

Local Common Property Exploitation with Rewards

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ABSTRACT

This paper analyses coalition formation in a livestock-pasture system where livestock are privately owned and the pasture is a common property. While the standard models on coalition formation predict rather low prospects of cooperation, this paper introduces a cost advantage of cooperation based on Saami reindeer herding which may explain higher coalition participation. In contrast to the existing fishery literature on coalition formation, all players are assumed *ex ante* homogenous, but may differ *ex post* due to the cost advantage. A stable equilibrium with cooperation can be reached and a moderate exploitation level can be sustained compared to the ‘tragedy of the commons’ outcome.

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I. Introduction

For a long time it has been recognized that institutions play an important role in common property management (e.g., Bromley 1991), and that an efficient exploitation requires an integrated system of cooperation and ethical codes (e.g., Ostrom 1990). Privately owned livestock grazing on common land is a classic example. When cooperation fails and the individual herdsman ignores the externality imposed on the other herdsman by his grazing animals, and the *vice versa*, the possible result may be serious overgrazing and reduced livestock productivity; in short, ‘the tragedy of the commons’ (Hardin 1968). However, several studies have challenged the ‘tragedy of the commons’ as a general characterization of social behaviour when applied to local commons such as pastures, forests and inshore fisheries. Examples include, among others, grazing areas on the Alpine meadows in Switzerland (Ostrom 1990), irrigation systems in Nepal (Ostrom and Gardner 1993), and community forests in Himalaya (Ostrom et al. 1997, chap 12). More examples are provided in Ostrom (1990).

The above cited studies indicate that social norms fostering cooperation can result in well-functioning common property management. This contrast the rather grim prospects of cooperation presented in the early literature on coalition formation. This literature, analyzing international environmental agreements, demonstrates that stable coalitions are large if there is not much to gain from cooperation, and typically very small otherwise (Barrett 1994). See also Hoel (1992). However, more recent theoretical studies have hypothesized that social norms may promote cooperation. Hoel and Schneider (1997), for example, model social norms as a cost on non-cooperators being socially *punished* (or disliked) by co-operators, while Osés-Eraso and Viladrich-Grau (2007), studying cooperation in the utilization of a common property pasture, consider social norms through a *reward* to cooperators when assuming that cooperative behaviour produces social approval and recognition. On the other hand, Sethi and Somanathan (1996) assume that punishment imposes a cost on both non-cooperators and cooperators enforcing the punishment. Both punishment and reward create incentives to cooperate as punishment reduces the benefit of being a free-rider, while social reward enhances the benefit of cooperation. To what extent such incentives succeed in internalizing the actual externalities hinges crucially on the resulting *level of cooperation*. Depending on the strength of these incentives and the systems being studied, the presence of social norms may result in a stable equilibrium consisting of a mix of cooperators and non-cooperators (Osés-Eraso and Viladrich-Grau 2007), or cooperators only (Sethi and

Somanathan 1996). In the last case, externalities are fully internalized because the coalition of cooperators maximizes the collective benefit of its members. In the former case, on the other hand, externalities are partly internalized because the coalition ignores the externalities imposed on non-cooperators. Still, however, decentralized management of common property resources results in more efficient and sustainable resource utilization compared to a situation with no cooperation.

Rewards for joining the coalition or punishment for defecting, may, however, be caused by other characteristics than social norms, and in this paper an alternative explanation based on experience from Saami reindeer herding in northernmost Norway (Finnmark county) is offered. See Figure 1. In interviews with more than forty management units (July 2007) a number of herdsman emphasized that cooperation creates a *cost advantage*. The reindeer flocks migrate across an extensive area during the year. While the interior continental parts of Finnmark is used for grazing during the winter, the summer ranges are located on the islands and peninsulas near the coast (Johansen and Karlsen 2005). The migration route is mainly determined by the reindeer herd itself, but the herdsman follows the flock to guard and keep it gathered. This is a highly time consuming activity. When the herdsman cooperate, however, individual herds are merged together and herdsman look after the flock in shifts. Herdsman claim that this enables them to spend less time on the grazing ranges than they would have if operating alone. Hence, cooperation means less individual effort use. See also Paine (1970). In this way, cooperation reduces their individual herding cost. Therefore, this paper assumes that there is a cost advantage, or ‘reward’, of being a cooperator. A somewhat similar approach is found in Yi (1998) who studies efficiency gains in research coalitions in a Cournot oligopoly.

Figure 1 about here

The following model analyses cooperation in the above mentioned livestock-pasture system of reindeer herding, where livestock is privately owned while the pasture is a common property. Reindeer husbandry in Norway is by law reserved for Saamis from Saami husbandry families. That is, herdsman must have parents or grandparents with reindeer herding as their main occupation (Austenå and Sandvik 1998). The system considered is therefore of local common property type with a fixed number of herdsman (more details on Saami reindeer herding in section five below). As in Yi (1998), the model analysed is of the

open membership type; 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. The possibility to form multiple coalitions is ignored, meaning that non-members of the single coalition will act independently and in pure self-interest. Cooperation is primarily a way of internalizing grazing externalities, while the cost advantage of cooperation comes as an additional effect. Non-cooperators ignore the external effect they impose on others and benefit by free-riding on the pasture improvement induced by livestock restrictions by cooperators. At the same time, however, cooperators gain a cost advantage of cooperating. Because of this asymmetry, a coalition of partial, or full, cooperation may be a stable equilibrium outcome.

Our reasoning and model differ from coalition formation in high seas fisheries as modelled by Kaitala and Lindroos (1998). In their paper it is simply assumed that the coastal state fleet *ex ante* is more cost efficient than the distant water states fleets. See also Kaitala and Pohjola (1988), Pintassilgo (2003), and Pintassilgo and Lindroos (2007). As a consequence, in a stable coalition, the most cost efficient nation is the only active coalition member and stability is ensured by sharing the benefits with all other coalition members.¹ In contrast to this, as indicated, we have an explanation why cooperation may result in a cost advantage. That is, in our model, players are *ex ante* cost identical, but may be different *ex post*.

The paper is organized as follows. The livestock-pasture system is presented in section two. This is obviously a dynamic system, but is, just as the above mentioned fishery studies, analysed in ecological equilibrium only. Next, in section three, the exploitation of the system is studied when there is no cost advantage of cooperation. Hence, the individual herding cost is *ex ante* and *ex post* identical among the herdsmen. This model is referred to as the homogeneous case and serves as a benchmark when the model of *ex post* cost advantage is introduced in section four. A numerical illustration of reindeer herding (Finnmark county) follows in section five, while section six concludes the paper.

II. The livestock-pasture ecological system

There are surprisingly few economic studies of livestock and common grazing land systems, and they all consider the degree of cooperation exogenously; either as full cooperation, or no cooperation at all (e.g., Barrett 1989 and Brekke et al. 2007). Perrings (1993) studies the same ecological model as Barrett (1989), but is basically interested in how the system recovers

from ecological shocks related to adverse weather conditions such as drought. Skonhofs (1999) assumes no cooperation and compares the standard neoclassical model of resource rent maximization with a model of herdsman maximizing their herd size, subject to an income constraint. See also Bosted (2005).

