Economic Perspectives on the Nordic Wolf Re-Colonization – the Role of Compensation Payments

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Abstract

The paper presents some economic perspectives on the Nordic wolf re-colonization with a specific focus on redistribution and compensation policies. We argue that the compensation arrangement of the current wolf management in Norway violates the efficiency criteria both in terms of Pareto optimality and the potential Pareto improvement test. From the perspective of welfare economics, we consider various policies which may remedy the problem. In particular, we discuss whether compensation payments as a management tool may facilitate or impede the process of institutional change and environmental protection.

Key words: Wolf and livestock conflicts, Property rights, Compensation payments

JEL: Q20, Q15

1. Introduction

The re-colonisation of wolves in Scandinavia began in the 1970s, as a wolf preservation policy replaced the earlier arrangement of paying wolf bounties. The protection of the Scandinavian wolf was strengthened in the 1980s when Norway and Sweden became signatory members of the Bern-convention. As the wolf population slowly recovered, conflicts associated with wolves preying on domestic livestock increased both in scope and frequency. Wolf management has since been subject to fiery debate.

The current overall wolf management objective in Norway is to have three successful wolf reproductions within the management area annually. This goal has been reached in recent years (Norwegian Environment Agency, 2017). However, the wolf is still on the Norwegian red list and characterized as a critically threatened species. Hence, wolf management in Norway must be based on other considerations than a mere safeguarding of a viable wolf population. Indeed, together with the fact that the state pays full compensation for sheep and reindeer killed by wolves, this indicates that the interests of the livestock industry may also be influential on wolf management.

The present paper analyses the wolf conflict and explores the mechanisms by which the livestock industry may influence the wolf management in Norway. Particularly, we study the role of compensation arrangements. We discuss the distributional consequences and show how compensations violate the efficiency criteria of welfare economics. Moreover, by forming the public opinion, the compensation arrangement may influence the political process and thus the determination of the wolf management objective in the longer term. We also study the social planner solution to the management problem and discuss various policy alternatives.

We start out in section 2 by presenting the historical records of Norwegian wolf management and the Norwegian commitment to international conventions. By the aid of bioeconomic modeling, we study the sheep and wolf economies in sections 3 and 4, respectively. Then we explore the property rights structure and the distributional dimension of the compensation arrangement in section 4. Here, efficiency is assessed in terms of Pareto optimality. In section 5 we introduce the social planner, and study the efficiency of the compensation arrangement from the perspective of the potential Pareto improvement test. We offer a policy discussion in section 6, while section 7 summarizes our findings.

2. Historical records and the current management of wolves and sheep

Before the twentieth century, the Norwegians, who were comparatively poorer than today, probably had deeper worries than the survival of the Scandinavian wolf. Considered a threat to both livestock and people, the wolf was hunted down locally without much resistance. Only a minority of people valued the wolf positively and wanted to have a viable population of wolf in the country. Moreover, farmers wanted to bring livestock to the pastures without any interference from wolves. Hence, the number of wolves had to be reduced, and this could be achieved by intensifying wolf hunting. Correspondingly, the state stimulated hunting in 1845 by establishing a bounty for killing wolves (see, e.g., Soeilen 1995). As a result, the number of wolves was severely reduced. In the 1950- and 60s the wolf population in Norway was close to extinction, thus leaving the sheep stock almost unaffected by predation.

However, in line with the so-called post-materialism hypothesis by Inglehart (1971), which states that when basic material needs are met, individuals begin to give larger priority to "post-material" issues like caring for the environment, culture and so forth, attitudes became more in favour of wolf existence in the course of the 20th century. Rather than seeing the wolf as a mere nuisance, people began to appreciate the idea of having a viable wolf population in their country, i.e., wolves eventually generated *existence value* (Krutilla, 1967; Aldred, 1994; Attfield, 1998). The prevailing institutional structure - which was the product of a time when the wolf was considered a mere nuisance - fell out of step with the contemporary attitudes. The formerly awarded killing of wolves eventually triggered claims to protect the wolf from a broader group of people. Indeed, more than 60% of the Norwegians became in favour of having a viable wolf population and came to think that the wolf has a right to exist in Norway (Dahle et al., 1987; Linnell and Bjerke, 2002).

As a policy response, the wolf was preserved by the state in 1972, and earlier hunting practices of wolves were banned. The time had come for re-colonizing the Scandinavian wolf in Norway. In addition to the state preservation, wolf protection became institutionalized through various international conventions and legal provisions. Notably, Norway became a signatory to the Bern-convention in 1986, meaning that the country remains committed to sustaining a viable wolf population on Norwegian territory.

The current overall wolf management objective in Norway is to have three successful wolf reproductions within the management area annually. Moreover, the Norwegian Government has declared that wolf management must take place in a multi-use landscape. As forested and mountainous areas are important grazing resources, there will therefore be conflicting interests in the form of wolf preying on livestock. Thus, another important dimension of wolf management is to reduce the conflict associated with it (Ekspertutvalget 2011). As a response to this ambition, the Norwegian state established full compensation payments for sheep killed by wolves to mitigate the conflict. The overall wolf management objective of the Norwegian wildlife authority has been reached in recent years (Norwegian Environment Agency, 2017). But even though, the wolf is still on the Norwegian red list and characterized as a critically threatened species. Together with the compensation arrangements, this indicates that the Norwegian wolf management is a compromise between the opposing interests of the livestock owners and the wolf sympathizers.

Today, the number of wolves in Norway, when also including migratory packs from Sweden, is about 90 individuals (Wabakken et.al., 2016). On the other side, there are about 13,000 sheep farms and more than two million animals during the outdoor grazing season. Most of the sheep farms are located in mountain- and forest covered areas and other sparsely populated areas. The main product is meat, while any remaining income comes from wool, as sheep milk production is non-existent. Housing and indoor feeding is required throughout the winter because of snow and harsh weather conditions. Lambs are born during late winter to early spring. When weather conditions allow, sheep are released into rough grazing areas in the valleys and mountains, which are typically communally owned. Hence, during the summer rough grazing period, the sheep flocks may be vulnerable to large predators such as the wolf (but also the lynx, wolverine and bear). On average, about 26 000 sheep are compensated annually as killed by these large predators in the period of 2010-2016 (Rovbasen 2017). Of these, the wolf is responsible for about 2000 (less than 8%). The average annual compensation payments for sheep killed by large predators amounted to NOK 62.3 million in this period, of which NOK 4.8 million was compensated for sheep killed by wolves (Rovbasen, 2017).

