

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.

1. 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 hypothesis has also been modelled in several papers. 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) 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 member. 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. 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. While cooperators realize efficiency gains by merging their herds, non-cooperators suffer a competitive disadvantage. In this way, the reward gained by cooperators is in fact a negative externality imposed on non-cooperators. A somewhat similar approach is found in Yi (1998) who studies efficiency gains in research coalitions in a Cournot oligopoly

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 herdsman who are willing to abide by its rules. Thus, any herdsman can choose either to join the coalition, or not. However, the model differs from Yi as cooperation creates simultaneously positive and negative externalities. 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. This is the positive externality imposed by cooperators. At the same time, however, cooperators impose a negative externality on non-cooperators due to their cost advantage. Because of this externality asymmetry, a coalition of partial, or full, cooperation may be a stable equilibrium outcome. Our model also differs 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 members¹. 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 (Finmark county) follows in section five, while section six concludes the paper.

2. 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 drought. Skonhoft (1999) assumes no cooperation and compares the standard neoclassical model of resource rent maximization with a model of herdsmen 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 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 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:

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

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).

3. Exploitation without cost advantage

The economic motives for keeping animals and slaughtering are now introduced under the assumption that the herdsmen are *homogeneous*; that is, there is no cost advantage attached to cooperation³. Therefore, the per animal herding cost w is assumed identical across all herdsmen either they cooperate ($i = c$), or not ($i = nc$). With p as the per animal slaughtering price, assumed to be fixed, the individual profit writes:

$$\pi^i = ph^i - wy^i; \quad i = c, nc \quad (4)$$

The prospects of coalition formation, where slaughtering effort is coordinated to maximize total harvesting profit of the coalition, are then considered. This includes 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 numerous 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. The first order condition of this problem is given by:

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

The first term here 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. 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 in (1)-(2) (with $dX / dt = 0$ and $dy^i / dt = 0$). The first order condition of this problem yields:

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

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. The second order condition reads now $-2pqb^2(K/r)n < 0$.

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

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

and

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

and where the number n within the left hand side parenthesis implies that n herdsmen 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 herdsmen act as singletons, $n = 1$, we find $y^c(1) = y^{nc}(1) = r(1 - w/(pqbkK))/(b(N + 1))$.

In the first stage of the game the individual herdsmen 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 be better 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 better 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 satisfy conditions (9) and (10) is stable.

Because the coalition members restrict their flock sizes, non-members are typically better off when more herdsmen 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 model⁴. Apart from the situation when the local common consists of just *two* herdsmen (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)⁵, and in the (static) Gordon-Schaefer fishery model by Pintassilgo and Lindroos (2007). 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 herdsmen act as singletons. By inserting $n = 1$ into (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 $X = K(1 + Nw/(PqbK))/(N + 1)$.

4. Cost advantage of cooperation

Above it was demonstrated that the prospect of cooperation is bleak when the herdsmen 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 economic 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 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 equations (11)-(12) 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. When inserting (11) and (12) into (1) (when $dX/dt = 0$) the corresponding vegetation quantity equals:

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

This equation demonstrates two contradicting effects on the vegetation quantity of a changing coalition size. The term outside the bracket reflects that a larger proportion of the grazing externalities are taken into account as the number of coalition members increases. The second and third terms within the bracket reflect that the average marginal herding cost reduces as more herdsmen join the coalition. The last effect works in the direction of reduced vegetation quantity, leaving the total effect unclear. For more details, see Appendix A2.

The definition of a stable coalition is again given by the conditions (9)-(10). Depending on the shape of the cost function $w(n)$, i.e., the sensitivity of the cost to changes in the number of cooperators, the possible coalitions structures are full cooperation (grand coalition stable), partial cooperation ($2 \leq n < N$) and non-cooperation. Note that under partial cooperation stability y^c must be below y^{nc} . Otherwise, non-members will always be better off by joining the coalition.