The ecological part of the model used in this paper is a modified version of the celebrated Noy-Meir biomass model (Noy-Meir 1975). Vegetation quantity (i.e., lichen) on the pasture grows according to a logistic function and decreases due to consumption by the grazing livestock (reindeer). Hence, growth in vegetation quantity X at time t (the time subscript is omitted) is governed by $rX(1 - X/K)$ with K as the vegetation carrying capacity, and r as the intrinsic (maximum specific) vegetation growth rate. The vegetation consumption is governed by a *fixed* number (see above) N *ex ante* identical herdsman that utilizes the pasture.

$0 \leq n \leq N$ of these herdsman form a single coalition and each of them keeps y^c number of animals at time t . Each of the remaining $(N - n)$ non-cooperators holds y^{nc} animals. The total number of animals is accordingly $Y = ny^c + (N - n)y^{nc}$. Noy-Meir assumes that the vegetation consumption *per animal* increases in the amount of vegetation, but at a decreasing rate. In order to keep the model traceable, however, the per animal consumption is supposed to increase linearly in the vegetation quantity as given by bX with $b > 0$.² Therefore, the vegetation consumption is $bX(ny^c + (N - n)y^{nc})$ and the vegetation growth equals:³

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

For a fixed vegetation quantity $dX/dt = 0$, we hence find the equilibrium animal-vegetation relationship as $X = K(r - b(ny^c + (N - n)y^{nc}))/r$. The equilibrium vegetation quantity thus decreases linearly in the number of grazing animals.

The livestock population changes according to natural growth and slaughtering. Following Noy-Meir (1975), the per animal growth is assumed to be proportional to the vegetation consumption, i.e., qbX , where the parameter $0 < q < 1$ measures the transformation of vegetation biomass into meat biomass. With h^i as the animal offtake by herdsman i ($i = c, nc$), the population growth of the individual flock size reads:

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

so that the individual equilibrium slaughtering is $h^i = qbXy^i$. Total population growth adds simply up to $dY / dt = qbXY - H$, where $H = nh^c + (N - n)h^{nc}$. The equilibrium slaughtering-vegetation relationship may be found by eliminating livestock from the system when $dX / dt = dY / dt = 0$ and reads:

$$H = qrX(1 - X / K). \quad [3]$$

Therefore, this model indicates a standard logistic relationship between the amount of vegetation and slaughtering as well, with $H = 0$ when $X = K$ accompanied by $Y = 0$, or $H = 0$ when $X = 0$ together with the livestock population size as $Y = r / b$. Furthermore, $X = X^{msy} = K / 2$ is the vegetation quantity associated with the maximum sustainable harvest. In line with traditional reasoning, *ecological* overgrazing is said to take place if the equilibrium vegetation quantity is below X^{msy} (but see Mysterud 2006 for a critical assessment).

III. Exploitation without cost advantage

The economic motives for keeping animals and slaughtering are now introduced under the assumption that the herdsman are *homogeneous*; that is, there is no cost advantage attached to cooperation.⁴ Therefore, the per animal herding cost w is assumed identical across all herdsman whether they cooperate ($i = c$), or not ($i = nc$). With p as the per animal slaughtering price (net of slaughtering costs), assumed to be fixed, the individual profit, π^i , is:⁵

$$\pi^i = ph^i - wy^i; \quad i = c, nc. \quad [4]$$

The prospects of coalition formation, where slaughtering effort is coordinated to maximize total harvesting profit of the (single) coalition, are then considered. This includes a one-shot game with a two stage process. In the first stage, each herdsman considers two options. Those (if any) who initially cooperate decide whether to stay in the coalition or leave, while those who initially stay outside decide whether to remain playing singleton or to join the coalition.

In the second stage, the harvest and livestock number, as well as the accompanying grazing pressure, are determined through a simultaneous Nash-Cournot game, where the coalition plays Nash against singletons, and singletons play Nash against all. This is the same set-up as in most coalition formation game models (e.g., Hoel 1992, Sethi and Somanathan 1996, Hoel and Schneider 1997, Yi 1997 and 1998, Finus et al. 2006, Osés-Eraso and Viladrich-Grau 2007).

The game is solved by backward induction. Given the choice of non-cooperation, a singleton determines slaughtering and 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 $(N - 1)$ herdsman. When inserting for the steady state ecological constraints (section two above) into [4], the profit of a singleton reads $\pi^{nc} = pqbK(r - bny^c - b(N - n)y^{nc})y^{nc} / r - wy^{nc}$. Therefore, with y^{nc} as the single control variable, the first order condition of this problem is given by:

$$pqbX - pqb^2(K/r)y^{nc} - w = 0. \quad [5]$$

The first term in this condition represents the private marginal income of adding another animal to the herd, for a given vegetation quantity. The second and third terms are the marginal cost components, and where the second term implies that the herdsman takes into account his *own* impact only on the vegetation quantity. It reflects the loss of future slaughtering income due to own herd size increase. The optimal number of livestock kept by a singleton is thus determined by the equity between the private marginal income and private marginal costs. When inserting for the steady state vegetation quantity

$$X = K(r - b(ny^c + (N - n)y^{nc})/r$$

into equation [5], the second order condition reads

$$-2pqb^2(K/r) < 0.$$

The coalition maximizes its total profit while taking the vegetation impact on all herdsman within the coalition into account. The individual number of animals is hence determined when accounting for the grazing externalities working *between* the n coalition members, while ignoring the impact on the $(N - n)$ non-cooperators. Therefore, the decision problem of the coalition is to determine the individual number of animals maximizing the joint profit

$n\pi^c = n(ph^c - wy^c)$ subject to the ecological conditions [1]-[2] (with $dX/dt = 0$ and $dy^i/dt = 0$, see above). When inserting for these conditions, the profit of the coalition yields $n\pi^c = n\left[pqbK(r - bny^c - b(N - n)y^{nc})y^c / r - wy^c \right]$. The first order condition of this problem is then:

$$pqbX - pqb^2(K/r)ny^c - w = 0. \quad [6]$$

The second term equals now the social marginal cost of the coalition of an additional animal in the individual herd flock and implies that the vegetation quantity impact upon the others in the coalition is taken into account as well. The optimal number of animals kept by a coalition member is thus determined by the equity between the private marginal income and the *within* coalition social marginal cost. By substituting the steady state vegetation quantity (see above) into [6], we derive the second order condition $-2pqb^2(K/r)n < 0$.

Solving equations [5] and [6] when inserting $X = K(r - b(ny^c + (N - n)y^{nc})) / r$ (section two above), yields:

$$y^c(n) = \frac{r(1 - w/(pqbK))}{bn(N - n + 2)} \quad [7]$$

and

$$y^{nc}(n) = \frac{r(1 - w/(pqbK))}{b(N - n + 2)}, \quad [8]$$

and where the number n within the left hand side parenthesis implies that n herdsman are included in the coalition. Because the coalition internalizes the grazing externalities among its members, the resulting herd size of a cooperator is below that of a non-cooperator for all $2 \leq n \leq N$. In absence of cooperation, that is all herdsman act as singletons, $n = 1$, we find $y^c(1) = y^{nc}(1) = r(1 - w/(pqbK))/(b(N + 1))$.