3. The sheep economy: Wolf predation and compensation payments

We will now analyse the economics of sheep farming in the presence of a wolf population by the aid of a bioeconomic model. We consider a given area with sheep farming and a wolf population. The sheep farmers are imposed costs from the wolf population through predation loss. As the wolves migrate and disperse over huge areas, the area is supposed to be relatively large so that inflows and outflows of animals can be neglected. There are typically many sheep farmers within this area. However, for simplicity we assume that they operate in a cooperative manner and act as a single agent. Sheep farming is basically a controlled biological process, and with the possible exception of predation, there are no density dependent effects regulating population growth. Therefore, the natural growth function is linear (more details in e.g., Skonhoft 2008). With X_t as the sheep population size (in number of animals) at time (year) *t* and W_t as the size of the wolf population, also in number of animals, the sheep population growth is first given as:

$$(1) \qquad \frac{dX_t}{dt} = sX_t - G\left(X_t, W_t\right) - h_t \ .$$

Here, $s > 0$ represents the fixed proportional natural growth, $h_t \geq 0$ is the slaughtering and $G\left(X_t, W_t\right)$ is the wolf predation (functional response). The predation is assumed to be increasing in the wolf density, $\partial G\left(X_t, W_t\right) / \partial W_t = G_W > 0$, as well as the number of sheep $G_X > 0$. Additionally, the sheep predation per wolf on the margin increases in the sheep density, $G_{XW} > 0$.

Norwegian sheep farmers get their income from meat and wool production, where the income from meat sales comprises about 80 % of their total income. With *p* as the fixed per animal slaughtering price, ph_t hence describes the yearly income when ignoring income from wool sale. The state also compensates the farmers for the loss caused by wolf preying on sheep (see, e.g., Ekspertutvalget, 2011). With $0 \le k \le p$ as the per killed animal compensation, the yearly compensation benefit is $kG(X_t, W_t)$. On the cost side, we find that the cost structure of the farmers differs sharply between the outdoor grazing season and the indoor feeding season, in that the indoor variable costs are substantially higher. These costs include fodder, labour (as an opportunity cost) and veterinarian costs, and are directly related to the size of the stock, $C(X_t)$, with $C' > 0$, $C'' \ge 0$ and $C(0) = 0$. When ignoring the outdoor costs and the fixed costs of sheep farming, the farmer net current benefit writes:

(2) $$\pi_t = ph_t - C(X_t) + kG(X_t, W_t).$$

The problem for the group of sheep farmers is to maximize net present value benefit $\int_0^\infty \pi_t e^{-\delta_1 t} dt$ subject to the population growth equation (1). In addition, the initial sheep stock size has to be known. $\delta \ge 0$ is the discount rate of the farmers. The current value Hamiltonian of this problem reads $H = ph_t - C(X_t) + kG(X_t, W_t) + \lambda_t \left[sX_t - G(X_t, W_t) - h_t \right]$ where $\lambda_t > 0$ is the shadow price of the sheep population. The first order conditions are the control condition $\partial H / \partial h_t = p - \lambda_t \le 0$ and the portfolio condition $-\partial H / \partial X_t = C'(X_t) - kG_X(X_t, W_t) - \lambda_t \left(s - G_X(X_t, W_t) \right) = d\lambda_t / dt - \delta \lambda_t$.

The interpretation of these conditions is straightforward. The sheep control condition says that sheep harvesting should take place up to the point where the marginal sheep slaughtering value is equal to or below its cost, as reflected by the sheep shadow price. When it is below the shadow cost, there is no slaughtering. Hence, this indicates a bang-bang control or singular control as is expected when the objective function is linear in the control. The sheep portfolio condition steers the shadow price value. Essentially, it indicates that the capital gain of the sheep population $d\lambda_t / dt$ plus the value of net marginal stock effect $\left[\lambda_t\left(s-G_X\left(X_t,W_t\right)\right)-C'\left(X_t\right)+kG\left(X_t,W_t\right)\right]$ must be equal to the marginal benefit of slaughtering and putting the proceeds in the bank, $\delta\lambda_t$. Because the Hamiltonian of the above problem is linear in the control, we find that the sufficient condition is that the maximized Hamiltonian is concave in the stock variable, i.e., $-\left(p-k\right)G_{XX}-C_{XX}\leq 0$ when $\lambda_t = p$.

After some small manipulations and dropping the time subscript, we find the steady state sheep 'golden rule' condition as:

(3) $$s-\frac{\left(p-k\right)G_X\left(X,W\right)}{p}-\frac{C'\left(X\right)}{p}=\delta .$$

To obtain some clear-cut results, we specify the functional forms. The sheep functional response is given as $G\left(W_t,X_t\right)=\alpha X_t W_t$ with $\alpha>0$ indicating that the wolf per capita consumption increases linearly with the number of sheep.[1] Accordingly, we have $G_W=\alpha X_t$, $G_X=\alpha W_t$, $G_{WW}=G_{XX}=0$ and $G_{XW}=G_{WX}=\alpha$. The sheep indoors cost function is given by $C_t=\left(c/2\right)X_t^2$ with $c>0$, where $C_X=cX_t$ and $C_{XX}=c$. For these specific functions the sheep golden rule condition, or best response function, now becomes:

[1] A more realistic assumption may be that the wolf per capita consumption increases at a decreasing rate, as exemplified by the function $G\left(X_t,W_t\right)=\left[\alpha X_t/\left(\beta+X_t\right)\right]$. $\beta>0$ is a shape parameter and $\alpha>0$ is the maximum consumption per animal.

(3’) $s-\frac{(p-k)\alpha W}{p}-\frac{c}{p}X=\delta$

The sufficiency condition for the optimization problem is satisfied as $c>0$. Solving the best response function of (3)’ with respect to the sheep population we have:

$X=\frac{(s-\delta)p}{c}-\frac{\alpha(p-k)}{c}W$ and $\frac{dX}{dW}=-\frac{\alpha(p-k)}{c}\leq 0$. Figure 1 below shows the optimal stock of sheep as a function of the size of the wolf population. The function is drawn for the two cases of no compensation ($k=0$) and full compensation ($k=p$). The sheep stock equilibrium for a positive wolf population of $\overline{W}$ for the cases of no compensation and full compensation is given as $\overline{X}_{k=0}$ and $\overline{X}_{k=p}$, respectively . When the state pays full compensation for sheep killed by wolves, the optimal number of sheep is independent of the size of the wolf population.

Figure 1 about here.

