal tax rate on coalition members varies with the size of the coalition. Furthermore, when specifying the marginal cost $w(n)$ as in the numerical analysis below, it can be demonstrated that the optimal tax rate t^c decreases with the size of the coalition. The reason is that increased cooperation means that larger fractions of the grazing and tax payment externalities are accounted for, which work in the direction of coalition members keeping smaller herds. In order avoid herd reductions below the efficient level y^*, it is therefore optimal to adjust the tax rate on coalition members for a changing coalition size.

Assume now that the pre-tax scenario is characterized by partial cooperation and imagine that the regulator impose ambient taxation based on heterogeneous tax rates in order to correct for present inefficiency. For a given level of cooperation, the incentive to join the coalition is increased due to the relatively high tax rate imposed on singletons. As the size of the coalition increases, the tax rate imposed on coalition members reduces even further below that on singletons, which attracts additional herdsmen to join the coalition. This reinforcing impact on the coalition size will continue until the system settles in full cooperation stability. See also the numerical analysis in section six below.

For the ambient taxation scheme with heterogeneous tax rates to ensure efficient common property exploitation, the regulator must be able to perfectly distinguish singletons from coalition members and charge them a higher tax rate. This may not be a trivial task. First, efficiency requires that the regulator can observe the level of cooperation and adjust the tax rate imposed on cooperators accordingly. The level of cooperation can be observed directly if membership is registered. If, however, cooperating behaviour follows some kind of informal agreement, then direct observation of the coalition size can be difficult. If this is the case, then the regulator can still calculate the coalition size indirectly through the deviation between the actual and optimal aggregate herd. A second problem inherent in charging heterogeneous tax rates is that cooperators are imposed a lower tax rate than singletons. If the regulator is not able to perfectly identify a herdsman's type, then singletons will pretend to be cooperators to achieve the most favourable tax rate. One possible solution is to offer alternative deals which satisfy a self-selection constraint. Another possible way of overcoming this information problem is to impose uniform instead of heterogeneous tax rates.

4.2 Uniform tax rates

Let us consider an ambient tax mechanism with uniform tax rates. Then, by equating the first order efficiency condition with the private first order conditions (with $t^{nc} = t^{c} = t$), the uniform tax rate that ensures the efficient aggregate herd size, and thereby compliance with the targeted aggregate level, is given by:

$$t = \frac{1}{2N}\left[(N-n)pqbK + (N-n+2)w(N) - 2w(n) - 2(N-n)w^{nc}\right] \qquad [15]$$

Setting the uniform tax rate as in [15] stimulates the herding community to reduce the aggregate herd size to the targeted aggregate level. Note that with uniform tax rates the regulator allows for individual deviation from the efficient individual herd size y^{*} and sets instead the tax rate so as to ensure group compliance with the aggregate target. It can be demonstrated that the optimal uniform tax rate is somewhere between the optimal heterogeneous tax rate imposed on cooperators and singletons, that is $t^c \leq t \leq t^{nc}$ for all $1 \leq n \leq N$. See Appendix A1. Hence, for a fixed level of cooperation, singletons benefit from uniform taxation when compared to heterogeneous taxation in the sense that the relatively low uniform tax rate enables singletons to exceed the efficient individual herd size y^*. In absence of cooperation, however, the two taxes rates coincide. Coalition members, on the other hand, are faced with a higher tax rate under the uniform taxation scheme for a fixed level of cooperation, which stimulates herd sizes below the efficient individual level in the coalition.

The new equilibrium is, however, associated with less cooperation than the pre-tax scenario. While all herdsmen face the same tax payment under uniform ambient taxation, coalition members are hit harder on the margin than singletons because they account for the reciprocal effect on within-coalition tax payments. The following excessive herd size reductions by coalition members result in improved free rider benefits. Hence, as opposed to an optimal heterogeneous ambient taxation scheme, uniform tax rates result in less cooperation. If the regulator fails to correct the tax rate accordingly then, because a smaller fraction of the grazing externalities is accounted for, the aggregate herd size will increase above the social optimal level. In order avoid non-compliance with the targeted aggregate herd size the regulator should increase the tax rate for all. See also Appendix A1. Again, a higher uniform tax rate hits cooperators more than singletons on the margin stimulating herdsmen to leave the coalition. This reinforcing impact on the coalition size and the optimal uniform tax rate will continue until the system settles in a new stable equilibrium where the aggregate herd size is in compliance with the targeted level, but where all herdsmen act as singletons. Therefore, in the new stable equilibrium the optimal uniform tax rate equals [14].