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

$$\pi^c(n) \geq \pi^{nc}(n-1) \quad \forall \text{cooperators} \quad [9]$$

and

$$\pi^{nc}(n) \geq \pi^c(n+1) \quad \forall \text{non-cooperators} . \quad [10]$$

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 [9] and [10] is stable.

Because the coalition members restrict their flock sizes, non-members are typically better off when more herdsman join the coalition as free rider strategies can be adopted. The presence of free-rider incentives therefore creates low prospects of coalition formation in this model.⁶ Apart from the situation when the local common consists of just *two* herdsman (i.e., $N = 2$), a stable coalition simply does not exist (see Appendix A1). The same result is also the outcome of the well known global pollution model by Barrett (1994), and in the (static) Gordon-Schaefer fishery model by Pintassilgo and Lindroos (2007).⁷ Indeed, the result in our model stems from the *homogenous* and *linear* shape of the livestock-pasture model as the ecological equilibrium individual profits read $\pi^i = pqbXy^i - wy^i$, which has the identical structure as in the Gordon-Schaefer fishery model. Therefore, for $N > 2$, the system settles in a non-cooperative equilibrium where all herdsman act as singletons. By inserting $n = 1$ into equations [7] and [8] the herd size of each singleton equals $y^{nc} = r[1 - w/(pqbK)]/[b(N+1)]$ and the corresponding vegetation quantity is $X = K(1 + Nw/(PqbK))/(N+1)$.

IV. Cost advantage of cooperation

Above it was demonstrated that the prospect of cooperation is bleak when the herdsman are identical with constant marginal herding costs. Except when the number of players is two,

each individual herdsman is better off by following his narrow self interests and play singleton. As mentioned (section one above) reindeer herders in northernmost Norway report that cooperation means reduced individual herding cost; that is, coalition members may earn efficiency gains by merging their herds, and hence exploit economies of scale advantages in animal herding and guarding. The model is now extended to take care of this. Again, it should be stressed that this possible type of efficiency gain is quite different from that in the above (introductory section) mentioned fishery models with heterogeneous agents. While *ex ante* cost heterogeneity promotes coalition formation in these fishery models, the herdsmen are assumed *ex ante* homogenous in our problem. If a coalition emerges, however, all members earn an endogenous cost advantage over the remaining non-cooperators. Hence, herdsmen may be *ex post* heterogeneous.

Let now $w = w^{nc}$ be the marginal herding cost of non-cooperators, again assumed fixed. On the other hand, for cooperators the marginal cost is no longer constant, but decreases with the number of cooperators, i.e., $w = w(n)$ with $w' < 0$ and $w'' \geq 0$ for all $2 \leq n \leq N$. Therefore, notice that $w(1) = w^{nc}$. When using the same arguments as above (section three), the profit maximizing number of animals kept by a member of the coalition and a non-cooperator is found as:

$$y^c(n) = \frac{r}{bn(N-n+2)} \left[1 - \frac{(N-n+1)w(n)}{pqbK} + \frac{(N-n)w^{nc}}{pqbK} \right] \quad [11]$$

and

$$y^{nc}(n) = \frac{r}{b(N-n+2)} \left[1 - \frac{2w^{nc}}{pqbK} + \frac{w(n)}{pqbK} \right], \quad [12]$$

respectively. It is seen directly from these two equations that reducing $w(n)$ relatively to w^{nc} for a given coalition size, allows coalition members to keep more livestock, while non-cooperators reduce their stock. This last effect works through changed vegetation quantity. For details, see Appendix A2.2. When inserting [11] and [12] into [1] (when $dX/dt = 0$) the corresponding vegetation quantity equals:

$$X(n) = \frac{K}{(N-n+2)} \left[1 + \frac{(N-n)w^{nc}}{pqbK} + \frac{w(n)}{pqbK} \right]. \quad [13]$$

The definition of a stable coalition is again given by the conditions [9]-[10]. If the cost advantage is small and negligible, each herdsman will again find it beneficial to follow his narrow self interests and act as singleton, i.e., the system settles with no cooperation. For a herdsman to join the coalition, the cost advantage must be sufficient to offset the free riding benefit. See Appendix A2.1. In this case, as the size of the coalition increases, the marginal herding cost of coalition members declines which works towards an increase in the incentives to join the coalition. However, a larger coalition accounts for a larger proportion of the grazing externalities, which works towards increased free riding incentives of staying outside the coalition. Herdsmen will join the coalition as long as the cost advantage of doing so exceeds the free rider incentive. A stable coalition emerges where coalition members have no incentives to break out and non-cooperators have no incentives to join the coalition. Therefore, depending on the shape of the cost function $w(n)$, i.e., the cost sensitivity of being a coalition member, the possible coalition structures are partial cooperation ($2 \leq n < N$) and full cooperation (grand coalition stable).

Equation [13] demonstrates that cooperation imposes two contradicting effects on the vegetation quantity compared to the homogeneous case (section three). The term before the bracket indicates that a larger proportion of the grazing externalities is taken into account in presence of cooperation. This effect works hence in the direction of fewer total animals and reduced vegetation pressure compared to the homogeneous case. On the other hand, cooperation implies – on average – reduced marginal herding cost, as reflected by the second and third terms within the bracket and works in the direction of more grazing animals and less vegetation compared to the homogeneous model. Therefore, the net effect of cooperation on the vegetation quantity is ambiguous, i.e., cooperation driven by a cost advantage may result in higher or lower grazing pressure than in absence of cooperation. However, the stable coalition conditions imply that the vegetation quantity under partial cooperation stability exceeds what is found in absence of cooperation. Recall that the external stability condition states that non-members 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 a situation of no cooperation, otherwise there would be nothing

to gain from free riding on the coalition. Moreover, also *grand* coalition stability may result in improved vegetation quantity compared to the homogeneous model as long as the vegetation effect of taking the grazing externalities into account dominates the impact of reduced marginal herding cost. In the opposite case, however, grand coalition stability means less vegetation compared to the homogeneous model. See Appendix A2.2 for more details.

The various economic and ecological forces influence the coalition size, livestock number and vegetation quantity. We now take a brief look at this while the effects on profit and distribution are illustrated in the numerical example in section five below. Consider first an exogenous reduction in the marginal herding cost of coalition members $w(n)$ relative to that of non-cooperators w^{nc} . The direct effect (i.e., for a fixed coalition size n) means that each coalition member finds it beneficial to keep more animals, and this works in the direction of reduced vegetation quantity (equation [13]). The new equilibrium is, however, associated with more cooperation as the profit of being a coalition member improves relative to that of a non-cooperator. This indirect effect works in the direction of fewer animals because those shifting from being a non-cooperator to a cooperator reduce their herd sizes. The total effects on livestock numbers and grazing pressure are thus ambiguous. Increased cost discrepancy in favour of coalition members may therefore promote vegetation conservation, even though the average marginal herding cost declines.

Next, consider a more profitable production through a higher slaughtering price p which may happen through changing demand conditions, a higher subsidy (see section five below), or both. The direct livestock number effect (n fixed) is positive. This is seen from equation [13] as the vegetation quantity effect is negative. Again, the indirect effect works through a changing coalition size. Because non-cooperators initially keep more animals than coalition members, the profit of being outside the coalition increases relative to that of joining. Hence, the coalition number declines. As the coalition size shrinks, a smaller proportion of the grazing externalities is taken into account, which strengthens the positive effect on the total animal number. Therefore, in the new equilibrium the vegetation quantity reduces.