For a given wolf population, the compensation makes it optimal for the sheep farmers to hold a higher stock of sheep. As we will see later, this complies with Coase’s (1960) argument, that compensating victims of externalities may give them incentives to stock too many sheep compared to social efficiency. Moreover, an increase in the discount rate will shift both curves downwards, implying that the optimal number of sheep will be reduced by the same amount in the case of full compensation ($k=p$) and no compensation ($k=0$) for the given wolf population of $\overline{W}$. Furthermore, a higher price to cost ratio (p/c) will shift both curves upwards as well as making the curve of no compensation steeper. Hence, for the given wolf population of $\bar{W}$, the optimal number of sheep will increase by more under full compensation than under no compensation.

3. The wolf economy: Existence value and compensation payments

Based on Samuelson (1954), Musgrave (1969) introduced the terms non-rivalry in consumption and non-excludability from consumption in order to characterize a public good. Existence value as appropriated from the wolf complies perfectly with both of the features, and thus represents a pure public good. However, the individual valuations of wolf existence will in general be distributed unequally among individuals within the public. We assume that the cost of providing the public good is limited to the predation loss. Under the arrangement of full compensation for sheep killed by wolves, the costs of providing existence value are imposed on the public and shared equally among the individual taxpayers. In the absence of compensation payments, the full cost of providing existence value would be imposed on the sheep farmers in the form of killed sheep. Finally, the wolf generates income in terms of license hunting. This income is collected by the state on behalf of the public.

The Norwegian wildlife authority controls the wolf population. However, in the present section we optimize the net benefits of the wolf economy from the perspective of the public, as if the public is in control of the wolf population. Hence, by this optimization we derive the *hypothetical* best response functions of the public. Weighting the net benefits equally among individuals, the current benefits and costs of the public write:

(4) $$w_t = qy_t + A(W_t) - kG(X, W),$$

where $q > 0$ is the net harvesting value assumed to be fixed and independent of the number of wolves shot,[2] and $y_t \geq 0$ is the number of animals controlled, or hunted. $A(W_t)$ is the existence value of the wolf as appropriated by the public. The existence value is associated with the probability of survival for the species. A larger population implies a higher probability of survival, and thus a larger existence value. Hence, the marginal existence value is positive. Moreover, when the population of a species is low and threatened, the marginal existence value is high, while when the population is relatively high, the marginal existence value is low. Furthermore, for a certain size of the population we assume that a further increase in the population does not contribute to a higher probability of survival, that is, the marginal existence value is zero. Thus, letting $\hat{W}$ represent the wolf population at which the existence value turns into a constant, we have that $A' > 0$ and $A'' < 0$ for $W < \hat{W}$, and $A' = A'' = 0$ for $W \geq \hat{W}$. Finally, we have $A(0) = 0$.

In order to derive what is the optimal wolf management from the perspective of the public, we need to specify the wolf population dynamics. As food sources such as moose and roe deer are the critical factors for the wolf population during the winter, any possible numerical response to variations in the sheep population is neglected (see, e.g., Nilsen et al. 2005). The wolf population growth thus simply reads:

(5) $$dW_t / dt = F(W_t) - y_t,$$

[2] For simplicity, and not far from reality as the wolf operates in packs ('schooling'), we assume that the wolf harvest function is stock independent

where $F\left(W_t\right)$ represents the natural growth, which is assumed to be density dependent and governed by a one-peaked value function in a standard manner (see below).

The problem is to maximize the public net present value wolf benefit $\int_0^\infty w_t e^{-\delta_2 t} dt$ subject to the population dynamics as given by (5). δ is the discount rate of the public (for simplicity we assume that it is equal to the discount rate of the sheep farmers). The current value Hamiltonian of this problem reads $L = qy_t + A(W_t) - kG\left(X_t, W_t\right) + \mu_t\left[F\left(W_t\right) - y_t\right]$, where μ_t is the shadow price of the wolf population. The control condition is $\partial L / \partial y_t = q - \mu_t = 0 \Leftrightarrow \mu_t = q$. This means that the shadow price is positive and that $d\mu_t / dt = 0$. Hence, the portfolio condition reads $-\partial L / \partial W_t = d\mu_t / dt - \delta\mu_t \Leftrightarrow A'\left(W_t\right) - pG_W\left(X_t, W_t\right) + qF'\left(W_t\right) = \delta q$ when the possibility of extinction is ruled out; that is, it is always beneficial with a positive wolf population, $W_t > 0$.

The wolf control condition says that one should harvest wolves up to the point where the marginal net harvesting value is equal to the wolf shadow price. As the objective function is linear in the control variable, we can find a bang-bang control or singular control for the wolf population. As the capital gain of the wolf population $d\mu_t / dt$ is zero, the portfolio condition states that the marginal value of the net stock effect $\left[A'\left(W_t\right) - pG_W\left(X_t, W_t\right) + qF'\left(W_t\right)\right]$must be equal to the marginal benefit of harvesting and putting the proceeds in the bank, δq. Because the Hamiltonian of the above problem is linear in the control, the sufficient condition is that the maximized Hamiltonian is concave in the stock variable, i.e., $A_{WW} - kG_{WW} - qF_{WW} \leq 0$ when $\mu_t = q$.

The wolf golden rule condition now reads:

(6) $$F'(W) + \frac{A'(W) - kG_W(X,W)}{q} = \delta .$$

To obtain some clear-cut results, we also here apply some specific functional forms. The wolf natural growth is specified to be logistic, $F(W_t) = rW_t(1 - W_t / K)$, with $r > 0$ as the intrinsic growth rate and $K > 0$ as the carrying capacity. Moreover, the wolf existence value function is specified as $A(W_t) = \begin{cases} vW_t(K - W_t) & \text{for } W_t \le \frac{K}{2} \\ \frac{vK^2}{4} & \text{for } W_t > \frac{K}{2} \end{cases}$, with $v > 0$ and $W_t = \hat{W} = \frac{K}{2}$ as the wolf population where the existence value turns into a constant. Hence, we have a decreasing marginal existence value for $W_t < \hat{W}$ and a zero marginal existence value for $W_t \ge \hat{W}$. Because the existence value function changes at $W = \hat{W}$, there are really two wolf golden rule conditions; one for $W \le \hat{W}$ and one for $W > \hat{W}$. However, as the harvesting cost is independent of the size of the stock, as the marginal existence value is zero for $W > \hat{W}$, and as there are stock costs related to wolf preying on sheep, there are net costs related to the wolf population when $W > \hat{W}$. As a consequence, it will never be optimal to have $W > \hat{W}$. Hence, the best response function of the wolf is reduced to the one condition of $W \le \hat{W}$.