Both ambient taxation schemes based on optimal heterogeneous and optimal uniform tax rates ensure compliance with the targeted aggregate herd size. The advantage of uniform over heterogeneous tax rates is, however, that less information is required to calculate the optimal tax rate. Because uniform tax rates lead to no-cooperation stability, the regulator can set the optimal tax rate as in [14] and hence, irrespective of the current level of cooperation and coalition membership. As in case of optimal heterogeneous tax rates, however, information about the cost structure is required. The disadvantage of uniform compared to heterogeneous tax rates is that the former results in a stable equilibrium where herdsmen fail to utilize the cost advantage and hence, the overall profit is below the maximum level.

5. REINDEER HERDING IN NORWAY

This section provides a numerical example based on data from Sámi reindeer herding in northernmost Norway. In this region, reindeer are privately owned but graze on common property pastures. Although there are long traditions of cooperation in pasture utilization between herdsmen, the industry has been internal conflicts over the past decades. For details, see Johannesen and Skonhoft (2008). The common property pastures have experienced periods of substantial overgrazing, and suffered a significant decline in vegetation cover (Johansen and Karlsen 2005). As mentioned in section one, the traditional the Norwegian government has specified district level quotas in order to regulate herd sizes (NRHA 2007). However, the traditional law has been unclear on how to sanctioning quota violations (NOU 2001:35). One intention of the new Reindeer Management Act of 2007 is to implement a tax on quota violations. However, as mentioned in section one, uncertainty still prevails to whether sanctions should be specified on the group or the individual level.

The numerical analysis is based on data from western Finnmark reindeer herding area, which is the main grazing area in Norway. The vegetation cover is specified as kilo vegetation (i.e., lichen) per km^2. The number of management units N (i.e. households) is fixed as 10. The herd sizes are measured as number of animals per management unit. The marginal herding cost of a coalition member is specified as $w(n) = w^{nc} / n$ for all $2 \le n \le N$. Table 1 presents the baseline economic and ecological parameter values.

Table 1 about here

Table 2 demonstrates the profit, individual and aggregate herd size, and vegetation level corresponding to each possible *n* in the pre taxation baseline case. Total profit in the herding community is defined as $\Pi = n\pi^{c}(n) + (N-n)\pi^{nc}(n)$. It is seen that the aggregate herd size in absence of cooperation (i.e., $n=1$) is significantly above the social optimal level (i.e., $n=10$). However, the aggregate herd decreases with the number of herdsmen in the coalition. As $\pi^{nc}(1) < \pi^{c}(2)$, it is profitable for a singleton to form a coalition with another herdsman. The reason is that they benefit more from a reduced marginal herding cost than the cost of accounting for the within coalition externalities. Table 2 then indicates that non-cooperators always do better by joining the coalition for $n < 5$. For all $n \geq 5$, on the other hand, non-cooperators are better off by staying outside the coalition. Hence, a coalition consisting of $n^* = 5$ herdsmen is the only stable equilibrium in the baseline case. Not surprisingly, when compared to a situation with no cooperation (i.e., $n = 1$), all herdsmen are better off in the partial cooperation stable equilibrium. However, the community profit and vegetation quantity are below the efficient levels. We therefore proceed by analysing the impact of ambient taxation.

Table 2 about here

Table 3 demonstrates how ambient taxation based on fixed uniform tax rates affects the system. It is assumed that the regulator sets the tax rate so as to ensure the efficient grazing intensity *given* the baseline coalition size (i.e., for $n = 5$) that is, without considering any change in the level of cooperation. The targeted aggregate herd size is set equal to the optimal size of 2625 animals (see Table 2 above). The uniform tax rate evaluated at $n = 5$ and ensuring non-negative profits equals 373 NOK. For the coalition members, this tax rate implies that the marginal cost of keeping reindeer is above the marginal benefit which stimulates the herdsmen in the coalition to restrict their herd sizes to zero. The marginal cost of reindeer keeping increases also for singletons but less than that of cooperators, because the latter accounts for the reciprocal impact on tax payments within the coalition. For a fixed level of cooperation $n = 5$, singletons reduce their herds to meet the aggregate target. At this level of cooperation cooperators earn zero profit while the profit of singletons is significantly improved due to improved vegetation quantity, animal growth and slaughtering. At the community level the vegetation improvement dominates the negative impact on profit of reduced herd sizes and results in increased community profit. Note that this differs from the pollution literature where firms are assumed not to benefit from a cleaner environment and hence, worse off from taxation.

However, the uniform tax scheme increases the free rider benefits and stimulates cooperators to leave the coalition. For the given tax rate, Table 3 demonstrates that the new stable equilibrium is characterized with no cooperation and excess grazing intensity when compared to the targeted aggregate herd. That is, the lower level of cooperation renders the uniform ambient taxation scheme inefficient but, in contrast to what is claimed in experiments of ambient taxation in the pollution literature (e.g., Poe et al. 2004; Vossler et el. 2006), inefficiency results in economic *over*grazing and not the opposite.

