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An Institutional Perspective on Externalities.

The Nordic Wolf Re-Colonization

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Abstract

The paper discusses and redefines the traditional concept of externalities. Inspired by J.R. Commons' theory of institutional evolution we define externalities as policy relevant institutional interdependencies. Our concept of externalities is more general and reflects institutional failure rather than market failure. We exemplify our institutional concept of externalities by discussing the conflicts associated with the re-colonization of wolves in Scandinavia. Pinpointing the conflict between wolf management and sheep farming, we identify externalities in the *de jure* property rights to the pastures, and discuss how they can be internalized.

1. Introduction

The economic literature on externalities is enormous and it has been claimed to be "one of the least coherent and most contentious areas of economic analysis" (Bromley, 1991:67). The present paper scrutinizes the institutional aspect of externalities. Our approach is inspired by J. R. Commons' selection theory of institutional evolution where at each moment of time the prevailing institutional structure defines the opportunity set for individual action, and where one indivisual's right is another's duty (Biddle, 1990; Bromley 1991). However, various *de jure* individual rights and correlated duties may be mutually exclusive, and hence in conflict with each other, so that one individuals right may affect the *de facto* individual rights of others. For example, the institution of having complete private control of land may be in conflict with the public right of biodiversity preservation. Accordingly, when a private landowner follows his narrow selfinterests and, say, legally maximizes the net benefits of his timber logging value, this will in general come in conflict with the public right of biodiversity preservation. Hence, the legal claims of the different agents are mutually exclusive, or in other words, the prevailing assignment of property rights are inconsistent.

In this article we will analyse such conflicts from a conceptual point of view. The analysis will be exemplified with a real life example, namely the much debated conflicts caused by the re-colonization of wolves in Scandinavia. Some few decades ago there were bounties for killing wolves in Norway (as well as in Sweden). However, in 1972 the bounties were replaced by a wolf preservation policy. The protection of the Scandinavian wolf was strengthened during the 1980s when Norway and Sweden became signatory members of the Bern-convention. The institutional change - opening up for the re-colonization of the wolf - reflected a change of preferences; 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 new preferences were opposed to the old institutional setting of bounties and triggered institutional change.

In the present paper we will redefine the term externality and understand it as a driving force in the process of institutional change. Our principal discussion starts in section 2 with a rather broad discussion about the traditional concept of externalities. In section 3, we discuss more closely the institutional perspective on externalities inspired by the work of J. R. Commons. In section 4 we present the Scandinavian wolf example, which in section 5 is studied more formally by constructing a stylized bioeconomic model including two agents with conflicting interests; a group of sheep farmers and the wildlife authority. The sheep farmers have the legal right to graze their sheep on public, as well as on private, land during the summer outdoors season. The sheep farmers follow their selfinterest and maximize the economic benefit of their sheep stock. However, because of predation by the wolf this will come in conflict with the public right of keeping a viable wolf population. The management of the wolf population is assumed to be taken care of by the wildlife authority, or 'The Directorate of Natural Resource Management', with the goal of maxmizing the wildlife benefit consisting of the existence value of wolf, but also accounting for the fact that the wolf prey upon the sheep stock. The outcome of the model is discussed in section 6 while section 7 summarizes our findings.

2. On externalities

Our discussion of externalities begin with a look at the famous stag hunt example by Rousseau (1974)[1]. Five hunters, with a rudimentary ability to speak and to understand each other come together at a time when they are all hungry. Since the hunger of each one of them will be satisfied by a fifth part of a stag, they agree to cooperate to trap one. But the hunger of any one of them will also be satisfied by a hare, so as a hare comes within reach, one of them grabs it, and by pursuing his individual self interest in this manner permits the stag to escape.

From this simple story, the economist could make several observations[2]. First, if we presume that the utility functions of the participants are of the standard type preferring more food to less, each of the individuals utility functions are dependent on the others in the sense that the still hungry participants utility levels remain low because of a decision unit external to themselves. Second, the result is ineffective whether efficiency is defined in Pareto terms or in terms of maximizing total production: Assuming that a hare and a fifth part of a stag are perfect substitutes, cooperation will both raise total production and the welfare of the others without compromizing ones own welfare. Third, as the stag hunters agreed to cooperate, meaning that the transaction costs of *information* and *negotiation* were manageable, the transaction cost of *enforcement* were apparently not since cooperation failed to materialize. This points to the importance of transaction costs in the understanding of externalities.