For the specific functions, the wolf golden rule condition reads:

(6') $$r\left(1 - \frac{2}{K}W\right) + \frac{v(K - 2W) - k\alpha X}{q} = \delta$$

The sufficiency condition for the optimization problem is satisfied as $-\frac{2r}{K} < 0$. Solving for the optimal wolf population as a function of the sheep stock, we have:

$W = \frac{(r-\delta)q + vK}{2\left(\frac{rq}{K}+v\right)} - \frac{k\alpha}{2\left(\frac{rq}{K}+v\right)}X$ and $\frac{dW}{dX} = -\frac{k\alpha}{2\left(\frac{rq}{K}+v\right)} \leq 0$. Figure 2 shows the optimal wolf population as a function of the sheep stock. The function is drawn for the two cases of full compensation payments to the sheep farmers ($k = p$) and no compensation payments to the sheep farmers ($k = 0$). When there are full compensation payments, the existence value represents a *public good* for which individuals must pay collectively as taxpayers. When there are no compensation payments, the existence value as appropriated from the wolf represents a *public right*.

The optimal size of the wolf population from the perspective of the public for a positive sheep stock of $\bar{X}$ for the cases of no compensation and full compensation, is given as $\bar{W}_{k=0}$ and $\bar{W}_{k=p}$, respectively. Without compensation for sheep killed by wolves, the optimal number of wolves is independent of the size of the sheep stock. Moreover, for the given sheep stock of $\bar{X}$, the optimal wolf population will be lower under full compensation than under no compensation.

Figure 2 about here.

4. Compensation as distribution: The property rights structure

Considering property as a benefit stream, a property right is the capacity to control the current and future appropriation of the benefit stream (Bromley, 1991; Demsetz, 1967). According to this definition, the sheep farmers have the property right to the grazing area when they receive full compensation for sheep killed by wolves. In this case, their income is independent of the number of wolves preying on sheep.

Let $\bar{W}$ be the wolf management objective of the Norwegian wildlife authorities. In the current situation of full compensation for sheep killed by wolves, meaning that the property right is with the sheep farmers, the optimizing behavior of the sheep farmers results in an equilibrium at point *A* with a sheep stock of $\bar{X}_{k=p}$ (see Figure 3 below). In this case, the given wolf population and the associated existence value represents a public good which must be collectively paid for. Under the arrangement of full compensation, and given the optimizing behavior of the sheep farmers, the preferred wolf population of the public is $\widehat{W}_{k=p}$. Indeed, given that the property right is with the sheep farmers, the Pareto optimal solution is at point *B.* Hence, when located at point *A*, it is costly to have wolves in terms of the compensation payments, and there will subsequently be a formation of public opinion in the direction of *reducing* the population of wolves.[3]

Figure 3 about here.

[3] The result hinges on the assumption that the management objective of the Norwegian wildlife authorities, as given by $\bar{W}$, is larger than $\widehat{W}_{k=p}$. If $\bar{W}$ was lower than $\widehat{W}_{k=p}$, Pareto optimality would require that the wolf population was increased.

If, on the other hand, there was no compensation for sheep killed by wolves and the sheep farmers did not have the property rights, the optimizing behavior of the sheep farmers implies equilibrium at point *C* with a sheep stock of $\bar{X}_{k=0}$ (see Figure 3 above). With no compensation, and given the optimizing behavior of the sheep farmers, the preferred wolf population of the public is $\breve{W}_{k=0}$ at point D. Indeed, this would be the Pareto optimal solution if the control of the wolf population was in the hands of the public - more than a public good which must be collectively paid for, the presence of a wolf population equal to $\breve{W}_{k=0}$ would then be a public right. Hence, when located at point *C*, there is no public cost associated with the wolf population, and there will subsequently be a formation of public opinion in the direction of *increasing* the population of wolves.

We have thus identified two polar cases when it comes to the property rights structure: Given that the property rights are with the sheep farmers (full compensation), the Pareto optimal solution is located at point *B* in Figure 3. Moreover, under the assumption that the property rights are with the public (no compensation and the wolf population controlled by the public) the Pareto optimal solution is located at point *D*. The choice between the two property right regimes is obviously a matter of distribution – whose interests should count? Furthermore, the compensation payment may be said to violate incentive-neutrality also with regard to the public: For a given wolf management objective (e.g. $\bar{W}$ in Figure 3), the decision to compensate or not may have a considerable impact on the formation of public opinion. By making the Norwegian taxpayers liable to the costs associated with wolf preying on sheep, the compensation arrangement may in this way influence the political process and thus the determination of the wolf management objective in the longer run.

5. Compensation as inefficiency: Social optimization and externalities

The traditional concept of social optimization within economics maximizes the – typically equally – weighted sum of the total benefit and cost functions. The total net benefits of sheep farming and the wolf economy reads:

(7) $U_t = \pi_t + w_t = ph_t - C(X) + qy_t + A(W_t)$.

The problem of the social planner is to maximize the total net present value benefit $\int_0^\infty U_t e^{-\delta_2 t} dt$ subject to the population dynamics as given by (1) and (5). δ is the social discount rate (for simplicity we assume that the social discount rate equals the discount rate of the sheep farmers and the public). The current value Hamiltonian of this problem reads $M = ph_t - C(X_t) + qy_t + A(W_t) + \lambda_t\left[sX_t - G(X_t, W_t) - h_t\right] + \mu_t\left[F(W_t) - y_t\right]$, where λ_t is the shadow price of the sheep stock and μ_t is the shadow price of the wolf population. The control conditions are $\partial L/\partial h_t = p - \lambda_t = 0 \Leftrightarrow \lambda_t = p$ and $\partial L/\partial y_t = q - \mu_t = 0 \Leftrightarrow \mu_t = q$. This means that the shadow prices are both positive and that $d\lambda_t/dt = d\mu_t/dt = 0$. Hence, the portfolio conditions read $-\partial L/\partial X_t = d\lambda_t/dt - \delta\lambda \Leftrightarrow p\left(s - G_X(X_t, W_t)\right) - C'(X_t) = \delta p$ and $-\partial L/\partial W_t = d\mu_t/dt - \delta\mu_t \Leftrightarrow A'(W_t) - pG_W(X_t, W_t) + qF'(W_t) = \delta q$ when the possibility of extinction is ruled out; that is, it is always beneficial with a positive wolf population, $W_t > 0$.