The pasture utilization under non-cooperation and cooperation is first considered, and the difference compared to the above homogeneous model is explained. 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. Then $n = 1$ and $w(1) = w^{nc}$ and hence, equations (11) and (12) coincide with the solution of the homogeneous case $y^{nc} = r[1 - w/(pqbK)]/[b(N + 1)]$. Next, assume instead that the cost advantage is sufficient enough to promote coalition formation. As the size of the coalition increases, the marginal herding cost reduces, indicating that the free riding incentives reduce. However, while the number of coalition members increases, a larger proportion of the grazing externalities are taken into account. This effect works in the direction of reduced herd size per coalition member and hence, increases the free riding incentives of staying outside the coalition. A stable coalition emerges where coalition members have no incentives to break out and non-cooperators have no incentives to join the coalition. If the cost advantage of cooperation is strong enough to eliminate the free rider incentives for all coalition sizes, then all herdsmen will join the coalition.

Anyway, when comparing with the resulting pasture utilization in the homogeneous model (section three) it is useful to imagine that the same coalition size is realized in both models, meaning that the externalities are taken into account in the same degree. Having a cost advantage then works in the direction of higher stock levels of the coalition members, and hence less vegetation quantity, in the heterogeneous model. However, the only stable coalition structure in the homogeneous model is that of no cooperation, meaning that the grazing externalities are not accounted for at all. This works in the direction of coalition members keeping fewer animals in presence of a cost advantage compared to the homogeneous case. Therefore, the total effect on the number of livestock and vegetation quantity is ambiguous (more details Appendix A2). Hence, cooperation driven by a cost advantage may result in vegetation quantity above or below that in absence of cooperation. In any case, individual and total profit levels are above that of the homogeneous scenario.

We then analyse how the various economic and ecological forces may influence the coalition size, livestock number and vegetation quantity while the effects on profits and distribution are illustrated in the numerical example in section 5 below. Consider first, for a given coalition size, a reduction in the marginal herding cost per coalition member relatively to that of non-

cooperators. This stimulates each coalition member to keep more animals, while non-cooperators reduce their herd sizes (equations 11-12). This is the direct effect and works in the direction of a larger total animal number. However, the new equilibrium is associated with more cooperation as the profit of a being a coalition member improves relative to that of a non-cooperator. This effect reduces the total livestock number as those shifting from being a non-cooperator to a cooperator reduce their herd sizes. The total effect on livestock numbers and vegetation quantity (equation 13) is thus ambiguous. Increased cost discrepancy in favour of coalition members may therefore promote vegetation conservation, even though the average marginal herding cost reduces.

We next consider a more profitable production through a higher slaughtering price p which may happen through a higher subsidy (see below). The direct total livestock number effect (i.e., for a fixed coalition size) is positive (Appendix A2). Again, the indirect effect works through a changing coalition size. Because non-cooperators initially keep more animals than coalition members, the profit of a being outside the coalition increases relative to that of joining. Hence, the coalition size reduces. As the coalition size reduces, 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). 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 conservation is therefore ambiguous.

5. Reindeer herding in northernmost Norway

The theoretical reasoning will now be illustrated by data that fits reasonable 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 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, Mongolia and elsewhere in central Asia (O'Neil 2007).

On a national scale, reindeer herding in Norway is a small industry. The total industry comprises 556 management units keeping in total 240 000 reindeer. 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 culturally. In the 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 Skonhoft 2008). This indicates that some cultural identity is attached to being a reindeer herder.

In Finnmark reindeer migrate across a huge area during the year. 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 such cooperation.

In the numerical analysis the vegetation cover is specified as kilo vegetation (i.e., lichen) per km^2 . The total 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 $w(n) = w^{nc} / kn$ for all $2 \leq n \leq N$, and with $k \geq 1/2$ as a parameter⁶. Table 1 presents the baseline economic and ecological parameter values. See also Appendix A3.

Table 1 about here

Table 2 demonstrates the profit, herd size and vegetation level corresponding to each possible n in the baseline case. The 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. This enables each non-cooperator to keep more animals. These effects increase animal growth and slaughtering h^{nc} . Therefore, outsiders remaining non-cooperators are always better off as the size of the coalition increases (but see Appendix A2 and Table 5 below). 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 enough to cause a negative impact on the animal offtake. This effect dominates the cost advantage of cooperation. For $n > 5$, however, increased vegetation quantity enhances animal growth and hence, the animal offtake increases as well. This causes a positive association between the profit of a cooperator and the number of herdsman joining the coalition.