In line with this, interdependency of decision units, inefficiency and transaction costs are important factors when it comes to characterizing externalities. However, in the literature we find various externality definitions along these dimensions. First we have the view that externalities as interdependency should be confined to *unintended* concequences of intended individual actions. Among others, in the authoritative textbook, Baumol and Oates (1988, p. 17), state that: ‘An externaliy is present whenever some individual’s (say A’s) *utility* or *production* relationships include real (that is, nonmonetary) variables, whose values are chosen by others (persons, corporations, govererenments) without particular attention to the effects on A’s welfare’.

The motivation for this limitation seems reasonably clear. If someone comes driving into your garden and dumps his garbage, this is a different social phenomena than if smoke from a factory makes your lawn wither. The first is clearly intentional, the second to a certain extent, but only to a certain extent, an unintended by-product. It is only the second phenomena we should seek to address by externality theory.

However, problems with this distinction arises when the theory is applied to the real world. In the textbook example of the polluting firm, the firm will, after some time, surely learn that the smoke it emits has adverse effects on the neighborhood. If the emission continues, the externality may be incidental to the main business of the factory, but not unintended (Schmid, 1987). Theoretically it is also highly problematic to assume that the engineers in profit maximising factories are generally unaware that their production has some unfortunate by-products (Vatn and Bromley, 1997). Therefore, it seems reasonable to assume that the factory takes advantage of the opportunities that the institutional setting provides, i.e,whether abatement is required or not, to which degree it is required, compensation of affected parties, and so on.

Real world applications of a definition including the unintended aspect may be further thwarted by uncertainty and/or asymmetrical information. For a period it may be uncertain or even unknown if a certain pollutant is a health hazard. There may be uncertainty regarding how much the factory emits, presumably with the factory holding more information than the government, etc. For these and other reasons it seems doubtful if incorporating the unintended aspect will be very helpful in policy prescriptions.

Second, we may distinguish between externalities as market or non-market interdependency. This brings us to the different stands of the Coase (1960) influenced bargaining model and the Pigovian influenced model of state regulation (Vatn, 2005). These models consider externalities as inefficiency, and they do so quite differently. We start with exploring the Coasean perspective.

Conceptualizing externalities in Pareto-terms, Buchanan and Stubblebine (1962) make a distinction between Pareto-relevant and irrelevant externalities. If no gains can be obtained by one party without making the other worse off, then the externality is Pareto-irrelevant. For an economy located on a Pareto-optimal point, then, there can be only Pareto-irrelevant externalities. These reflect market interdependency between agents on a Pareto-efficient level.

The merits of this distinction can be viewed in light of the classical example of the polluting firm causing damage to a downstream fishery. It is possible for the factory to abate the pollutant rather than dumping it in the river, but this will be costly. Under the assumption of zero transaction costs, bargaining ensures that we arrive at an efficient equilibrium, where marginal abatement costs equal the marginal costs of pollution, either the firm is given the right to pollute or the fishery is given the right to an unpolluted river. In so far as transaction costs are zero, and all non-market values are privatized, all non-market interdependency will be turned into Pareto-efficient market interdependency through the process of bargaining. This result is often referred to as the Coase theorem: If only property rights are clearly defined, efficiency will be obtained irrespective of *who* is given the property rights. In equilibrium, the river will still be polluted and “externalities as market interdependency” will be present. But there will be no “externalities as inefficiency” - the level of pollution will be

Pareto-efficient and the externalities will be Pareto-irrelevant. This reasoning of course presupposes the absence of income effects (e.g., Bromley 1991).

This needs a little reflection. In the stag-hunt example above, the transaction cost of enforcement was the cause of the externality. How meaningful is it then to analyse externalities under the assumption of zero transaction costs? Indeed, Dahlman (1979:161) says that "without transaction costs externalities would be of no consequence," and Bromley (1991: 63) states that "in a world without transaction costs there could be no externalities."[3] It seems a little bit peculiar to analyse externalities where the relevance of externalities are assumed away! This points to the importance of integrating positive transaction costs in economic analyses (Coase, 1988).

Now, if transaction costs are positive and fixed, but less than the gain of eliminating "externalities as non-market interdependency" through bargaining, nothing of substance is changed and the Coase theorem still holds. However, if costs are fixed, but larger than the gain, the location of efficiency depends on the initial distribution of property rights. Therefore, in the above pollution example, efficiency will now be characterized by *no abatement* if the factory has the right to pollute and *no pollution* if the right to an unpolluted river is with the fishery.