The sheep control condition is similar to the optimization problem of the sheep farmers above, and the sheep portfolio condition coincides with the case of no compensation ($k = 0$) in the sheep farmer optimization problem. The social optimal solution for the sheep deviates from the private optimum of the sheep farmers when sheep killed by wolves are compensated

($k > 0$). The wolf control condition is similar to the optimization problem of the public above, and the wolf portfolio condition coincides with the above public optimization problem of the wolf economy in the case of full compensation ($k = p$). The social optimal solution for the wolf deviates from the optimum of the public when sheep killed by wolves is not fully compensated ($k < p$). As the objective function of the social planner is linear in both of the control variables, we can find a bang-bang control or singular control for both the sheep stock and the wolf population.

The social planner's sheep and wolf golden rule conditions now read:

(8) $$s - G_X(X,W) - \frac{C'(X)}{p} = \delta \text{ and}$$

(9) $$F'(W) + \frac{A'(W) - pG_W(X,W)}{q} = \delta .$$

For the specific functions, the sheep and wolf golden rule conditions are:

(8') $$s - \alpha W - \frac{c}{p} X = \delta$$

(9') $$r\left(1 - \frac{2}{K} W\right) + \frac{v(K - 2W) - \alpha p X}{q} = \delta .$$

The weak Arrow sufficiency conditions for the optimization problems are given in the Appendix. The sheep golden rule condition of the social planner obviously coincides with that of the sheep farmers in the case of no compensation ($k = 0$: see equation (3’) above) and that of the public in the case of full compensation ($k = p$: see equation (6’) above). We thus have $X = \frac{(s-\delta)p}{c} - \frac{\alpha p}{c} W$ as the optimal sheep stock as a function of the wolf population, where $\frac{dX}{dW} = -\frac{\alpha p}{c} < 0$ implies a negative relationship between the optimal sheep stock and the number of wolves. Moreover, for the optimal wolf population as a function of the sheep stock we have $W = \frac{(r-\delta)q + vK}{2\left(\frac{rq}{K} + v\right)} - \frac{\alpha p}{2\left(\frac{rq}{K} + v\right)} X$ and $\frac{dW}{dX} = -\frac{\alpha p}{2\left(\frac{rq}{K} + v\right)} < 0$, implying a negative relationship between the optimal wolf population and the size of the sheep stock. From the weak Arrow sufficiency conditions, we may derive that the best response function of the sheep stock is steeper than that of the wolf population.

Figure 4 about here.

The social planner optimum refers to a wolf population size where the marginal cost of the wolf, in terms of killed sheep, equals the marginal benefit in terms of its existence value. In Figure 4, point *E* represents the steady state solution of the social optimization problem $\left(X^*_{k=0}, W^*_{k=p}\right)$. The optimal number of wolves corresponds to the number wanted by the public when loaded with a tax burden equal to the slaughtering value of sheep killed by wolves. Moreover, the optimal number of sheep corresponds to the number wanted by the sheep farmers in the absence of compensation payments.

Rather than assigning the property right to one of the parties, the social planner applies the principle of efficiency to solve the wolf management problem. The potential Pareto improvement test (Kaldor, 1939; Hicks, 1939) replaces the Pareto-optimum: The *net* benefits are now maximized, meaning that institutional change may be efficient even though representing higher costs or reduced benefits to some individuals. In our context, the understanding of the social planner solution is that the public's claim to have a viable population of wolves imposes an externality on the sheep farmers in the form of wolves preying on sheep.[4] Hence, to internalize the externality and satisfy efficiency, the public's demand for having a viable wolf population cannot be fully saturated. We will consider two ways of "internalizing" the externality in the following, the Pigovian-inspired state regulation model and the payment for environmental services (PES) approach.

6. Implementing social optimality: Solving the externality problem

The Pigovian-inspired state regulation model clearly defines who is responsible and who is victim, and is typically associated with the "polluter pays" principle. Holding the public responsible for the negative impacts that wolf preservation imposes on the sheep farmers, this policy identifies the number of wolves wanted by the public when liable to pay the full slaughtering value for sheep killed by wolves ("internalizing" the externality at $W^{*}_{k=p}$). Moreover, compared to the current management, the Pigovian-inspired state regulation model withdraws the compensation payments to the sheep farmers and reallocates the tax income into alternative public use.

Quite the opposite, the PES approach maintains the tax financed compensation payments to the sheep farmers. However, the compensation is linked to the number of wolves in the area, rather than the number of sheep killed by wolves. For example, let the state (as representing

[4] See Baumol and Oates (1988) for a definition of an externality.

the public) pay a sum to the sheep farmers which increases in proportion to the size of the wolf population. This will not influence the best response curve of the farmers, which still will be given by (3') for $k = 0$ in Figure 4. However, for a specific proportionality factor, the accompanying payment shifts the vertical best-response curve of the public ((6') for $k = 0$) to the left until it intersects with the best response curve of the farmers at the equilibrium solution of point *E*. Hence, PES keeps the sheep farmers compensated as well as incentive-neutral, while the preference of the public complies with the socially optimal wolf population.

7. Discussion

The compensation payment for sheep killed by wolves plays a key role in the model. First, k determines the distribution of benefit and cost flows between the sheep farmers and the public, and the two polar cases of $k = 0$ and $k = p$ also represent two opposite property right regimes for a given wolf population.

Second, in line with the reasoning of Coase (1960), the compensation payment for sheep killed by wolves is not incentive-neutral with regard to the sheep farmers (see Figure 1). Hence, even though the wildlife authority identifies and keeps the socially optimal size of the wolf population ($W^*_{k=p}$ in Figures 4 and 5), the farmers will stock too many sheep due to the compensation arrangement ($\bar{X}_{k=p}$ in Figures 4 and 5). By compensating for sheep killed by wolves, the state thus violates the efficiency criteria in terms of the potential Pareto improvement test.

Third, the compensation payment for sheep killed by wolves may influence the formation of public opinion. Due to the overstocking behavior of the farmers when compensated, the public, when liable to the compensation payment, may prefer a wolf population which is lower than the management objective of the wildlife authority. In this case, there will be a formation of public opinion in the direction of reducing the wolf population in this case. If not loaded with the compensation payment, however, the public prefers a wolf population which is higher than the management objective of the wildlife authority. Then there will be a formation of public opinion in the direction of increasing the wolf population. In either case, the efficiency criterion in terms of Pareto optimality is violated. Moreover, the resulting formation of public opinion may influence the policy process and thus affect the management objective in the longer run.