Consider finally a reduction in the vegetation carrying capacity K which may be caused by, say, encroachments such as infrastructure expansions and cottage villages (Nelleman et al. 2001). Reindeer herdsman have frequently claimed such encroachments to have reduced the

vegetation cover over the past decades (Kitti et al. 2006). The direct vegetation quantity effect is obviously negative. The indirect effect works through a changing coalition size. Reduced vegetation means reduced per animal value $pqbX$. Because non-cooperators keep more animals than coalition members, we find the profit of a coalition member to increase relative to that of a non-cooperator. Consequently, the degree of cooperation increases as the common property resource becomes more scarce. A larger coalition accounts for a greater proportion of the grazing externalities and hence, the indirect effect works in the direction of increased vegetation quantity. The total effect on vegetation the quantity is therefore ambiguous.

V. Reindeer herding in northernmost Norway

The theoretical reasoning will now be illustrated by data that fits well with reindeer herding in Finnmark county, the main area of reindeer herding in Norway. Reindeer herding in Finnmark can be traced to the hunting of wild reindeer since time immemorial. During the 15th century, entire reindeer herds were domesticated and part of the Saami people became herding nomads. This tradition has preserved until today (Johansen and Karlsen 2005). A similar pastoral system (while the grazing scheme is somewhat different) is found in Sweden (Parks et al. 2002, Bostedt et al. 2003, and Bostedt 2005). Other well-known pastoralist systems include cattle herding in East Africa and central Asia (e.g., Perrings 1993).

On a national scale, reindeer herding in Norway is a small industry. The total industry comprises just 556 management units keeping in total 240 000 reindeer (NRHA 2007). There is a restriction on entering the industry which can be performed by Saami people only (NRHA 2007). A unit leader (i.e. the owner and manager of a management unit) must have herding as his main occupation (Austenå and Sandvik 1998). Very often, a management unit includes reindeer belonging to the owner's spouse and children, as well as sisters and brothers. In total some 3000 persons own reindeer (NRHA 2007). Even though reindeer herding is a small industry on a national scale, it is of great importance to the Saami people both economically and, not at least, culturally. In our survey of reindeer herders in Finnmark, 80 per cent of the unit leaders seem reluctant to quit reindeer herding, even if given better income alternatives (Johannesen and Skonhøft 2008). This indicates that an important cultural identity is attached to being a reindeer herder.

Vegetation studies indicate that the vegetation cover of the pasture land in Finnmark has declined significantly during the past three decades or so (Johansen and Karlsen 2005).

Reduced cooperation and higher reindeer flock sizes are regarded as the main explanations (Johansen and Karlsen 2005). Today, some 50 per cent of the management unit leaders claim that other herdsmen interrupt and enter in conflict with them over grazing land, especially on winter ranges (Johannesen and Skonhøft 2008). At the same time, however, when spending time with herdsmen in Finnmark, we observed unit leaders to be in close collaboration with each other.

When asking herdsmen why they cooperate, it became obvious that there is an advantage attached to cooperation and this advantage is related to the migratory pattern of reindeer. In Finnmark reindeer migrate across a huge area during the year (again, see Figure 1). The migratory pattern is related to food and snow conditions. During the summer reindeer graze on grass, herbs and sedges on the islands and peninsulas near the coast, while the winter ranges are found in the interior continental parts characterized by vegetation types rich in lichens (Johansen and Karlsen 2005). The Reindeer Farming Act gives the Saamis in Finnmark the right to graze their herds in practically all non-private land areas in the county (Austenå and Sandvik 1998) to secure the migration between coast and inland. This migration route has been important to secure an appropriate balance between winter and summer ranges (Johansen and Karlsen 2005). During the migration, as well as while on the summer and winter pastures, the herdsmen follow the flock to guard it and keep it gathered (cf. the introductory section). When the herdsmen cooperate, they merge the individual herds together and look after the flock in shifts. As argued in section one, this sharing of responsibility creates a cost advantage, or efficiency gain, of cooperation. The following numerical analysis focuses on the prospects of cooperation in presence of such a cost advantage. That is, whether a cost advantage can make herdsmen account for grazing externalities.

In the numerical analysis 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 (but see Appendix A3.2). The herd sizes are measured as number of animals per management unit. The marginal herding cost of a coalition member is specified as $w(n) = w^{nc} / (\beta n)$ for all $2 \leq n \leq N$, and with $\beta \geq 1/2$ as a parameter.⁸ Table 1 presents the baseline economic and ecological parameter values. See also Appendix A3.1.

Table 1 about here

Table 2 demonstrates the profit, herd size and vegetation level corresponding to each possible n in the baseline case. Total profit is defined as $\Pi = n\pi^c(n) + (N - n)\pi^{nc}(n)$. It is seen that the vegetation quantity increases with the members of the coalition. The reason is that more cooperation implies that a higher proportion of the externalities is accounted for, which in the baseline case dominates the vegetation effect of reduced marginal herding cost. Improved vegetation enables each non-cooperator to keep more animals. Both effects increase animal growth and slaughtering h^{nc} of non-cooperators. Therefore, in the baseline calculation, outsiders remaining non-cooperators are better off as the size of the coalition increases. In contrast, the profit of a cooperator reduces along with increased cooperation for $2 \leq n \leq 5$. The reason is that accounting for a higher proportion of the externalities restricts the individual flock size of cooperators sufficient to cause a negative impact on animal growth and slaughtering h^c . This effect dominates the positive cost advantage effect on the profit of coalition members. For $n > 5$, however, a further increase in vegetation quantity enhances animal growth and hence, the animal offtake of coalition members increases as well. Within this range, this causes a positive association between the profit of a cooperator and the number of herdsman joining the coalition.

Table 2 about here

In the baseline calculation we hence find that $n^* = 5$ represents the stable equilibrium. Recall that $n = 1$ means no cooperation at all and compare $\pi^{nc}(1)$ with $\pi^c(2)$. As $\pi^{nc}(1) < \pi^c(2)$, it is profitable for a non-cooperating herdsman to form a coalition with another herdsman. By continuing in this way, Table 2 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 five herdsman is the only stable equilibrium in the baseline case. Not surprisingly, when compared to a situation with no cost advantage (i.e., $n = 1$), all herdsman are better off in the partial cooperation stable equilibrium. As explained in the above section four, the remaining non-cooperators free ride on the coalition and hence, obtain a higher profit level than the coalition members.

Table 3 demonstrates what happens to n^* , as well as grazing pressure and profit, when the slaughter price p shifts while the other parameters are kept fixed at their baseline values. As

indicated in the theoretical analysis (section four), a lower price increases the coalition size, and when reducing the price to $p = 600$ the system is even grand coalition stable.

Furthermore, when comparing Table 3 and Table 4, which reports the situation with no cost advantage (section three) for some few values of the price, it is seen that a coalition joined by many herdsmen (e.g., $p = 600$) increases the vegetation quantity and community profit significantly compared to the non-cooperative outcome. This result differs from Barrett (1994), who finds that if stable coalitions are large there is not much to gain from cooperation.