Table 3 about here

We now consider the impact of ambient taxation when assuming that the regulator can perfectly distinguish singletons from cooperators and hence, the regulator imposes heterogeneous tax rates. Again it is assumed that the tax rates are set so as to ensure the efficient grazing intensity *given* the baseline coalition size (i.e., for $n = 5$) and without taking into account possible changes in the level of cooperation. The heterogeneous tax rates that ensure the targeted aggregate herd size at $n = 5$ are $t^c = 65$ NOK and $t^{nc} = 442$ NOK. As demonstrated in section five above, the relatively low tax rate on coalition members reflects that they account for the reciprocal grazing- and tax payment externalities within the coalition. Consequently, for a given level of cooperation, the incentive to join the coalition improves. When more herdsmen join the coalition, the new coalition accounts for a larger fraction of the grazing externalities, which, even with the imposed tax rate, enables the remaining singletons to increase their herd size as well as the number of animals slaughtered. Actually, the increased slaughtering income dominates and makes the remaining singletons better off, even before the subsidy payment, compared to the baseline scenario. The positive impact on the vegetation quantity is strong enough to ensure enhanced slaughtering in the coalition as well. The system settles with a stable coalition of size $n = 6$ and the new equilibrium is characterized with a grazing intensity some three per cent *below* the efficient level.

Table 4 about here

This section is closed by investigating the impact of a taxation scheme based on individual quotas. This scheme is motivated from the government’s intention for future regulation of reindeer herding in Norway. The theoretical background is provided in Appendix A2.

Table 5 reports the results when reindeer herding is regulated with individual quotas and uniform tax rates. It is again assumed that the regulator sets the tax rates so as to ensure the efficient grazing intensity given the baseline coalition size (i.e., for $n = 5$) without considering any impact on the level of cooperation. A uniform tax rate of 442 NOK per excessive animal ensures the targeted aggregate herd size (2625 animals) at $n = 5$. For a fixed level of cooperation and when compared to the baseline scenario (Table 2), cooperators reduce their individual herds further below the individual allowable quota which allow for singletons to exceed the quota level. The improvement on vegetation quantity ensures increased profits for all. The indirect effect of individual uniform quotas works through a changing coalition size. Because non-cooperators initially keep more animals than coalition members, the tax payment of singletons is high relatively to that of coalition members. Hence, the profit of being outside the coalition reduces relative to that of joining which enhances the incentives to join the coalition. As the coalition size increases, a larger proportion of the grazing externalities is taken into account, which strengthens the negative effect on the total animal number and carries the grazing intensity below the efficient level. The system settles in a stable equilibrium with $n = 7$ cooperating herdsmen and grazing intensity some 5 per cent below the efficient level.

Table 5 also demonstrates that all herdsmen are better off compared to the baseline scenario. Because singletons exceed the allowable quota they are imposed a positive tax payment. However, the vegetation improvement and subsequent slaughter increase is strong enough to compensate for the tax payment. This is obviously a strange result, but can be explained by the cooperating behaviour of the coalition members. Because coalition members account for the negative externalities within the coalition, additional externalities are accounted for as the size of the coalition increases. The remaining singletons are therefore better off if this effect dominates the tax payment. Coalition members receive a subsidy payment which strengthens the positive profit effect of increased vegetation quantity.

Table 5 about here

Assume instead that non-compliance with the individual quota is taxed with heterogeneous tax rates so as to ensure individual compliance. The individual quota is $\hat{y} = 262$ and that the tax rates are set to ensure individual compliance with the quota at $n = 5$, so that $t^{c} = 325$ NOK and $t^{nc} = 442$ NOK. Table 6 reports the results. For a fixed level of cooperation, all herdsmen are in compliance and better off compared to the baseline scenario. However, due to a relatively high tax rate, the marginal cost of reindeer keeping increases more for singletons than those cooperating and hence, the incentive to join the coalition improves. The new stable coalition consists of nine herdsmen and accounts for a larger fraction of the grazing externalities, which results in a grazing intensity significantly below the aggregate targeted level. The present tax scheme increases the marginal cost of reindeer keeping for cooperators and non-cooperators just as much as the ambient taxation scheme with heterogeneous quotas. Still, the individual tax scheme has a stronger effect on the level of cooperation and the aggregate herd size than the former. The reason is that the present tax/subsidy payment is based on individual, and not ambient, deviations which favour members of the coalition and increase the incentive to join even more. Furthermore, although all herdsmen are better off compared to the baseline scenario, cooperators prefer individual before ambient quotas while the opposite applies for singletons.