Now, let the current wolf management policy be represented by point *A* in Figure 5 below.[5] As noted, this solution both violates incentive-neutrality and the efficiency criteria. We have considered various policy alternatives which may potentially cope with the problem. The first two policy alternatives were based on a distributional decision and the efficiency criterion of Pareto optimality. Given that the property right to the pasture *rightfully* belongs to the sheep farmers, the state will obtain Pareto optimality simply by reducing the wolf population to $\widehat{W}_{k=p}$ (see Figure 5; solution at point *B*). On the other hand, given that the property right to the pasture *rightfully* belongs to the public, Pareto optimality will be obtained by withdrawing the compensation payments and increasing the wolf population to $\breve{W}_{k=0}$ (see Figure 5; solution at point *D*). This policy represents a full redistribution of the property rights, and makes the presence of a viable wolf population a public right.

Figure 5 about here.

[5] It is reasonable to assume that the current wolf management objective at point *A* is lower than the wolf population associated with the social optimum at point *E*. As the wolf is a Red-list species, it will likely be close to – or even lower than – that of point *B*.

The next two policy alternatives we have considered are based on efficiency criteria in terms of the potential Pareto improvement test. The first, the Pigovian-inspired state regulation model, withdraws the compensation payment to the sheep farmers, while increasing the wolf population to $W^*_{k=p}$ (see Figure 5; solution at point *E*). Compared to the current management, this policy represents a moderate redistribution of property rights to the public. Moreover, the policy is incentive-neutral with respect to the sheep farmers as the tax income is not used for compensation payments but some alternative public use.

Finally, we have the PES approach, which maintains the compensation payment to the sheep farmers, but links it to the number of wolves in the area rather than the number of sheep killed by wolves. At the same time, the wolf population is increased to $W^*_{k=p}$ (see Figure 5; solution at point *E*). The compensation payment must be of a size for which the optimal solution of the public is equal to $W^*_{k=p}$. In this way, the PES approach is incentive-neutral both with respect to the sheep farmers and the public. The PES approach represents a so called *ex ante* conservation policy in contrast to the *ex post* policy of paying compensation for the actual number of livestock killed by the carnivores (Zabel et al. 2011).

Various considerations must be taken into account when choosing among the above policies. In order to adapt to rapidly changing circumstances, for instance, the institutional structure should possess a certain degree of flexibility. In a common pool setting, Libecap (1989) discusses how flexibility may be blocked by economic agents with vested interests, and points out how a political consensus for beneficial institutional change may emerge by paying compensations to those potentially harmed by the change. That is, compensation should be paid to the farmers in order to prevent that the livestock industry blocks the re-colonization of the Scandinavian wolf.

However, keeping in mind that property is a benefit stream and that a property right is the capacity to control current and future appropriation of the benefit stream, compensations actually maintain immunity of the livestock owners. Hence, with regard to the property rights structure, it is the status quo which is cultivated rather than flexibility. Indeed, the compensation strategy promotes what North (2008) holds forth as one of the main components of an ideal political and economic model, namely "a stable structure of exchange relationships in both political and economic markets." In contrast to Libecap (1989), Fleischer (1999) has this in mind when he emphasizes the *shortcoming* of an environmental policy whereby paying compensations to individuals with vested interests is a prerequisite – such a policy necessarily gives a low priority to environmental protection. Compensations like this also violate the "polluter pays" principle, as those in favor of environmental protection are made liable to the costs of achieving it.

The current Norwegian wolf management is a relevant target both for the criticism of Coase (1960) and Fleischer (1999). The Pigovian-inspired state regulation model and the PES approach, both respond to the Coase criticism and satisfy the demand for incentive-neutrality. However, while the former responds to Fleischer's (1999) criticism by withdrawing the compensation payments, the latter falls in line with the reasoning of Libecap (1989) by offering incentive-neutral compensation payments to the livestock industry in order to avoid a blocking of the re-colonization of the Scandinavian wolf. Thus, the PES approach maintains the property rights structure of the current management, while the Pigovian-inspired state regulation model represents a redistribution of the property rights.

6. Concluding remarks

The paper presents some economic perspectives on the Nordic wolf re-colonization with a specific focus on redistribution and compensation policies. We argue that the compensation arrangement of the current wolf management in Norway violates the efficiency criteria both in terms of Pareto optimality and the potential Pareto improvement test. From the perspective of welfare economics, we consider four different policies which may remedy the problem: Two of them are primarily based on distributional decisions, but also satisfy Pareto optimality. The other two are primarily based on efficiency criteria and satisfy the potential Pareto improvement test.

First, if the state is of the opinion that the property right to the pasture rightfully belong to the sheep farmers, the wolf population should be reduced in order to achieve Pareto optimality (from *A* to *B* in Figure 5). In this case the public must pay for having wolves in the country and the number of wolves must be reduced in order to balance the marginal cost with the marginal benefit.

Second, if the state establishes that the presence of a viable wolf population in the country is a public right, the compensation to the sheep farmers should be withdrawn and the wolf population increased in order to achieve Pareto optimality (from *A* to *D* in Figure 5). As the compensation is withdrawn, the sheep farmers find it optimal to reduce the sheep stock.

Third, we have the Pigovian-inspired state regulation model. In this case, the social optimal solution is reached by withdrawing the compensation from the sheep farmers, and increasing the wolf population (from *A* to *E* in Figure 5). The wolf killing of sheep is considered an externality, and the externality is "internalized" by holding a wolf population that is lower than wanted by the public. Here, the public is seen as the responsible part (causing the externality by its demand for a viable wolf population), while the group of sheep farmers is seen as the victim.

Finally, we have the PES approach. Here, social optimization is implemented by compensating the sheep farmers for the number of wolves present in the region (from *A* to *E* in Figure 5). Hence, the public still pays compensation to the sheep farmers, but this form of compensation is incentive-neutral with regard to the sheep farmers, and does not violate the efficiency criteria.

The two ways of implementing the social optimal policies both pertain to efficiency considerations as they identify the social optimal equilibrium, but they have very different consequences when it comes to property rights and distribution. While the PES approach more or less maintains the status quo property right structure, where the property rights are still with the sheep farmers and wolf existence is a public good which must be collectively paid for, the Pigovian-inspired state regulation model represent a moderate redistribution of the property rights in favor of the public.

The literature looks upon the role of compensations very differently. Coase (1960) reminds us that compensations are not incentive-neutral and may violate efficiency criteria, Libecap (1989) holds that compensations may promote flexibility and pave the way for desired institutional change, while Fleischer (1999) understands compensations as impediments to environmental protection and desired institutional change. In compliance with Coase (1960), the present paper shows that the current compensation arrangement in Norway violates incentive-neutrality and the efficiency criteria. However, as over assessment of the PES approach shows, compensations may be designed in such a way that the incentive-neutrality and inefficiency problems are avoided.