Tables 3 and 4 about here

In order to reduce the grazing pressure on winter pastures, Saami reindeer herdsmen receive a subsidy per kilo slaughtered meat (NRHA 2007). This works in the direction of higher slaughtering price, and hence more valuable animals. The direct effect (n fixed) on the total reindeer number is therefore positive (cf. equation [13]).⁹ Furthermore, the indirect effect working through increased free rider incentives and reduced coalition size (section four above) strengthens the direct animal number effect. Accordingly, this example indicates that the negative impact on vegetation conservation of a price subsidy may even be stronger when the coalition size effect is taken into account.

The last three columns of Table 3 report the profit effects of increased slaughter price. A higher price accompanied with no coalition size impact (e.g., from $p = 1346$ to $p = 1400$) result in improved profit for all herdsmen. Whenever a price increase causes a reduction in the coalition size, those shifting from being a coalition member to becoming a non-cooperator are always better off; otherwise they would not leave the coalition. On the other hand, the remaining cooperators are better off only if the direct positive profit effect dominates any indirect negative effect of possible lower slaughtering caused by a reduction in the vegetation quantity. In contrast, the initial non-cooperators experience an economic loss because the direct positive effect is dominated by the indirect effect of reduced slaughtering. This is obviously a strange result, but can be explained by the non-cooperating behaviour of the singletons. Because each singleton imposes negative externalities on each other, as well as on the coalition members, additional negative externalities are imposed on the initial singletons as the size of the coalition declines. Singletons may therefore be worse off with a higher slaughtering price. This possible outcome follows the logic of the classic externality paper by

Lipsey and Lancaster (1956). The last column of Table 3 demonstrates that a more valuable harvest leaves the herding community as a whole worse off whenever non-cooperating herdsman are worse off.

Table 5 illustrates what happens when the cost parameter w^{nc} shifts. A higher cost with no coalition size impacts (e.g., from $w^{nc} = 225$ to $w^{nc} = 250$) results in reduced community profit, but increased vegetation quantity.¹⁰ However, increased w^{nc} hits singletons more serious than those cooperating because of the relative efficiency gains obtained by the coalition members. Consequently, the incentive to join the coalition improves. Whenever more herdsman join the coalition (e.g., from $w^{nc} = 200$ to $w^{nc} = 225$), the new coalition accounts for a larger fraction of the grazing externalities, which, even with higher cost, enables the remaining singletons to increase their herd size as well as the number of animals slaughtered. Actually, the increased slaughtering income dominates the cost effect, making the remaining singletons better off. In most instances, the positive impact on vegetation utilization is strong enough to ensure enhanced slaughtering in the coalition as well (except for the new members of the coalition). In sum, following our numerical example, increased w^{nc} means lower vegetation utilization and higher community profit whenever the coalition size increases.

Table 5 about here

Finally, in Table 6, we consider a reduction in the vegetation carrying capacity K , which, as mentioned (section four), may be caused by infrastructure expansions.¹¹ It is seen that the vegetation quantity reduces, but the effect is rather modest. The reason is that reduced carrying capacity stimulates increased cooperation, which prevents a larger drop in the vegetation quantity. We also see that the herding community as a whole may actually be better off from encroachments. This result is surprising, but may be explained as follows. First, consider a reduction in the carrying capacity from, e.g., $K = 1200$ to $K = 900$. Such reduction stimulates more cooperation which enables the remaining singletons to increase their animal numbers and slaughtering. The remaining singletons are therefore better off. This effect is, however, dominated by the negative impact on coalition members within this range, leaving the community as a whole worse off. Second, assume instead that vegetation carrying capacity is initially low ($K = 800$). Then further encroachments make the initial coalition

members better off. The reason is that a larger coalition reduces the marginal herding cost enough to stimulate coalition members to increase their herd size. As a consequence, eventually the number of animals slaughtered increases and the individual profit within the coalition improves. As more herdsman join the coalition, the free rider benefits per remaining singleton increases as well. This happens because the last member of the coalition reduces its herd size more than the total increase of the former members. Hence, every herdsman remaining outside the coalition is also better off. So is the community as a whole. The equilibrium is full cooperation stable for $K = 500$. Certainly, encroachments reducing the vegetation carrying capacity below this level will reduce the profit of the community.

Table 6 about here

VI. Concluding remarks

This paper analyses cooperation and coalition formation in a livestock-pasture system where livestock are privately owned while the pasture is a common property. The standard literature on coalition formation draws a rather pessimistic picture of the prospective of cooperation (e.g., Hoel 1992, Barrett 1994). However, modifications of the standard models to include social approval (Osés-Eraso and Viladrich-Grau 2007), or sanctions (Hoel and Schneider 1997), demonstrate incentives to cooperate because social approval (sanctions) works as a reward to members of the coalition.

This paper offers an alternative type of reward based on experience from reindeer herding in northernmost Norway (Finnmark county). When herdsman cooperate the individual herds are merged together and every individual herdsman benefit through less effort use. This creates a cost advantage of being a member of the coalition and implies that a coalition of partial, or full, cooperation may be stable equilibria. The model differs from coalition formation in high seas fisheries (Kaitala and Lindroos 1998) because the herdsman are assumed *ex ante* cost identical, but may be different *ex post*. While fishery models may imply that the most cost efficient coalition member is the only active member, the present (endogenous) cost difference model allows for all coalition members to be active. Hoel (2008) also analyzes a kind of cost advantage of cooperation, but in a model of international environmental agreements where the cost of adopting a new and more efficient abatement technology is lower when the coalition investing in the new technology is large.

Although the cost advantage of cooperation itself works in the direction of more animals and increased grazing pressure compared to the non-cooperative scenario, it has been shown that coalition formation may compensate for reduced herding cost so that the equilibrium vegetation utilization in fact declines. This has also a positive effect on the cooperators and non-cooperators utility, or profit. Only if the herding cost of the coalition members responds rather strongly to an increased coalition size, cooperation may result in reduced grazing pressure and more vegetation compared to the scenario of no cooperation at all.

In line with existing models of coalition formation (Sethi and Somanathan 1996, Osés-Eraso and Viladrich-Grau 2007), this paper demonstrates that a higher resource value reduces the level of cooperation and leads to reduced vegetation conservation. This result contrasts the famous findings in Demsetz (1967) who argues that more valuable resources increase the benefit of creating institutions to internalize externalities. More precisely, Demsetz claims that institutions are promoted when the resource value is high relative to transaction and enforcement costs. Furthermore, and in contrast to the previous mentioned models of coalition formation, this paper examines the welfare effects of a higher resource value. The numerical analysis demonstrates that a higher slaughtering price may reduce the community welfare. This surprising result occurs if the indirect effect working through reduced vegetation quantity, and hence reduced slaughtering income, dominates the direct positive profit effect of a higher price. As apposed to full cooperation equilibrium, only a proportion of the grazing externalities are taken into account in case of partial cooperation. The partial cooperation equilibrium is therefore of a second-best type and hence the community may be worse off with a higher slaughtering price. This possible outcome follows the classic externality paper by Lipsey and Lancaster (1956).