Table 6 about here

Finally, consider again ambient taxation and assume that tax rates are perfectly adjusted for a changing coalition size. In case of heterogeneous tax rates the system settles with full cooperation and economic efficiency (community profit 1 813 534 NOK). Also optimal uniform tax rates ensure compliance with the aggregate target. However, the system settles in a stable equilibrium of no cooperation and hence, inefficiency (community profit 1 341 120 NOK).

6. CONCLUDING REMARKS

Several papers, beginning with Segerson (1988) have developed promising tax mechanisms that solve the group moral hazard problem inherent in non-point source damage by regulating a group of users (polluters) based on ambient rather than individual use. Yet, when individuals in a group can communicate in the sense that actions are coordinated to reduce the tax payment, experiments have demonstrated that group profit maximization will result in a damage level significantly lower than the social optimum (Suter et al. 2008; Vossler et al. 2006).

This paper considers how cooperation in the exploitation of a common property resource can affect the efficacy of a group performance incentive mechanism. Here, cooperation is mainly about internalising externalities in common property utilization, but cooperators also consider how they affect each others’ tax payment.

An ambient tax mechanism is applied in a coalition formation model that allows for endogenous determination of the level of cooperation. The specific system studied is livestock grazing on common property pasture, where a total allowable number of livestock is specified for the group of herdsmen and each herdsman is held liable for group level violations.

The paper considers several tax rules. The fixed uniform tax mechanism charges each herdsman a constant marginal tax without being adjusted for any change in the level of cooperation. It is demonstrated that this tax rule stimulates reduced cooperation which, in turn, results in a grazing pressure above the ambient targeted level. Furthermore, if the marginal tax rate is 'low', the aggregate number of livestock may exceed the pre-tax level. Fixed heterogeneous tax rates, on the other hand, stimulate the group of herdsmen to reduce the aggregate herd below the ambient target. The results suggest that recognizing the potential for cooperation is a critical factor in the design of group-based policies.

The paper also solves for the optimal tax rates and demonstrates how these should be adjusted according to a changing level of cooperation. In case of heterogeneous tax rates, the system credits cooperators by levying them a low marginal tax compared to singletons. This gives incentives to join the coalition which in the end results in full cooperation and economic efficient utilization of the pasture. Also uniform tax rates perfectly adjusted for a changing level of cooperation ensure compliance with the optimal grazing pressure. However, this tax rule stimulates herdsmen to leave the coalition and, eventually, the system settles in a stable equilibrium of no cooperation and hence, the overall profit is below the optimal level.

Determining optimal heterogeneous tax rates requires information about the level of cooperation in the group of herdsmen. Cooperation levels may, however, be difficult to accurately predict in a real-world setting. The advantage of uniform tax rates is then that less information is required to calculate the tax rate that ensures compliance with the optimal quota. It has been demonstrated that the marginal uniform tax can be determined irrespective of the current level of cooperation and hence, without identifying coalition members from non-members. An extension of this analysis for future work will be to include the regulator's joint decision of taxation and monitoring to further investigate the optimal tax scheme.

Appendix

A1. Optimal tax rates

When solving the first order efficiency condition the efficient individual herd size yields $y^* = r\left[1 - w(N)/(pqbK)\right]/(2b)$. When inserting this expression into inserting into [13] and [14] the optimal heterogeneous tax rates are given as

$t^{nc} = \left[(N-1)pqbK + (N+1)w(N) - 2Nw^{nc}\right]/(2N)$ and

$t^{c} = \left[(N-n)pqbK + (N+n)w(N) - 2Nw(n)\right]/(2Nn)$. By inserting $n=1$ into [15] we see that in absence of cooperation the optimal uniform tax rate coincides with the singleton optimal tax rate, that is $t(1) = t^{nc}$. Derivation of [15] with respect to n yields

$dt/dn = -\left[pqbK + w(N) - 2w^{nc} + 2w'(n)\right]/(2N)$ which is negative for all $1 \le n \le N$ for the model specification and reasonable parameter values used in the numerical analysis in section six. Consequently, $t \le t^{nc}$ for all $1 \le n \le N$. Furthermore,

$t - t^{c} = \left[(N-n)(n-1)pqbK + (N-n)(n-1)w(N) + 2(N-n)w(n) - 2n(N-n)w^{nc}\right]/(2Nn)$,

which is non-negative for all $1 \le n \le N$ for the model specification and reasonable parameter values used in the numerical analysis in section six. Hence, $t \ge t^{c}$ for all$1 \le n \le N$.