Moreover, if we have positive marginal transaction costs, the marginal willingness to pay for abatement and the marginal willingness to pay to omit abatement will be affected depending on the initial distribution of property rights (Vatn, 2005). If the factory has the right to pollute, the fishery has to initiate increasingly costly information gathering, contracting and enforcement in order to reduce the level of pollutants. That is, the fishery's willingness to pay for abatement will be reduced, and efficiency occurs at a lower level of abatement. In the opposite case, when the fishery has the right to an unpolluted river, the factory's willingness to pay for omitting abatement will be reduced due to transaction costs, and efficiency occurs at a higher level of abatement.

Surely, the location of efficiency depends on the nature of the transaction costs and on the distribution of property rights, the latter determining who has to bear the transaction costs. The notation of Pareto-irrelevant externalities and the domain of the Coase theorem are thus severely limited.

The Pigovian influenced state regulation model modifies the assumptions of the Coasean bargaining model in three important ways. First, the property rights structure and distribution are taken as given. In the presence of externalities, then, who is the responsible party and who is the victim is clearly defined. Second, the Pareto-optimum as an efficiency criterion is replaced by the potential Pareto improvement test (Kaldor, 1939; Hicks, 1939). Efficiency is here represented by maximizing *net* welfare (or net production value) and may thus be improved although representing costs or reduced benefits to some agents. Third, as argued by Vatn (2005), to make the model consistent, there must be an implicit assumption of positive transaction costs,[4] and the transaction costs of state regulation must be lower than the transaction costs of the bargaining process.[5] The role of the state, then, is to economize on transaction costs by correcting for these externalities. Due to the lower transaction costs, more of the externalities will be Pareto-relevant under state regulation as compared to the bargaining model. However, as far as there are positive transaction costs in state regulation, the location of the efficient resource allocation will also here be a function of the institutional setting and the property rights structure.

The Pigovian influenced state regulation model may be associated with the polluter pays principle. Considering the above example of the polluting factory, the state should impose a unit tax on the factory's emission in order to equalize the factory's (marginal) private costs with the (marginal) social costs of emission, that is, the costs imposed on the fishery (the victim). In the presence of positive transaction costs, the location of efficiency will obviously depend on the initial property rights distribution.

To sum up, whether we consider the bargaining- or the state regulation model, the important point is that the economically efficient level of pollution depends on the institutional setting when transaction costs are positive (Bromley, 1991: 77-78). Thus, there will be an efficient solution for every institutional setup, or put differently: Both efficiency criteria are biased towards the status quo. As Papandreou (1994) observes, economic litterature on institutions tends to conclude that the existing is optimal. Thus, efficiency defined in Pareto or potential Pareto terms is not an ethically neutral concept as efficiency and distribution cannot be analysed independently of each other. Accordingly, it seems justified to conclude like Martinez-Alier and O'Connor (1999), that all general equilibrium models presuming such independence are inaccurate at best.[6]

3. An institutional perspective of externalities

Based on the above criticism we will apply an institutional understanding of the concept of externality in the present analysis. The approach is inspired by J.R. Commons artificial selection theory of institutional evolution (see e.g. Biddle, 1990 for an account). At each point in time the prevailing institutional structure - which is a result of prior collective action - guides individual action. Within this structure there will be institutional interdependency: An individual's right is another's duty and an individual's privilege is another's absence of a right (Bromley, 1991). For example, an individual's right to sole access to a resource must be backed by the correlated duty of everybody else not to interfere with this right.

However, various individual rights and correlated duties may be mutually exclusive, that is, in conflict with each other. The institution of having complete private control of land may for example be in conflict with the public right of biodiversity preservation (cf. also the introductory section). Thus, rather than being supported by a correlated duty the claim to private property of land is challenged by a conflicting claim to a public right. Ultimately, it is how individuals behave with respect to the given institutional structure which determines the nature of institutional interdependency. Obviously, the way the land is used by the private landowner will affect the honouring of the public's claim to biodiversity preservation.

Looking at property as a benefit stream, a property right is the capacity to control current and future appropriation of the benefit stream (Bromley, 1991; Demsetz, 1967). For a property right to have effect, other individuals must voluntarily refrain from interfering with the property right or must be compelled to do so by the state. Effective protection of a property right is thus the correlated duty of all others not to interfere with this right, voluntarily or forced (Bromley, 1991).[7] Within the given structure of rights and correlated duties, one individual's action will in general affect the benefit and cost flow of others (Biddle, 1990). For instance, within the institution of open access, the harvesting behavior of an individual will affect the profit opportunities of others through the stock-effect. This is institutional interdependency revealed; that is, an individual's opportunity field depends on the *de jure* institutional structure of rights, the enforcement of those rights and on the behavior of other individuals.