Appendix

A1. No cost advantage of cooperation (homogeneous herdsmen)

When inserting equations [1] (with $dX/dt = 0$), [7] and [8] into equation [4] the profits read

$$\pi^c(n) = pqbKr(1-w/(pqbK))^2 / (bn(N-n+2)^2) \text{ and}$$

$$\pi^{nc}(n-1) = pqbKr(1-w/(pqbK))^2 / (b(N-n+3)^2) \text{ and hence, } \pi^c(n) - \pi^{nc}(n-1) =$$

$$pqbKr(1-w/(pqbK))^2 \left[(N-n+3)^2 - n(N-n+2)^2 \right] / \left[n(N-n+2)^2 (N-n+3)^2 \right].$$

A stable coalition (equation [9] main text) requires $\pi^c(n) - \pi^{nc}(n-1) \geq 0$ and hence,

$$(N-n+3)^2 - n(N-n+2)^2 \geq 0.$$

Result 1

If $N = 2$, this condition is fulfilled for $n = 2$. That is, in case of two herdsmen, the stable equilibrium consists of a grand coalition. For $N \geq 3$, however, the grand coalition is not stable.

Proof Assume that $N = n$. Then $(N-n+3)^2 - n(N-n+2)^2 = 9 - 4n$ which is negative for all $n \geq 3$. Hence, $\pi^c(n) - \pi^{nc}(n-1) < 0$ for all coalitions of full cooperation when $N \geq 3$. QED.

Result 2

A self-enforcing coalition of partial cooperation $n < N$ does not exist.

Proof Assume that $n = 2$ is a stable coalition. Then

$$(N-n+3)^2 - n(N-n+2)^2 = (N+1)^2 - 2N^2 < 0 \text{ for } N \geq 3 \text{ and hence, } \pi^c(n) - \pi^{nc}(n-1) < 0 \text{ for}$$

$N \geq 3$. This means that a coalition of two herdsmen can not be stable when there are three or more herdsmen in the community. From *Result 1* it then follows that there is no cooperation when $N = 3$. Assume now that $N \geq 4$. Again, a stable coalition requires

$$(N-n+3)^2 - n(N-n+2)^2 = (1-n)(N-n)^2 + 2(N-n)(3-2n) + (9-4n) \geq 0.$$

The first term on the right hand side is negative for all coalitions of partial cooperation. The second term and third terms are negative for all coalitions of partial cooperation consisting of $n \geq 3$ herdsmen. Together with *Result 1* this proves that a self-enforcing coalition of partial cooperation does not exist. QED.

A2. Cost advantage of cooperation

A.2.1 Stability

When inserting [11], [12] and [13] into [4] the profits read

$$\pi^c(n) = pqbKr \left[1 - (N - n + 1)w(n) / pqbK + (N - n)w^{nc} / pqbK \right]^2 / (bn(N - n + 2)^2) \text{ and}$$

$$\pi^{nc}(n - 1) = pqbKr \left[1 + w(n - 1) / pqbK - 2w^{nc} / pqbK \right]^2 / (b(N - n + 3)^2). \text{ When comparing}$$

these expressions, the denominators reflect a positive free rider incentive created by coalition members accounting for grazing externalities for all $2 \leq n \leq N$ and $N > 2$. This is identical the homogeneous case in Appendix A1. What differs from the homogeneous model is the cost advantage of cooperation found in the bracket terms. When assuming $w(n) = w^{nc} / n$ (see section five), the difference between the bracket terms in $\pi^c(n)$ and $\pi^{nc}(n)$ equals

$$w^{nc} \left[(n - 1)^2 (N - n + 2) \right] / (pqbKn(n - 1)), \text{ which is positive for all } 2 \leq n \leq N. \text{ That is, the}$$

brackets reflect a positive incentive to join the coalition due to the cost advantage. A herdsman will join the coalition if the cost advantage exceeds the free riding benefit.

A2.2 Herd size and vegetation quantity

It is here demonstrated how stock levels and vegetation quantity under cooperation may differ from the homogeneous case of no cooperation. In the homogeneous case the herd size is equal across all herdsman, $y = y^c(1) = y^{nc}(1) = r(1 - w^{nc} / (pqbK)) / (b(N + 1))$ (equation [7] and [8] with $n = 1$). When subtracting this from [11] and [12] we find

$$y^{nc}(n) - y = r \left[(n - 1) - (N + n)w^{nc} / (pqbK) + (N + 1)w(n) / (pqbK) \right] / (b(N - n + 2)(N + 1)) \text{ and}$$

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

, respectively. Hence, in presence of a stable cooperating coalition, non-cooperators keep more and cooperators keep fewer animals than in the homogeneous case if

$$n - 1 > (N + n)w^{nc} / (pqbK) - (N + 1)w(n) / (pqbK). \text{ The left hand side of this condition reflects}$$

that a larger fraction of the grazing externalities is accounted for in presence of cooperation, while the right hand side reflects that cooperation means reduced marginal herding cost in the coalition. Hence, a dominating first effect implies that coalition members keep fewer animals than in absence of cooperation, while non-cooperators free ride on the coalition by keeping more animals. Of course, when comparing the vegetation quantity in equation [13] with the homogeneous model (section three), it is seen that a stable cooperating coalition ($2 \leq n \leq N$) means improved vegetation quantity if this condition holds.

If instead $n-1 < (N+n)w^{nc}/(pqbkK) - (N+1)w(n)/(pqbkK)$ for $2 \leq n \leq N$, then members of a stable coalition keep more animals than in the homogeneous model. This is because the cost advantage is strong enough to stimulate coalition members to increase their herd sizes.

Because this condition also implies $y^c(n) > y^{nc}(n)$ for $2 \leq n < N$, a coalition of partial cooperation can no longer be stable. The reason is obvious: the cost advantage dominates the free rider incentives, making outsiders better off by joining the coalition. So if

$n-1 < (N+n)w^{nc}/(pqbkK) - (N+1)w(n)/(pqbkK)$ for $2 \leq n \leq N$, then the system settles in full cooperation stability with a vegetation quantity below that in the homogeneous model.

A3. Numerical analysis

A3.1 Numerical specification

The ecological parameter values are based on Moxnes et al. (2003). They assume the vegetation carrying capacity K to be 1 200 000 kilo per km² and the maximum vegetation growth (i.e. at X^{msy}) to 64 000 kilo per km². Therefore, when utilizing the logistic vegetation growth function (section two), the intrinsic growth rate r equals 0.213.

The ecological per animal vegetation consumption parameter b is calculated from the vegetation equilibrium $X = K(r - b(ny^c + (N-n)y^{nc}))/r$, when using the above K and r values. In addition, reasonable values for the vegetation quantity and reindeer stock are applied. Data from 2005/06 shows that the average management unit in West Finnmark kept 409 animals (NRHA 2007). This number is used as a proxy for all herds when calculating the baseline value of b . There exists, however, no accurate data on the vegetation cover in this area. Analyses of some of the districts in the area imply that during 1987-2000 the vegetation cover was reduced to 20 per cent of the 1987 level (Johansen and Karlsen 2005). When calculating the parameter b a rough proxy for the vegetation quantity X is assumed, namely $0.2K = 240\,000$ kilo per km². The result is $b = 0.00004$.