Another dimension of paying compensations is attached to the views of Libecap (1989) and Fleischer (1999). Compensations represent a redistribution of property rights from the public to the sheep farmers. As the cost of having a viable wolf population in the country then is loaded on the public, there may be a formation of public opinion in the direction of reducing the wolf population. In this way, our analysis gives support to Fleischer (1999) by indicating that paying compensations to individuals with vested interests may be an impediment to environmental protection.

Appendix

The second-order conditions require that the Hamiltonian should be jointly concave in the state and control variables. Concavity of the Hamiltonian means that the Hesse matrix should be negative semi-definite in optimum. It can be demonstrated that this requires

$$C''(X) + pG_{XX}(X,W) \geq 0,$$

$$\left(-C''(X) - pG_{XX}(X,W)\right)\left(qF''(W) + A''(W) - pG_{WW}(X,W)\right) - p^2 G_{XW}(X,W) G_{WX}(X,W) \geq 0$$

and $qF''(W) + A''(W) - pG_{WW}(X,W) \leq 0$ when $\lambda_t = p$ and $\mu_t = q$.

For the specific functions the following is required:

$c \geq 0$, $2c\left(\frac{rq}{K} + v\right) - \alpha^2 p^2 \geq 0$ and $-2\left(\frac{rq}{K} + v\right) \leq 0$ when $\lambda_t = p$ and $\mu_t = q$.

Litterature

Aldred, J. 1994. Existence Value, Welfare and Altruism. *Environmental Values 3: 381- 402.*

Attfield, R. 1998. Existence Value and Intrinsic Value. *Ecological Economics* 24(2-3): 163-68.

Baumol, W. and W. Oates 1988. The Theory of Environmental Policy. Cambridge University Press, Cambridge

Bromley, D.W. 1991. *Environment and Economy: Property Rights and Public Policy*. Oxford: Basil Blackwell Inc.

Coase, R.H. 1960. The Problem of Social Cost. *Journal of Law and Economics* 3: 1-44.

Dahle, L., B. Solberg and D.P Soedal 1987. Haldningar til og betalingsvillighet for bjørn, jerv og ulv i Noreg (Attitudes to and willingness to pay for bear, wolverine and wolf in Norway). Report No. 5/1987, Dept. of Forest Economics, Agricultural University of Norway.

Demsetz, H. 1967. Toward a theory of property rights. *The american economic review* 57: 347-59.

Ekspertutvalget 2011. Innstilling fra ekspertutvalg vedrørende endringer I erstatningsordningen for rovviltskade på husdyr (in Norwegian). Direktoratet for Naturforvaltning, Trondheim

Fleischer, C.G. 1999. *Miljø- og ressursforvaltning. Grunnleggende forutsetninger*. Oslo: Universitetsforlaget (In Norwegian).

Hicks, J.R. 1939. The Foundations of Welfare Economics. *Economic Journal* 49(196): 696-712.

Inglehart, R. 1971. The Silent Revolution in Europe: Intergenerational Change in Post-industrial Societies. *American Political Science Review* 65: 991-1017

Kaldor, Nicholas. 1939. Welfare Propositions in Economics and Interpersonal Comparisons of Utility. *Economic Journal* 49: 549–52.

Krutilla, J. 1967. Conservation reconsidered. American Economic Review 57, 778-786.

Libecap, G.D. 1989. *Contracting for Property Rights*. Cambridge: Cambridge Unviversity Press.

Linnell, J.D.C and T. Bjerke (eds) 2002. Fear of wolves: An Interdisciplinary study. Trondheim: NINA Oppdragsmelding 722: 1-110. (In Norwegian with an abstract in English).

Musgrave, R.A. 1969. Provision for social goods. In: Margolis, J. and H. Guitton (eds), Public Economics. McMillan, London, p. 124-144.

Nilsen, E., T. Pettersen, H. Gundersen. A. Mysterud, J. Milner, E. Solberg, H. Andreassen and N. C. Stenseth 2005. Harvesting strategies in presence of wolves. *Journal of Applied Ecology* 42, 389-399.

North, D.C. 2008. *Understanding the process of economic change*. Princeton, New Jersey: Princeton University Press.

Norwegian Environment Agency 2017: www.environment.no.

Rovbasen 2017. http://www.rovbase.no

Samuelson, P. A. 1954. The Pure Theory of Public Expenditure, The Review of Economics and Statistics 36(4), 387-389.

Skonhoft, A. 2008. Sheep as capital and farmers as portfolio managers: A bioeconomic model of Scandinavian sheep farming. *Agricultural Economics* 38: 193-200.

Soeilen. E. 1995. Sportsmenn i veideland. Jubileumsberetning for Norges Jeger- og Fiskerforbund, 1871-1996. Stikka Trykk, Asker og Bærums Budstikke, Billingstad (In Norwegian).

Zabel, A., K. Pittel, G. Bostedt and S. Engel 2011. Comparing conventional and new policy approaches for carnivore conservation: Theoretical results and applications to tiger preservation. *Environmental and Resource Economics* 48: 287-311.

Wabakken, P., Svensson, L., Maartmann, E., Åkesson, E. and Flagstad, Ø., 2016. Bestandsovervåking av ulv vinteren 2015-2016, Rovdata NINA, Trondheim.

List of Figures

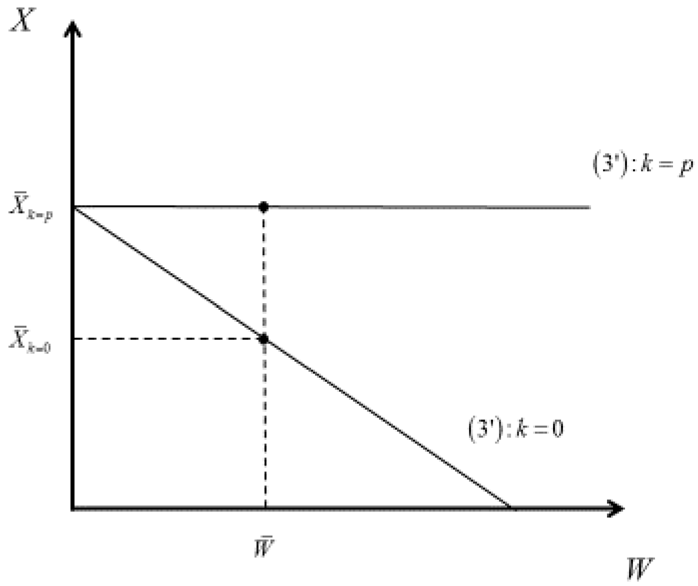

Figure 1 Best response functions (3') for the sheep farmers.