A2. Individual quotas

Assume that the regulator has full information and issues uniform individual quotas $\hat{y}$ so that $T^i(y^i) = t^i(y^i - \hat{y})$, $i = c, nc$. Then the first order conditions for singletons and coalition members read $pqbX - pqb^2(K/r)y^{nc} - w - t^{nc} = 0$ and

$pqbX - pqb^2(K/r)ny^{c} - w - t^{c} = 0$, respectively.

When compared to the first order conditions under an ambient taxation scheme ([4'] and [5']) the only difference is that coalition members have no direct impact on each others tax payment in the present. Consequently, when solving for the optimal heterogeneous tax rates, the tax rate imposed on singletons will be the same as in [14], while the tax rate imposed on coalition members is n times that derived in [13]. For the regulator, the only difference from the ambient taxation scheme is that information about individual herd sizes is required in order to calculate tax payments. Because the pre tax stable equilibrium is characterized by cooperators keeping smaller herds than singletons, the optimal tax rate on coalition members is again below that of singletons, i.e. $t^{c} < t^{nc}$. Because of this, and because singletons initially exceed the individual quota by more than coalition members, this individual quota system increases the incentive to join the coalition. Because coalition members reduce their individual herd sizes as the level of cooperation increases, the optimal tax rate on coalition members reduces accordingly. In turn, this increases the incentive to join the coalition and eventually, the system settles in full cooperation stability.

If instead tax rates are set equal for all, then regulation by individual quotas differs significantly from that of an aggregate quota. The optimal uniform tax rate equals $t = \left[(N-n)pqbK + (N-n+2)w(N) - 2w(n) - 2(N-n)w^{nc}\right] / \left[2(N-n+1)\right]$. Because singletons initially exceed the individual quota by more than coalition members, this taxation scheme reduces the net profit of singletons more than that of cooperators and hence, increases the incentive to join the coalition. In order to avoid deviations from the individual quota, the optimal tax rate reduces accordingly. The system settles in a new stable equilibrium with full cooperation and hence, compliance with the individual quota.

References

Acheson, J., 1987, The lobster fiefs revisited: economic and ecological effects of territoriality in Marine lobster fishing, in B.J. McCay and J.M. Acheson (Eds.), The question of the commons: The culture and ecology of communal resources, University of Arizona Press, 37-65.

Austenå, T. and G. Sandvik. 1998. “The legal status of rights to the resources of Finnmark with reference to previous regulations of the use of nonprivate resources.” In Law and the governance of renewable resources – studies from northern Europe and Africa, eds. Berge, E. and N. C. Stenseth, 205-219. California: ICS Press.

Barrett, S. 1994. “Self-enforcing international environmental agreements.” Oxford Economic Papers 46: 878-894.

Bostedt, G., 2005, Pastoralist economic behaviour: Empirical results from reindeer herders in Northern Sweden, Journal of Agricultural and Resource Economics, 30, 381-396.

Brekke, K.A, B. Øksendal, and N.C. Stenseth. 2007. “The effect of climate variations on the dynamics of pasture-livestock interactions under cooperative and non-cooperative management.” PNAS 104: 14730-14734.

Cabe, R. and Herrges, J.A., 1992, The regulation of non-point-source pollution under imperfect and asymmetric information, Journal of Environmental Economics and Management, 22, 134-146.

Deacon, R., D. P. Parker, and C. Costello, 2010, Overcoming the common pool problem though voluntary cooperation: The rise and fall of a fishery cooperative, Working Paper.

Hansen, L. G., 1998, A damage based tax mechanism for regulation of non-point emissions, Environmental and Resource Economics, 12, 99-112.

Hansen, L. G., F. Jensen, U. S. Brandt, and N. Vestergaard, 2006, Illegal landings: An aggregate catch self-reporting mechanism, American Journal of Agricultural Economics, 88, 974-985.

Hoel, M. and K. Schneider. 1997. “Incentives to participate in an international environmental agreement.” Environmental and Resource Economics 9: 153-170.

Horan, R. D, J. S. Shortle, and D. G. Abler, 1998, Ambient taxes when polluters have multiple choices, Journal of Environmental Economics and Management, 36, 186-199.

Jensen, F. and N. Vestergaard, 2002, Moral hazard problems in fisheries regulation: the case of illegal landings and discard, Resource and Energy Economics, 24, 281-299.

Johannesen, A. B. and A. Skonhoft, 2008, Kultur, økonomi og konflikter i reindriften, SØF report 3, Trondheim (in Norwegian).

Johannesen, A. B. and A. Skonhoft, 2009, Local common property exploitation with rewards, Land Economics, forthcoming.

Laakso, A. M., 2008, The shadow field of reindeer management: A case study from Finland, Acta Borealia, 25, 138-159.