Some of the institutional interdependencies may comply with the purpose of the prevailing institutional structure, meaning that they are approved by the collective. Others, however, may be unintended consequences of collective action: As there are nothing like perfect foresight in the collective process of establishing and reshaping institutions, some individual actions within the prevailing institutional structure may affect other individuals in ways that are not anticipated by the collective (Biddle, 1990). In so far the unintended consequences are socially undesired, collective action and institutional change will be triggered in order to re-establish compliance.

Moreover, preferences may be endogenous (e.g., Bowles, 1998, Kahneman 2011, Ch. 27). This means that the collective purpose may change over time. The institutional structure - being a product of prior collective action and purpose - may thus fall out of step with the resurgent collective purpose. That is, some of the institutional interdependencies which were formerly approved by the collective no longer are. Also in this case collective action and institutional change will be triggered to re-establish compliance between the institutional structure and the prevailing collective purpose.

This means that at each moment in time some of the institutional interdependencies may be policy relevant and some may not. We suggest that the term externality is used to denote the case of *policy relevant institutional interdependency*. Being unintended and undesired consequences of collective action, externalities are thus *institutional interdependency external to the prevailing collective purpose*. Rather than representing market failure, then, externalities are more general and represent institutional failure.

In this way externalities become driving forces of institutional change. Caused by unintended consequences of collective action and changed preferences, externalities represent institutional failures in the form of policy relevant institutional interdependencies. The economist's role in this should be to trace such failures. This implies to analyse the structure and enforcement of the *de jure* individual rights and correlated duties and how individuals behave within this institutional structure, that is, to identify the *de facto* opportunity field of individuals. In the next step, the opportunity field must be evaluated against the prevailing collective purpose. If the *de facto* functioning of the institutional structure deviates from the prevailing collective purpose, there is institutional failure as a result of externalities. In this case a policy response (collective action) is required.

4. Institutional changes and the benefit and cost flow of the Scandinavian wolf

We now proceed to discuss the particular example of the Scandinavian wolf re-colonization, the related institutional changes and changes of the cost and benefit streams connected to the most relevant stakeholders.

The rather poor Norwegians before the twentieth century probably had deeper worries than the survival of the scandinavian wolf. Considered as a threat for both livestock and people, the wolf was hunted down locally without much resistance. In the absence of a state or a significant group of people valuing the wolf positively, there was no negative externality associated with wolf killings. Or, in the preceding terminology, the prevailing collective purpose was negative toward wolves. However, as wolf hunting of one farmer reduced the costs of other farmers in terms of reduced loss of livestock, there was still an institutional interdependency present: The collective wanted any farmer to have the right to bring livestock to the pastures without any interference from wolves, and wolf hunting had to be intensified in order to secure that right. Accordingly, the state established a bounty for killing wolves in 1845 (see, e.g., Soilen 1996). Wolf hunting therefore represented a positive externality in the form of a policy relevant institutional interdependency.

However, in line with the so-called post-materialism hypothesis by Inglehart (1971), which states that when basic material needs are met, individuals to a larger extent give priority to "post-material" issues like caring for the environment, culture and so forth, attitudes were changed more in favour of wolf existence in the course of the 20th century. The collective purpose changed with the new attitudes, and the prevailing institutional structure - which was the product of a time when the wolf was considered a mere nuisance - fell out of step with it. The formerly awarded killing of wolves thus eventually came to represent a negative externality. This triggered collective action and institutional change. To avoid wolf extinction and loss of existence value the wolf was preserved by the state in 1972 and earlier hunting practises of wolves were banned. The time had come for re-colonizing the scandinavian wolf in Norway. The existence value of wolf was also institutionalized through various international conventions and legal provisions. Notably, Norway became a signatory to the Bern-convention in 1986, which means that the country is committed to keep a viable population of wolf on Norwegian territory. The overall wolf management objective in Norway the last decades is to secure a sustainable population of the scandinavian wolf.[8] However, it is also declared that wolf management must take place in a multi-use landscape . As forested and mountainous areas are important grazing resources, this means there will be conflicting interests in the form of wolf preying on livestock. Thus, besides securing a critically threatened wolf population, an important dimension of wolf management is to reduce the conflict associated with it (Ekspertutvalget 2011) .