Table 2 about here

This table hence shows 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 hence profitable for a non-cooperating herdsman to form a coalition with another herdsman. By continuing in this way, the table 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 herdsmen are better off in the partial cooperation stable equilibrium. As explained above, 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. As indicated in the theoretical analysis (section four), a lower price increases the coalition size, and when reducing the price to $p = 500$ the system is even grand coalition stable. Further, when comparing Table 3 and Table 4, which reports the section three situation with no cost advantage (homogeneous model), we see that, for the given parameter values, a coalition joined by many herdsmen increase the vegetation conservation significantly compared to the non-cooperative outcome. This result differs from Barrett (1994), who finds the gains of cooperation to be small and negligible.

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 as an increase in the slaughtering price, and hence the value of keeping an animal increases. The direct effect on the total reindeer number is therefore positive (see Appendix A2)⁷. Furthermore, the indirect effect working through reduced coalition size (see section four) strengthens the direct effect on the total reindeer number. This reasoning demonstrates that the negative impact on vegetation conservation of a price subsidy is even stronger when including the effect of a changing coalition size.

The last three columns of Table 3 report the profit effects of increased slaughter price. Those shifting from being a coalition member to becoming a non-cooperator are always better off both directly and indirectly as the flock size and slaughtering increases when leaving the coalition. However, the slaughtering reduces for the remaining coalition members and the initial non-cooperators due to reduced vegetation quantity. Still, the remaining cooperators are better off because of the direct profit effect. In contrast, the initial non-cooperators are worse off if the indirect effect working through reduced slaughtering dominates the direct positive effect of a higher price. This is obviously a strange result, but can be explained by the non-cooperating behaviour of the singletons. Because each singleton ignores the externalities

imposed on the other herdsmen, the steady-state is of a second-best type, and hence singletons may be worse off with a higher slaughtering price. This possible outcome follows the classic externality paper by Lipsey and Lancaster (1956). The last column of Table 3 demonstrates that a price increase leaves the herding community as a whole worse off when non-cooperating herdsmen are worse off.

Table 5 presents the effects of an increased value of the cost parameter w^{nc} . Following our numerical example, this change hits singletons more serious than those cooperating because of the relative efficiency gains obtained by the coalition members. Consequently, more herdsmen join the coalition. The new coalition accounts for a larger fraction of the grazing externalities, which, irrespective of 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. The positive impact on vegetation utilization is strong enough to ensure enhanced slaughtering and profit of the coalition members as well (except for the new members of the coalition). In sum, increased w^{nc} means lower vegetation utilization and higher community profit.

Table 5 about here

Finally, we consider a reduction in the vegetation carrying capacity K , which, as mentioned (section 4), may be caused by infrastructure expansions⁸. Reindeer herdsmen have frequently claimed such encroachments to have reduced the vegetation cover over the past decades (Kitti et al. 2006). Table 6 demonstrates the effects.

Table 6 about here

It is seen that the vegetation quantity reduces, but the effect is rather modest. The reason is that the level of cooperation increases, which prevents a larger drop in the vegetation quantity. Second, if vegetation carrying capacity is initially low ($K \leq 800000$), the herding community as a whole is actually better off from further encroachments. This result is surprising, but may be explained as follows. As the size of the coalition increases the marginal herding cost becomes low enough to stimulate coalition members to increase their number of animals. As a

consequence, the number of animals slaughtered increases and the individual profit within the coalition improve. As more herdsmen join the coalition, the free rider benefits per remaining singleton increases. Hence, every herdsman remaining outside the coalition is better off as well. The equilibrium is full cooperation stable for $K = 500000$. Certainly, encroachments reducing the vegetation carrying capacity below this level will reduce the profit of the community.

6. 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). 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 (Finmark county). When herdsmen 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 a stable equilibrium outcome. The model differs from coalition formation in high seas fisheries (Kaitala and Lindroos 1998) because the herdsmen 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.