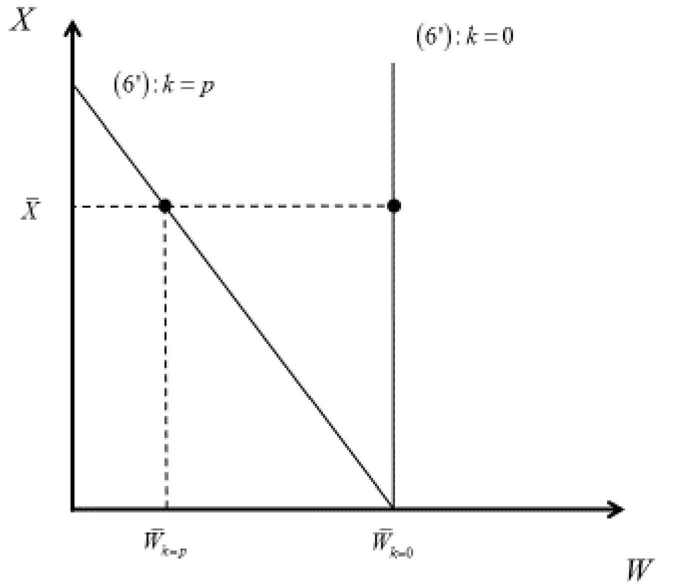

Figure 2 The hypothetical best response functions (6') for the public.

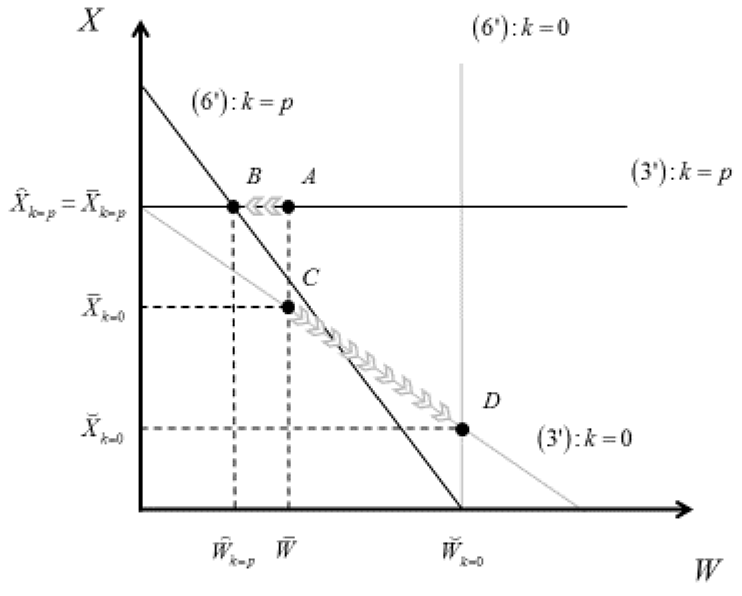

Figure 3 A: Equilibrium of the current management for a wolf population of and with compensation for sheep killed by wolves, B: Pareto optimality when the sheep farmers have the full property right to the pasture, C: Equilibrium for a wolf population of $\bar{W}$ and without compensation and *D*: Pareto optimality when the public has the full property rights to the pasture.

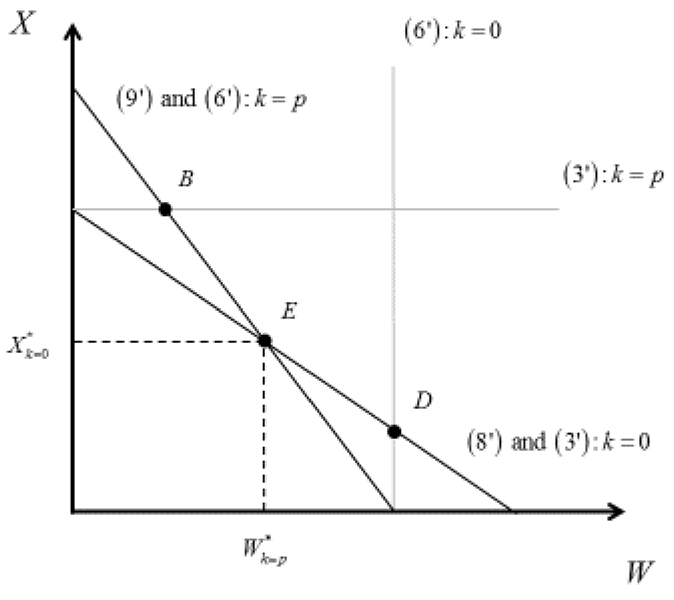

Figure 4 E: Social optimality, B: Pareto optimality when the sheep farmers have the full property right to the pasture and D: Pareto optimality when the public has the full property rights to the pasture.

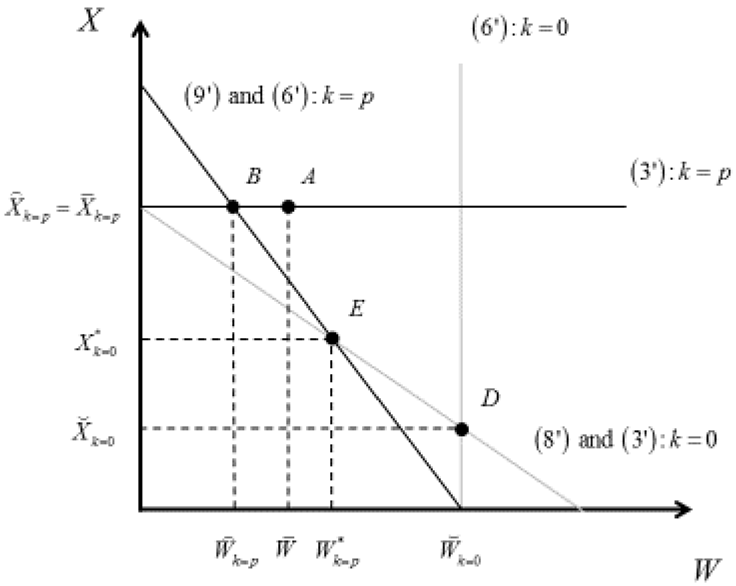

Figure 5 A: Equilibrium of the current management for a wolf population of and with compensation for sheep killed by wolves, B: Pareto optimality when the sheep farmers have the full property right to the pasture, C: Equilibrium for a wolf population of $\bar{W}$ and without compensation, *D*: Pareto optimality when the public has the full property rights to the pasture and *E*: Social optimality.