Data from 2005/06 shows that 99 animals were slaughtered by an average management unit (NRHA 2007). When inserting this number, together with the above values for the vegetation quantity and the average number of reindeer, into the ecological equilibrium [2] (with $dy^i/dt = 0$), q equals 0.0217. On average, this means that about 2 percent of the animal vegetation biomass intake is converted to meat biomass. This may seem as a small number,

but remember that we are considering a biomass model where the weight of adult animals is more or less fixed over the year cycle.

Following Moxnes et al. (2001) the per animal herding cost in absence of cooperation w^{nc} is set to 200 NOK. See also Bostedt et al. (2003). When accounting for the fraction of calves, adult males and females, the average slaughtering weight is calculated to 21.2 kilo per animal (NRHA 2007). The slaughtering price includes the price received at a registered slaughter and slaughtering subsidies. The price received at a registered slaughter is NOK 52 per kilo (Labba et al. 2006), while subsidies amount to roughly NOK 244 per animal (NRHA 2007). The per animal baseline value slaughtering price p is therefore assumed to be NOK 1346.¹²

A3.2 Sensitivity analysis

Table A1 demonstrates the impact of increased community size N while keeping all other parameters fixed at their baseline levels. Columns six and ten report the gain of cooperation in terms of vegetation quantity and community profit, respectively, compared to the corresponding non-cooperating outcomes. The results demonstrate that the fraction of herdsmen cooperating increases with the size of the community. However, the gains of cooperation in terms of vegetation conservation are reduced. Still, it takes a very large community to eliminate the conservation gains of cooperation. In contrast, the welfare gains increase with the size of the community. The reason is that large coalitions benefit more from the cost advantage.

Table A1 about here

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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
consumtion Slaughtering price	p	1346	NOK/animal	NRHA (2007)
Fixed cost parameter non- cooperators	w^{nc}	200	NOK/animal	Moxnes et al. (2001)
Sensitivity parameter, cost function coalition members	β	1		Assumed
Number of units	N	10	management unit	Assumed

TABLE 2
Stability analysis coalition size n .
Baseline parameter values.

n	y^c	y^{nc}	X	h^c	h^{nc}	π^c	π^{nc}	Π
1		415	264 713		95.4		45 352	453 516
2	399	419	265 507	92.0	96.5	83 909	46 125	536 813
3	319	451	272 817	75.6	106.8	80 446	53 551	616 196
4	267	499	283 738	65.8	123.0	75 243	65 678	695 041
5*	235	565	298 594	60.8	146.5	72 463	84 160	783 117
6	215	655	318 878	59.4	181.4	72 843	113 090	889 420
7	205	783	347 602	61.8	236.2	77 340	161 356	1 120875
8	205	975	390 942	69.6	330.9	88 500	250 374	1 208751
9	219	1 297	463 402	88.1	521.6	113 755	442 705	1 466503
10	262		608 559	138.6		181 353		1 813534

Notes: Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m²), slaughtering h^c and h^{nc} (number of animals) and profit π^c , π^{nc} and Π (NOK).

TABLE 3
Coalition size n^* , pasture utilization and profit.
Various values slaughter price p
(NOK/animal).

p	n^*	y^c	y^{nc}	X	h^c	h^{nc}	π^c	π^{nc}	Π
600	10	258		619 201	138.5		77 958		779 580
700	9	239	855	521 913	108.4	387.5	70 567	100 170	735 276
800	8	231	732	453 010	91.0	287.9	66 980	83 882	703 605
900	7	231	643	400 925	80.4	223.8	65 742	72 792	678 571
1000	7	223	685	384 832	74.5	228.9	68 146	91 844	752 551
1100	6	230	603	345 464	68.9	181.0	68 104	78 361	722 067
1200	6	223	627	333 342	64.5	181.5	69 952	92 322	789 001
1346 ¹⁾	5	235	565	298 594	60.8	146.5	72 463	84 160	783 117
1400	5	231	573	293 689	59.0	146.0	73 340	89 885	816 127
1500	4	257	517	270 008	60.2	121.1	77 479	78 278	779 585
1600	4	251	526	262 507	57.3	119.8	79 045	86 537	835 399
1700	4	246	534	255 889	54.7	118.6	80 681	94 843	891 784
1800	3	288	486	237 636	59.5	100.3	87 848	83 325	846 817
⋮									
2200	3	272	506	218 672	51.6	96.0	95 382	110 007	1 056 192
2300	2	344	466	205 153	61.3	82.9	106 506	97 620	993 075
⋮									
3200	2	322	485	181 204	50.7	76.2	129 933	146 976	1 435 679
3300	0		456	172 566		68.3		134 178	1 341 776

Notes: ¹⁾ Baseline value. Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m²), slaughtering h^c and h^{nc} (number of animals) and profit π^c , π^{nc} and Π (NOK).

TABLE 4

Homogeneous model.

Coalition size n^* , pasture utilization and profit. Various values slaughter price p (NOK/animal).

P	n^*	y^{nc}	X	h^{nc}	π^{nc}	Π
600	0	329	458 204	130.9	12 717	127 168
900	0	381	341 833	113.0	25 530	255 296
1346 ¹⁾	0	415	264 713	95.4	45 352	453 516
1700	0	429	232 307	86.6	61 317	613 171
2300	0	444	200 164	77.1	88 561	885 612

Notes: ¹⁾ Baseline value. Animal stock size y^{nc} (number of animals), vegetation X (kg/m²), slaughtering h^c and h^{nc} (number of animals) and profit π^{nc} and Π (NOK).

TABLE 5

Coalition size n^* , pasture utilization and profits.Various values cost parameter w^{nc} (NOK/animal).

w^{nc}	n^*	y^c	y^{nc}	X	h^c	h^{nc}	π^c	π^{nc}	Π
50	0		467	147 997		60.0		57 377	573 770
75	0		458	167 449		66.6		55 275	552 746
100	2	333	476	192 754	55.7	79.6	58 292	59 536	592 870
125	3	273	504	220 511	52.3	96.4	59 048	66 811	644 824
150	3	289	486	237 946	59.6	100.4	65 814	62 228	633 041
175	4	255	520	267 021	59.0	120.6	68 311	71 254	700 769
200 ¹⁾	5	235	565	298 594	60.8	146.5	72 463	84 160	783 117
225	6	223	626	333 738	64.6	181.5	78 620	103 299	884 916
250	6	231	597	348 598	70.0	180.8	84 617	93 951	883 508
275	7	225	677	387 953	75.6	228.0	92 985	120 687	1 012 958

Notes: ¹⁾ Baseline value. Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m²), slaughtering h^c and h^{nc} (number of animals) and profit π^c , π^{nc} and Π (NOK).

TABLE 6

Coalition size n^* , pasture utilization and profits.Various values vegetation carrying capacity K (1000 kg/km²).