The old conflict between sheep farming and the wolf reemerged with the wolf re-colonization and the goal of keeping a viable wolf population. To reduce the conflict, the state established compensation payments for sheep killed by wolves. These costs are borne by the general public. The negative effects of the re-colonized wolf don't stop here. Wolf preying on moose and other huntable wildlife species (like roe dear) constitute another wolf-related conflict in Scandinavia. Because wolves are few and patchily distributed the total effect is rather small. Still, some landowners and areas are seriously affected (see, e.g., Skonhoft, 2006 and the references therein). So far this is not compensated by the government. Yet another important dimension in the conflict is fear. According to one study, only about 23% would accept to live less than 10 km from wolf-areas, and 66% completely or partly agree that they would worry about the security of their family when being outdoors in areas with wolves (Linnell and Bjerke, 2002, Skogen et al. 2012).

This is the institutional setting and the major benefit and cost flows associated with current management of the wolf in Norway. We will now apply our institutional perspective on externalities to analyse the conflict associated with re-colonizing the Scandinavian wolf. Our focus is on the most relevant of the stakeholders in the conflict, namely the sheep farmers who bear the costs of the wolf population through predation loss, and the Directorate for Natural Resource Management (DNRM) representing the general public. The discussion is formalized by constructing a stylised bioeconomic model in the next section.

5. A bioeconomic model of wolf management and sheep farming

The following analysis is restricted to highlight the sheep predation problem. Hence, cost and benefit streams related to the moose and other harvestable wildlife populations subject to wolf predation are not taken into account, neither is the fear experienced by people living close to the wolf. Accordingly, the two agents considered in the model are a group of sheep farmers operating in a cooperative manner and assumed to act as a single agent, and DNRM. Acting on behalf of the general public, the DNRM is also treated as a single agent. We assume that both agents are 'rational' and aim to maximize present-value benefit over an infinite horizon, and where the two agents play a dynamic Cournot game. Only the open loop strategy is considered; that is, the group of sheep farmers and the wildlife authority commit their optimal management strategy to each other at $t = 0$ over an infinite planning horizon, given the expectation of the entire optimal strategy of the other player (Dockner at al. 2000). We focus on the steady state outcome of this game.

In Norway today there are about 15.000 sheep farms and there are more than two million animals during the outdoors 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. 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. It is hence during the summer rough grazing period, the sheep flocks may be vulnerable to large predators, such as the wolf (but also lynx, wolverine and bear). Sheep farming is basically a controlled biological process, and possible except for predation, it is therefore no density dependent effects regulating population growth. The natural growth function is therefore linear (more details in e.g., Skonhoft 2008). On the other hand, the natural growth of the wolf population is assumed to be density regulated.

In what follows, we consider a given area with sheep farming and a wolf population. As the wolf migrate and dispearse over huge areas, the area is supposed to be rather large so that inflows and outflows of animals can be neglected. There are typically many sheep farmers within this area, but as indicated they are supposed to operate as a single agent. 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) $$dX_t / dt = sX_t - G(X_t, W_t) - h_t .$$

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

While predation is determined by the size of the wolf pack, together with the size of the sheep population, there may also be a feedback effect as the size of the sheep population may influence the wolf population growth. However, as the wolf has different other food sources like moose and roe deer (see also above), and that these food sources 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). Therefore, the wolf population growth simply reads:

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

where $F(W_t)$ represents natural growth and $y_t \geq 0$ is the number of animals controlled, or hunted. The wolf natural growth is assumed to be density dependent and governed by a one-peaked value function in a standard manner (see below).

As already indicated, the Norwegian sheep farmers get their income from meat and wool production, and where the income from meat sale counts for about 80 % of 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 farmers are also currently compensated for the loss caused by wolf preying on sheep (see, e.g., Ekspertutvalget 2011). With $0 \leq k \leq p$ as the per 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 outdoors grazing season and the indoors feeding season, and where the indoors variable costs are substantially higher. These costs include fodder, labour (as an opportunity cost) and veterinarian costs, and is related to the size of the stock, $C(X_t)$, with $C' > 0$, $C'' \geq 0$ and $C(0) = 0$. Therefore, when ignoring the outdoors costs and the fixed costs, the farmer net current benefit writes:

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

The problem of 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), and the expected wolf controlling policy by the wildlife authority. In addition the initial sheep stock size has to be known. $\delta_1 \geq 0$ is the discount rent of the farmers. The current value Hamiltonian of this problem reads

$H = [ph_t - C(X_t) + kG(X, W_t)] + \lambda_t [sX_t - G(X_t, W_t) - h_t]$ where $\lambda_t > 0$ is the sheep population shadow price. The first order conditions are the control condition $\partial H / \partial h_t = p - \lambda_t \leq 0$ and the portfolio condition $-\partial H / \partial X_t = C'(X_t) - kG_X(X_t, W_t) - \lambda_t (s - G_X(X_t, W_t)) = d\lambda_t / dt - \delta_1 \lambda_t$.