Although the cost advantage of cooperation itself works in the direction of increased vegetation use 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 reduces. 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 number, cooperation may result in more vegetation use 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 transaction and enforcement costs are low relatively to the benefit obtained by internalizing externalities. 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 (1) (with $dX / dt = 0$), (7) and (8) into (4) the profit reads

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

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

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

coalition 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

$$(N-n+3)^2 - n(N-n+2)^2 = (1-n)(N-n)^2 + 2(N-n)(3-2n) + (9-4n) \geq 0. \text{ The first term on}$$

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

Taking the derivative of (13) with respect to n and rearranging yields:

$$\frac{dX}{dn} = \frac{bK}{r(N-n+2)} \left[y^{nc}(n) + \frac{rw'(n)}{pqb^2K} \right] \quad (A1)$$

The sign of this expression is unclear. The first term in the bracket reflects that a higher n means fewer free riders and more attention paid to the grazing externalities, while the second term reflects that a higher n reduces the marginal herding cost for all coalition members.

Taking the derivative of (11) and rearranging yields:

$$\frac{dy^c(n)}{dn} = -\frac{y^c(n)}{n} + \frac{y^{nc}}{n(N-n+2)} - \frac{r(N-n+1)}{n(N-n+2)} \frac{w'(n)}{pqb^2K} \quad (A2)$$

The sign of this expression is unclear as well. The first term captures that each coalition member accounts for a larger proportion of the externalities as n increases, and this works in the direction of smaller herds in the coalition. The second term reflects that the number of free riders reduces and works in the direction of larger herds in the coalition. The third term reflects that the marginal herding cost reduces for members of the coalition when n increases and works in the direction of the coalition members keeping larger herds.

Taking the derivative of (12) and rearranging yields:

$$\frac{dy^{nc}(n)}{dn} = \frac{1}{(N-n+2)} \left[y^{nc}(n) + \frac{rw'(n)}{pqb^2K} \right] \quad (A3)$$

Again, the sign is unclear. The first term in the bracket reflects that the number of free riders reduces and works in the direction of larger herds among the remaining singletons. However, the second term in the bracket works in the direction of a larger total herd in the coalition and hence, reduced herds for the remaining singletons.

When inserting (11) and (13) and rearranging, the profit function of a coalition member is given as:

$$\pi^c(n) = \frac{npqb^2K}{r} (y^c(n))^2 \quad (A4)$$

It is seen from (A4) that the direct effect on profits of an increase in the number of coalition members is positive. The indirect effect working through a changing stock size is, however, unclear.

When inserting (12) and (13) and rearranging, the profit function of a singleton equals:

$$\pi^{nc}(n) = \frac{pqb^2K}{r} (y^{nc}(n))^2 \quad (\text{A5})$$

From (A5) it is seen that the profit of a singleton increases with the number of cooperators only if the herd size increases.

Hypothetically, given a coalition of size, the total livestock population in the homogeneous case equals

$$Y = \frac{r}{b(N-n+2)} \left[(N-n+1) - (N-n+1) \frac{w^{nc}}{pqbK} \right] \quad (\text{A6})$$

The total livestock population in case of a cost advantage reads

$$Y = \frac{r}{b(N-n+2)} \left[(N-n+1) - \frac{w(n)}{pqbK} - (N-n) \frac{w^{nc}}{pqbK} \right] \quad (\text{A7})$$

By comparing (A6) and (A7) for a fixed coalition size, we see that the partial effect of introducing a cost advantage is to increase the livestock population. For $N > 2$, however, there will be no coalition formation in the homogeneous model and hence, the individual herdsmen pay no attention to the externalities working between them. According to this effect a cost advantage will reduce the livestock population as long as the coalition size is positive. The total effect on the livestock population is therefore unclear.

Taking the differential of (A7) with respect to p for a given coalition size n yields:

$$\frac{dY}{dp} = \frac{r}{p^2qb^2K(N-n+2)} \left[w(n) + (N-n)w^{nc} \right] > 0 \quad (\text{A8})$$

A3. Numerical specification

The ecological parameters 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 growth function, the intrinsic growth rate r equals 0.213.