K	n^*	y^c	y^{nc}	X	h^c	h^{nc}	π^c	π^{nc}	Π
1200 ¹⁾	5	235	565	298 594	60.8	146.5	72 463	84 160	783 117
1100	5	242	548	284 309	59.7	135.1	70 738	72 377	715 573
1000	6	228	609	285 545	56.5	123.4	68 493	81 364	736 417
900	7	222	689	287 602	55.5	172.0	68 382	93 686	759 731
800	7	231	642	267 602	53.7	149.1	65 680	72 294	676 643
700	8	233	721	265 942	53.7	166.4	66 437	79 801	691 098
600	9	241	818	263 402	55.1	187.1	68 806	88 177	707 431
500	10	257		258 559	57.7	208.8	72 533		725 330

Notes: ¹⁾ Baseline value. Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m²), slaughtering h^c and h^{nc} (number of animals) and profit π^c , π^{nc} and Π (NOK).

TABLE A1

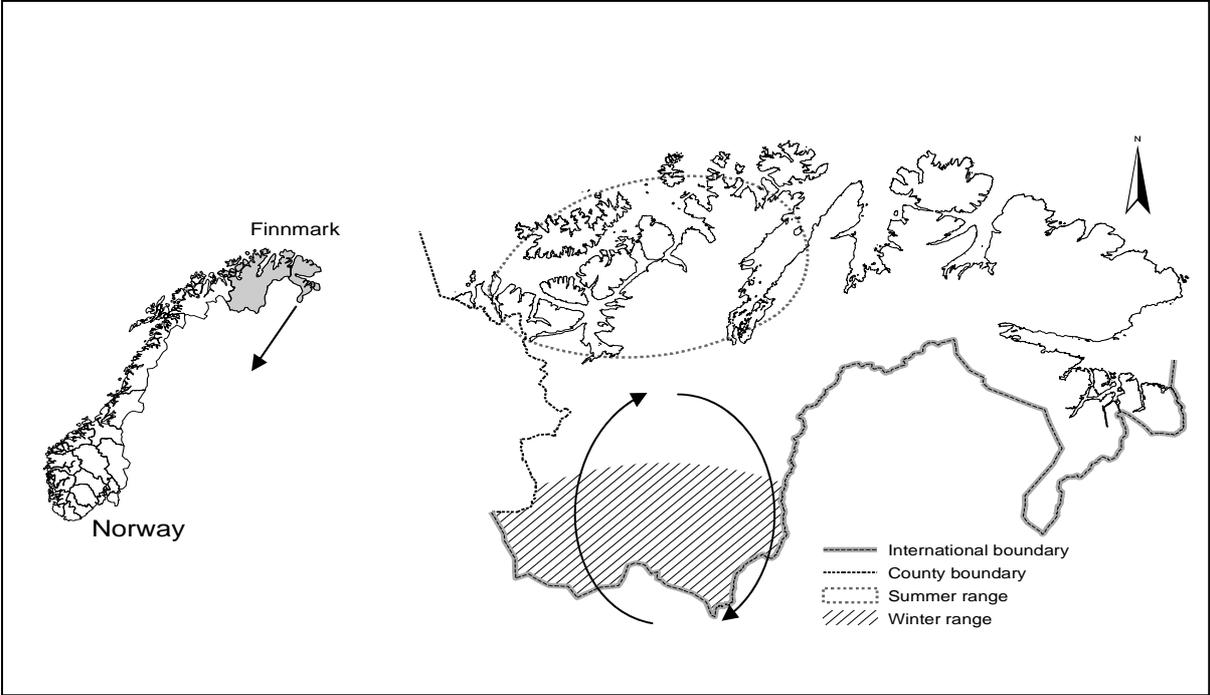
Sensitivity analysis.

Various values of the size of the herding community N .

N	n^*	y^c	y^{nc}	X	gain X	π^c	π^{nc}	Π	gain Π
10 ¹⁾	5	235	565	298 594	13 %	72 463	84 160	783 117	73 %
20	10	101	323	244 081	11 %	26 706	27 549	542 552	118 %
30	16	60	241	225 455	10 %	14 944	15 270	452 885	164 %
40	23	40	202	216 715	10 %	9 872	10 747	409 757	214 %
50	30	30	174	210 427	10 %	7 243	7 984	376 964	257 %
100	66	13	106	195 080	8 %	2 910	2 960	292 736	444 %
150	106	8	83	189 864	7 %	1 733	1 809	263 318	629 %
200	146	6	68	186 521	6 %	1 220	1 219	243 949	798 %
250	188	4	60	184 600	5 %	930	933	232 776	969 %

Notes: ¹⁾ Baseline value. Animal stock sizes y^c and y^{nc} (number of animals), vegetation X (kg/m²), slaughtering h^c and h^{nc} (number of animals) and profit π^c , π^{nc} and Π (NOK).

Figure 1: Map of Finnmark reindeer herding area indicating the migration route in West Finnmark.



¹ Kaitala and Lindroos (1998) assume linear cost functions. In contrast, by assuming convex costs, Kronbak and Lindroos (2007) allow for *all* coalition members to be active.

² Noy-Meir (1975) specifies vegetation consumption as $mX/(X + \theta)$, where m is the maximum consumption rate per animal and θ measures the vegetation level at which livestock is half-satiated. A linear specification, however, do not capture satiation. Still, this specification seems reasonable in cases where vegetation is not too abundant.

³ Other factors than grazing pressure may certainly affect the vegetation cover, especially in arid pasture-livestock systems as the one considered here (see e.g., Brekke et al. 2007 who emphasize the effects of climate change). Such possible factors are, however, ignored in this paper.

⁴ In reality, the cost among the herdsmen may also vary due to skills, herding techniques and practices, and so forth. In this paper, however, such possible differences are neglected.

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 The relationship between the stability of coalition structures and free rider incentives in the management of high seas fisheries is thoroughly explored by Pintassilgo (2003).

⁷ In one of several model specifications Barrett (1994) demonstrates that stable coalitions do not exist under the assumption of constant and identical marginal costs across the polluting countries.

⁸ By definition $w^{nc} \geq w(n)$ for all $n \geq 2$. With the present specification this implies $\beta \geq 1/n$ for all $n \geq 2$ and hence, $\beta \geq 1/2$.

⁹ For a given level of cooperation, singletons always increase their herd size when the slaughtering price increases, while coalition members may either increase or reduce their herds. The latter is seen by differentiating [11] with respect to p , while keeping n fixed, $dy^c / dp = r \left[(N - n)(w(n) - w^{nc}) + w(n) \right] / (b^2 n(N - n + 2)p^2 qK)$. However, from equation [13] we see that the direct vegetation effect is negative, which implies a direct positive effect on the total reindeer population.

¹⁰ Notice that coalition members are better off in this example. This is surprising, but the reason is that the marginal cost of coalition members reduces relative to that of singletons; that is, $\partial w(n) / \partial w^{nc} = 1/n < 1$ for all $n \geq 2$. Hence, restrictions on animal numbers made by singletons enable coalition members to increase their animal numbers. This implies increased slaughtering and profit in the coalition.

¹¹ Such encroachments may also have a direct negative impact on reindeer growth, as indicated by studies of wild reindeer (see e.g., Nellemann et al. 2003). In our model this effect may be captured through a reduction of the biomass transformation parameter q (section two). However, this possible effect is not taken into account.

¹² Transfers to management units also include a general grant. This is not included in the numerical analysis.