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 reflected by the sheep shadow price. When it is below the shadow cost, there is no slaughtering. It hence indicates a bang-bang control or singular control as is expected when the objective function is linear in the control. The 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 $[\lambda_t (s - G_X(X_t, W_t)) + wG_X(X_t, W_t) - C'(X_t)]$ must be equal to the marginal benefit of slaughtering and putting the proceeds in the bank, $\delta_1 \lambda_t$. 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., the weak Arrow sufficiency condition is satisfied (see Appendix).

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

(4) $$s - \frac{G_X(X, W)\left(p - k\right)}{p} - \frac{C'(X)}{p} = \delta_1 .$$

In addition, the sheep steady state harvest is governed by $h = sX - G(X,W)$, while the profit reads $\pi = psX - (p-k)G(X,W) - C(X)$. Both the stock size and the harvest are contingent upon the degree of compensation. With full compensation ($k = p$) condition (4) is reduced to $s - C'(X)/p = \delta$ and the optimal long-term sheep population is hence similar to a situation without predation. The same is true for the profit. While the regular slaughter income of the farmers is reduced through predation, the slaughter income is maintained through predation as an animal taken by the wolf has the same value for the farmer as supplied at the slaughterhouse. Without full compensation and $k < p$, however, the farmers will experience a negative economic effect of predation, and equation (4) will yield a negative relationship in the $X - W$ diagram (more details below). If the size of the sheep population has negligible effect on the per head wolf consumption and $G_X = 0$, the golden rule condition will also be identical to the situation without wolf. That is, the golden rule number of sheep will be similar with and without wolf predation. However, the optimal number of animals slaughtered will be lower and so will the profit.

The wolf population is managed by the DNRM on behalf of the general public. Hence, the wildlife authority responds to those wolf related costs and benefits which flows to the general public. On the benefit side, the general public attach a positive existence value to the wolf. Moreover, under certain conditions, the wolf may also represent a positive harvesting value. On the cost side, there are expenses associated with both controlling the wolf population and compensating the sheep farmers. The current net benefit stream related to the wolf population may therefore be written as:

(5) $$U_t = qy_t - B(W_t)y_t + A(W_t) - kG(X_t, W_t),$$

where $q \geq 0$ is the harvesting value assumed to be fixed and independent of the number of wolves shot and $B(W_t)$ is the per unit harvesting cost assumed to be non-increasing in the population size, i.e., $B' \leq 0$, $A(W_t)$ is the existence value of wolf as appropriated by the general public where $A' > 0$, $A'' \leq 0$ and $A(0) = 0$.

The problem of the DNRM is to maximize the total net present value wolf benefit $\int_0^\infty U_t e^{-\delta_2 t} dt$ subject to the population growth (2), the initial size of the wolf population and the expected sheep slaughtering policy by the farmers. δ_2 is the discount rent of the wildlife authority which may differ from the discount rent of the farmers. The current value Hamiltonian of this problem reads $L = [qy_t - B(W_t)y_t + A(W_t) - kG(X_t, W_t)] + \mu_t[F(W_t) - y_t]$, where μ_t is the wolf population shadow price. The control condition is $\partial L / \partial y_t = q - B(W_t) - \mu_t \leq 0$ while the portfolio condition reads $-\partial L / \partial W_t = -A'(W_t) + B'(W_t)y_t + kG_W(X_t, W_t) - \mu_t F'(W_t) = \delta_2 \mu_t / dt - \delta\mu_t$ 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 wolf harvesting should take up to the point where the net marginal wolf harvesting value is equal to or below its cost reflected by the wolf shadow price. When it is below the shadow price it is beneficial with no harvesting. Therefore, also for the wolf population we find a bang-bang control or singular control as the wildlife authority objective function is linear in the control variable. The shadow price is negative for sure when the harvesting value is zero and hunting takes place, $\mu_t < 0$. The portfolio condition states that the capital gain of the wolf population $d\mu_t / dt$ plus the marginal value of net stock effect $[A'(W_t) - B'(W_t)y_t - kG_W(X_t, W_t) + \mu_t F'(W_t)]$ must be equal the marginal benefit of harvesting and putting the proceeds in the bank, $\delta_2 \mu_t$. The weak Arrow sufficiency condition is given in the Appendix.