Ministry of Food and Agriculture (MFA) and Norwegian Reindeer Husbandry Administration (NRHA), 2008, Orientering om reindriftsloven av 15. juni 2007, Oslo/Alta (in Norwegian).

Moxnes, E., Ö. Danell, E. Gaare, and J. Kumpula. 2001. “Optimal strategies for the use of reindeer rangelands.” *Ecological Modelling* 145: 225-241.

Moxnes, E., Ö. Danell, E. Gaare, and J. Kumpula. 2003. “A decision-tool for adaption of reindeer herds to rangelands: the user’s manual.” *SNF Report* No. 19/03, Bergen, Norway.

Norwegian Reindeer Husbandry Administration (NRHA), 2007, Ressursregnskap for reindriftsnæringen, Alta (in Norwegian).

Oseés-Eraso, N. and M. Viladrich-Gran, 2007, On the sustainability of common property resources, Journal of Environmental Economics and Management, 53, 393-410.

Ostrom, E., 1990, Governing the Commons, Cambridge University Press, Cambridge.

Pintassilgo, P. and M. Lindroos. 2008. “Coalition formation in High seas fisheries: A partition function approach.” International game theory review, 10, 303-317.

Poe, G. L., W. D. Schulze, K. Segerson, J. F. Suter, and C. A. Vossler, 2004, Exploring the performance of ambient-based policy instruments when nonpoint source polluters can cooperate, American Journal of Agricultural Economics, 86, 1203-1210.

Reindriftsnytt, 2007, nr 2, Alta (in Norwegian).

Schlager, E. and E. Ostrom, 1992, Property rights regimes and natural resources: a conceptual analysis, Land Economics, 68, 249-262.

Segerson, K., 1988, Uncertainty and incentives for nonpoint pollution control, Journal of Environmental Economics and Management, 15, 87-98.

Segerson, K., 1999, Flexible incentives: a unifying framework for policy analysis. In Casey, F., A. Schmitz, S. Swinton, and D. Zilberman (eds.): Flexible incentives for the adoption of environmental technologies in agriculture, Norwell, MA: Kluwer.

Sethi, R. and E. Somanathan, 1996, The evolution of social norms in common property resource use, American Economic Review, 86, 766-788.

Spraggon, J., 2002, Exogenous targeting instruments as a solution to group moral hazards, Journal of Public Economics, 84, 427-456.

St.prp. nr. 63, 2008, Om reindriftsavtalen 2008/2009 og om endringer i statsbudsjettet for 2008 m.m., Ministry of Food and Agriculture, Oslo (in Norwegian).

Suominen, O. and J. Olofsson, 2000, Impacts of semi-domesticated reindeer on structure of tundra and forest communities in Fennoscandia: a review, Annual Zoological Fennici, 37, 233-249.

Vossler, C. A., G. L. Poe, W. D. Schulze, and K. Segerson, 2006, Communication and incentive mechanisms based on group performance: An experimental study of nonpoint pollution control, Economic Inquiry, 44, 599-613.

Xepapadeas, A. P., 1991, Environmental policy under imperfect information: Incentives and moral hazard, Journal of Environmental Economics and Management, 20, 113-126.

Tables

TABLE 1

Baseline parameter values.

Description	Parameter	Value	Unit	Reference
Forage carrying capacity	K	1 200 000	kg/km^2	Moxnes et al. (2003)
Intrinsic growth rate forage	r	0.213		Moxnes et al. (2003)
Fraction forage consumption	b	0.00004	km^2/animal	Calibrated
Animal growth per kg forage	q	0.0217	animal/kg	Calibrated
Slaughtering price	p	1346	NOK/animal	NRHA (2007)
Fixed cost parameter non-	w^{nc}	200	NOK/animal	Moxnes et al. (2001)
Sensitivity parameter, cost function coalition	β	1		Assumed
Number of units	N	10	management unit	Assumed

TABLE 2

Stability analysis coalition size n.

Pre-tax scenario Baseline parameter values.

n	y^c	y^{nc}	Y	X	h^c	h^{nc}	π^c	π^{nc}	Π
1		415	4 150	264 713		95		45 352	453 516
2	399	419	4 147	265 507	92	97	83 909	46 125	536 813
3	319	451	4 114	272 817	76	107	80 446	53 551	616 196
4	267	499	4 066	283 738	66	123	75 243	65 678	695 041
5*	235	565	4 000	298 594	61	147	72 463	84 160	783 117
6	215	655	3 910	318 878	59	181	72 843	113 090	889 420
7	205	783	3 783	347 602	62	236	77 340	161 356	1 120875
8	205	975	3 590	390 942	70	331	88 500	250 374	1 208751
9	219	1 297	3 629	463 402	88	522	113 755	442 705	1 466503
10	262		2625	608 559	139		181 353		1 813534

Notes: Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m^2), slaughtering h^c and h^{nc} (number of animals) and profit π^c, π^{nc} and $\prod$ (NOK).