The ecological per animal vegetation consumption parameter b is calculated from the equilibrium $X = K(r - b(ny^c + (N - n)y^{nc}) / r$, when inserting K and r from above and some reasonable values for the vegetation quantity and reindeer stock. Data from 2005/06 shows that the average management unit in West Finnmark kept 409 animals (NRHA 2007). This 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 is assumed, namely $0.2K = 240\ 000$ kilo per km². The result is $b = 0.00004$.

Data from 2005/06 shows that the 99 animals were slaughtered by an average management unit (NRHA 2007). When inserting this, together with the above values for the vegetation quantity and the average number of reindeer, into the ecological equilibrium in (2) (with $dy^i / dt = 0$), q equals 0.0217.

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). The slaughtering price is measured in NOK per animal. 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 is therefore assumed to be NOK $p = 1346$ ⁹.

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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 consumption	q	0.0217	animal/kg	Calibrated
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	k	1		Assumed
Number of units	N	10	management unit	Assumed

Table 2: Stability analysis. 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

Table 3: Coalition size, pasture utilization and profit. Various values slaughter price p .

p	n^*	y^c	y^{nc}	X	π^c	π^{nc}	Π
500	10	256		623 041	64 109		641 087
900	7	231	643	400 925	65 742	72 792	678 571
1200	6	223	627	333 342	69 952	92 322	789 001
1346 ¹⁾	5	235	565	298 594	72 463	84 160	783 117
1500	4	257	517	270 008	77 479	78 278	779 585
1800	3	288	486	237 636	87 848	83 325	848 817

Table note: ¹⁾ Baseline value**Table 4:** Homogeneous model, pasture utilization and profit. Various values slaughter price p .

p	n^*	y^{nc}	X	π^{nc}	Π
500	0	298	528 027	8 696	86 962
900	0	381	341 833	25 530	255 296
1200	0	407	283 648	38 812	388 119
1346 ¹⁾	0	415	264 713	45 352	453 516
1500	0	422	248 736	52 282	522 819
1800	0	432	225 462	65 846	658 458

Table note: ¹⁾ Baseline value**Table 5:** Coalition size, pasture utilization and profits when varying the cost parameter w^{nc} .

w^{nc}	n^*	y^c	y^{nc}	X	π^c	π^{nc}	Π
200 ¹⁾	5	235	565	298 594	72 463	84 160	783 117
250	6	231	597	348 598	84 617	93 951	883 508
300	7	231	642	401 403	98 520	108 441	1 014 964

Table note: ¹⁾ Baseline value

Table 6: Coalition size, pasture utilization and profits for various values of K .

K	n^*	y^c	y^{nc}	X	π^c	π^{nc}	Π
1200000 ¹⁾	5	235	565	298 594	72 463	84 160	783 117
1000000	6	228	609	285 545	68 493	81 364	736 417
800000	7	231	642	267 602	65 680	72 294	676 643
700000	8	233	721	265 942	66 437	79 801	691 098
600000	9	241	818	263 402	68 806	88 177	707 431
500000	10	257		258 559	72 533		725 330

Table note; ¹⁾ Baseline value

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 $mX/(X+F)$, where m is the maximum consumption rate per animal and F 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 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.

⁴ 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).

⁵ In one of several model specifications Barrett (1994) demonstrates that stable coalitions do not exist in case of constant and identical marginal costs across the polluting countries.

⁶ By definition $w^{mc} \geq w(n)$ for all $n \geq 2$. With the present specification this implies $k \geq 1/n$ for all $n \geq 2$ and hence, $k \geq 1/2$.

⁷ 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, $dy^c / dp = r[(N-n)(w(n) - w^{mc}) + w(n)] / (b^2 n(N-n+2)p^2 qK)$. As seen, the sign is unclear.

⁸ Such encroachments may also have a direct negative impact on reindeer growth, as suggested by evidence from 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.

⁹ Transfers to management units also include a general grant. This is not included in the numerical analysis.