The wolf golden rule wolf condition now reads:

(6) $$F'(W) - \frac{B'(W)F(W) - A'(W) + kG_W(X, W)}{q - B(W)} = \delta_2$$

In addition the wolf population equilibrium offtake is given by $y = F(W)$ while the net benefit reads $U = [q - B(W)]F(W) + A(W) - kG(X, W)$ .With zero compensation and $k = 0$ the sheep management has for obvious reasons no influence on the wolf management and hence equation (6) alone determines the size of the wolf population. Otherwise, with compensation and $0 < k \leq p$, we find that (6) yields a negative relationship between the sheep population size and the number of wolves. That is, more sheep is only consistent with a lower wolf population for the wildlife authority.

Notice that while both equation (4) and equation (6) are based on present-value maximization with a strategic interaction in an open-loop setting, these equations can be given another interpretation. It can namely be shown that with zero discounting and $\delta_1 = 0$ condition (4) yields the solution of the problem of maximizing the sheep profit (3) in ecological equilibrium for a given size of the wolf population. Similarly, with $\delta_2 = 0$ equation (6) yields the solution of maximizing the current net wolf benefit (5) for a constant wolf population and taking the size of the sheep population as given. The solution is then of the static Nash-Cournot type.

To obtain some clear-cut results we specify the functional forms. The sheep functional response is given as $G(W_t, X_t) = \alpha X_t W_t$ with $\alpha > 0$ indicating that the wolf per capita consumption increases linearly with the number of sheep.[9] Accordingly, we have $G_W = \alpha X_t$ together with $G_X = \alpha W_t$ and $G_{XW} = \alpha$. 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. The sheep indoors cost function is given by $C_t = (c/2)X_t^2$ with $c > 0$. For simplicity, and not far from reality as the wolf operates in packs ('schooling'), we assume that the wolf harvest function is stock independent; that is, $B(W_t) = b$ with $b > 0$ as the fixed unit hunting/controlling cost. Finally, the wolf existence value function is specified as $A(W_t) = W_t(u - vW_t)$, with $u > 0$ and $v > 0$, indicating a decreasing marginal existence value. This function is scaled so that the wolf population never will be larger than $u/2v$. Thus, $A'(W_t) = u - 2vW_t > 0$ will always hold. For these specific functions, the sheep and wolf golden rule conditions now become:

(4') $$s - \frac{\alpha W(p-k)}{p} - cX / p = \delta_1,$$

and

(6') $$r\left(1 - \frac{2W}{K}\right) - \frac{k\alpha X - (u - 2vW)}{(q-b)} = \delta_2,$$

respectively. In the Appendix the sufficiency conditions for these specified functional forms are given which implies that (6') must be downward sloping for all $0 < k \le p$.

(Figure 1 about here)

Figure 1 depicts these two equations for various values of per sheep compensation value k. For all $0 < k < p$ the sheep equation (4') will be downward sloping while it will be vertical when the farmers are fully compensated and $k = p$. The wolf equation (6') will slope downward except when we have zero compensation and $k = 0$. Therefore, a higher compensation yields more sheep and less wolf, and *vice versa*. Not surprisingly, we also find that a higher marginal existence value of the wolf yields more wolf and less sheep while a more valuable sheep production through a higher slaughter price p leads in the opposite direction. We find similar effects with smaller sheep farming costs c. Higher discounting of the wildlife authority means that the authority will find it beneficial to keep fewer wolves. Therefore, the sheep farmers will increase the stocking rate and the profitability will be improved. A more myopic policy of the sheep farmers works in the opposite direction.

6. Discussion

As the above model demonstrates there is a mutual interdependency between the two agents when $0 < k < p$; the DNRM affects the sheep stocking rate and the profitability of the sheep farmers, and the sheep farmers affect the wolf related costs and benefits flowing to the general public. The compensation payment plays a key role in the model as it determines the distribution of benefit and cost flows between the agents. It is not only a matter of redistribution; it also affects the allocation of sheep and wolves in the considered area with sheep farming coexisting with a wolf population. As shown in Figure 1 we have two polar cases: *A* denotes the case without compensation and amounts to granting the sole property right to The Directorate for Natural Resource Management (DNRM). On the other hand, *B* denotes the case of full compensation and amounts to granting the sole property right to the sheep farmers. Point *C* exemplifies an intermediary case (less than full compensation) with $0 < k = \hat{k} < p$.

The current official policy of Norway is to grant full compensation to the sheep farmers for sheep killed by wolf (again, see Ekspertutvalget 2011), corresponding to point *B* in the figure. This amounts to giving the sheep farmers the sole property right to the grazing areas. Accordingly, having a viable population of wolf is *de facto* not so much a *public right* as it is a *public good* that must be collectively paid for. On behalf of the general public the wildlife authority responds by keeping a lower population of wolves. The current policy is solely based on a judgment concerning rightful ownership. In terms of potential Pareto improvement there is no efficiency criterion involved.