TABLE 3

Ambient taxation with fixed uniform tax rates (373 NOK). Pre tax/subsidy profits in parentheses.

n	y^c	y^{nc}	X	h^c	h^{nc}	π^c	π^{nc}	Π
1*		315	561 244		153		65 251 (143 525)	652 514 (1 435 245)
2	0	345	569 130	0	173	-65 228 (0)	97 468 (162 696)	649 290 (1 301 566)
3	0	394	578 987	0	198	-48 921 (0)	138 646 (187 567)	823 759 (1 312 966)
4	0	450	591 661	0	231	-27 955 (0)	193 069 (221 024)	1 046 596 (1 326 143)
5	0	525	608 559	0	277	0	268 224	1 341 120
6	0	630	632 217	0	346	39 167 (0)	378 415 (339 279)	1 748 481 (1 357 115)
7	0	787	667 703	0	456	97 841 (0)	554 584 (456 742)	2 348 640 (1 370 226)
8	0	1050	726 847	0	662	195 683 (0)	877 214 (681 531)	3 319 889 (1 363 062)
9	0	1575	845 136	0	1155	391 365 (0)	1 631 286 (1 239 920)	5 153 575 (1 239 920)
10	0		1 200 000	0		978 414 (0)		9 784 137 (0)

Notes: Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m^2), slaughtering h^c and h^{nc} (number of animals) and profit π^c, π^{nc} and $\prod$ (NOK).

TABLE 4

Ambient taxation with fixed heterogeneous tax rates ($t^c = 65$ NOK and $t^{nc} = 442$ NOK).

Pre tax/subsidy profits in parentheses.

n	y^c	y^{nc}	Y	X	h^c	h^{nc}	π^c	π^{nc}	Π
1		262	2 625	608 559		139		134 112	1 341 120
2	848	132	2 755	579 235	426	67	480 608 (489 079)	5 584 (63 085)	1 005 888 (1 482 842)
3	534	160	2 727	585 570	272	82	323 393 (330 034)	32 593 (77 673)	1 198 329 (1 533 815)
4	366	203	2 683	595 271	189	105	232 173 (236 012)	74 764 (100 821)	1 377 280 (1 548 977)
5	262	262	2 625	608 559	139	139	176 104	134 112	1 551 082
6*	195	343	2 544	626 752	106	187	141 667 (136 412)	218 335 (182 660)	1 723 346 (1 549 112)
7	151	458	2 429	652 549	85	259	123 446 (110 739)	343 640 (257 381)	1 895 046 (1 547 314)
8	124	630	2 256	691 498	75	378	121 380 (97 421)	545 910 (383 274)	2 062 862 (1 545 916)
9	116	920	1 967	756 640	76	604	143 113 (100 335)	919 355 (628 981)	2 207 372 (1 532 001)
10	139		1 388	887 161	107		221 595 (141 112)		2 215 946 (1 411 121)

Notes: Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m^2), slaughtering h^c and h^{nc} (number of animals) and profit π^c, π^{nc} and $\prod$ (NOK). The efficient level of grazing intensity is realized also at n=1. The reason is that the optimal tax rate of non-cooperators is determined independently of n.

TABLE 5

Individual quotas ($\hat{y} = 262$) and uniform tax rates (422 NOK).

Pre tax/subsidy profits in parentheses.

n	y^c	y^{nc}	Y	X	h^c	h^{nc}	π^c	π^{nc}	Π
1		269	2 692	593 464		139		129 958 (132 788)	1 299 581 (1 327 882)
2	319	258	2 703	590 970	164	132	164 453 (188 323)	128 422 (126 576)	1 356 281 (1 389 257)
3	260	273	2 688	594 262	134	141	164 158 (162 998)	130 463 (134 790)	1 405 718 (1 432 523)
4	217	299	2 662	600 161	113	156	160 544 (141 403)	134 402 (149 787)	1 448 589 (1 464 335)
5	189	336	2 625	608 559	100	178	157 794 (126 663)	140 633 (171 764)	1 492 135 (1 492 135)
6	179	388	2 573	620 233	92	209	156 625 (117 633)	150 508 (203 526)	1 541 786 (1 518 899)
7*	159	462	2 499	636 902	88	255	157 480 (113 773)	167 059 (251 329)	1 603 537 (1 550 398)
8	155	574	2 387	662 161	89	330	161 380 (115 912)	197 629 (329 255)	1 686 301 (1 585 807)
9	160	762	2 199	704 486	98	466	171 297 (127 872)	263 683 (474 660)	1 805 354 (1 625 508)
10	182		1 822	789 372	125		198 303 (164 404)		1 983 031 (1 6440 369)

Notes: Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m^2), slaughtering h^c and h^{nc} (number of animals) and profit π^c, π^{nc} and $\prod$ (NOK).

TABLE 6

Individual quotas ($\hat{y} = 262$) and heterogeneous tax rates ($t^c = 325$ NOK and $t^{nc} = 442$).

Pre tax/subsidy profits in parentheses.

n	y^c	y^{nc}	Y	X	h^c	h^{nc}	π^c	π^{nc}	Π
1		262	2 625	608 559		139		134 112	1 341 120
2	514	207	2 680	595 952	266	107	224 660 (306 607)	127 204 (102 482)	1 466 955 (1 433 068)
3	388	215	2 672	597 952	201	112	204 316 (245 172)	128 190 (107 391)	1 510 283 (1 487 252)
4	312	234	2 653	602 236	163	123	187 652 (203 635)	130 441 (118 043)	1 533 258 (1 522 795)
5	262	262	2 625	608 559	139	139	176 104	134 112	1 551 082
6	230	302	2 585	617 466	123	162	168 644 (157 924)	139 985 (157 450)	1 571 803 (1 577 340)
7	207	359	2 528	630 260	113	196	164 722 (146 810)	149 862 (192 416)	1 602 639 (1 604 921)
8	194	445	2 442	649 708	109	251	164 682 (142 394)	168 125 (248 813)	1 653 706 (1 636 779)
9*	190	590	2 297	682 346	112	349	170 690 (147 006)	207 589 (352 279)	1 743 800 (1 675 335)
10	201		2 006	747 860	130		191 414 (171 293)		1 914 137 (1 712 931)

Notes: Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m^2), slaughtering h^c and h^{nc} (number of animals) and profit π^c, π^{nc} and Π (NOK).

TABLE A1

Ambient taxation with fixed uniform tax rates (373 NOK). Pre tax/subsidy profits in parentheses. Coalition members ignore each others tax payment.

n	y^c	y^{nc}	Y	X	h^c	h^{nc}	π^c	π^{nc}	Π
1*									
2									
3	267	294		556 604	129	142	69 639 (155 635)	46 202 (132 198)	532 330 (1 392 293)
4*	223	322		563 090	109	158	60 310 (135 570)	72 344 (147 603)	675 302 (1 427 897)
5	194	363		572 246	96	180	61 925 (122 030)	109 982 (170 088)	859 531 (1 460 590)
6	175	419		584 928	89	213	74 894 (114 009)	163 556 (202 670)	1 103 592 (1 494733)
7									
8									
9									
10									

Notes: Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m^2), slaughtering h^c and h^{nc} (number of animals) and profit π^c, π^{nc} and $\prod$ (NOK).

[1] Vossler et al. (2006) analyses three incentive schemes: i) a tax/subsidy mechanism, ii) a group fine imposed if ambient pollution exceeds the targeted level but not otherwise, and iii) an approach combining i) and ii). In absence of cooperation, theory predicts that the tax/subsidy mechanism will induce the socially optimal outcome, whereas the social optimum is just one of multiple equilibria in scheme ii) and iii).

[2] Note, however, that Poe et al. (2004) find that cooperation under a pure tax mechanism induces firms to meet the abatement target with greater frequency.

[3] See (in Norwegian):
http://www.regjeringen.no/pages/14779177/011_Reindriftsforvaltningen_Vest_Finnmark.pdf.

[4] Other factors than grazing pressure may certainly affect the vegetation cover, especially in (see e.g., Brekke et al. 2007 who emphasize the effects of climate change). Such possible factors are, however, ignored in this paper.

[5] Meat is the dominating product from reindeer herding in Norway. Some herdsmen also earn income from handicrafts made by skin, fur, and antler from slaughtered animals, but these are ignored in this analysis. Products from live reindeer (e.g., milk and draught power) are no longer of any importance.

[6] Several authors have demonstrated poor prospects of cooperation in Nash-Cournot settings with homogeneous agents. See Barrett (1994) for a global pollution setting and Pintassilgo and Lindroos (2008) for a Gordon-Schaefer fishery. Others have demonstrated improved prospects of cooperation if there is some benefit attached to cooperation, besides more resource abundance or reduced environmental damage. Examples include social approval and recognition gained by cooperators in international environmental agreements (Hoel and Schneider 1997) and livestock-pasture systems (Osés-Eraso and Viladrich-Grau 2007), and social punishment of non-cooperators in a livestock-pasture system (Sethi and Somanathan 1996).