A Pigovian influenced state regulation model would also include the efficiency criterion. Based on maximization of the – typically equally – weighted sum of the agents' utility functions and equalizing the discount rents $\delta_1 = \delta_2 = \delta$, the optimal allocation of sheep and wolves may be derived. This takes place at the wolf population size where the marginal cost of the wolf in terms of killed sheep equals the marginal benefit in terms of the existence value. In Figure 1 this corresponds with point *D* which is the social planner solution of the model where the (unweighted) sum of the farm profit and DNRM net benefit is maximized. See the Appendix for details.

With zero compensation as the point of departure (*A* in the figure), the Pigovian influenced regulation model would identify the wildlife authority as the responsible party for imposing an externality (in terms of wolves killing sheep) on the victim, the group of sheep farmers. To internalize the externality the state should impose a unit tax on DNRM given by $t = p$ in order to reach the social optimal solution at *D*. This complies with the polluter pays principle where a unit tax on sheep killed by wolves is imposed on the general public. With reference to today's regime of full compensation (*B* in the figure), the Pigovian influenced regulation model suggests that the general public should still pay for wolves killing sheep, but the compensation payment to the sheep farmers should be withdrawn.

Now it is time to introduce our own concept of externality as policy relevant institutional interdependency. Based on this, and given the full compensation regime of today, where do we identify the externality? Obviously, whether sheep killed by wolves are fully compensated, $k = p$, not compensated at all, $k = 0$, or treated in terms of the polluter pays principle where the general public is imposed a unit tax on sheep killed by wolves while the group of sheep farmers is not compensated, one or both of the agents will be negatively affected by the other. Keeping the argument of Coases (1960) in mind, saying that it is not obvious who is the responsible part when an externality is present, we must go beyond the mutual negative effects between the agents in order to identify the externality. Rather, we must turn to the political objectives of the state.

The political objective is to have a sustainable population of the Scandinavian wolf in Norway without restricting the grazing rights of sheep farmers in wolf areas (cf. the declaration that wolf management must take place in a multi-use landscape) at the same time as conflict should be at a minimum. This is exactly where we find the policy relevant institutional interdependency: The *de jure* rights of the agents are mutually exclusive. Given the current institutional setting, the grazing right of the sheep farmers is in conflict with the right of the public to have a viable population of wolves in Norway. The prevailing assignment of property rights is inconsistent. To eliminate the externality the *de jure* property rights must be clarified. An obvious policy response would be to assign property rights which imply a separation of sheep and wolves, either geographically or, say, by the use of herdsmen.

7. Concluding remarks

The present paper offers a critical review of the traditional concept of externalities. Based on this, and inspired by Commons' theory of institutional evolution, we redefine the traditional concept. Rather than reflecting market failure, our understanding of externalities is more general and reflect institutional failure. In short, we define an externality to be *policy relevant institutional interdependency*. Institutional interdependencies originate from the structure of the *de jure* property rights, the enforcement of those rights and on the behaviour of individuals.

As an illustration we discuss our institutional understanding of externalities in the context of the conflict between sheep farming and wolf management in Norway. Here we identify externalities, i.e. policy relevant institutional interdependencies, in the *de jure* property rights structure: The sheep farmers' and the wildlife authorities' property rights to the multi-use landscapes are mutually exclusive. Compensation payments to sheep farmers only redistribute benefits and costs between the agents and do not reduce the conflict. One way to eliminate the externalities would be to clarify the *de jure* property rights and separate sheep and wolves.

Appendix

The weak Arrow sufficiency condition in the sheep farming optimization problem requires $\partial^2 H / \partial X^2 = (k - \lambda_t) G_{XX} - C'' \le 0$ which with singular control and $\lambda_t = p$ also reads $\partial^2 H / \partial X^2 = -(p-k) G_{XX} - C'' \le 0$. With convex sheep cost function together with $G_{XX} = 0$, we have $\partial^2 H / \partial X^2 \le 0$. The weak Arrow sufficiency condition in the maximization problem of the wildlife authority is satisfied when $\partial^2 L / \partial W^2 = A'' - B'' y_t - kG_{WW} + \mu F'' \le 0$. With singular control $\mu = q - B(W)$, this also reads $\partial^2 L / \partial W^2 = A'' - B'' y - kG_{WW} + \left(q - B\right) F'' \le 0$. When $B'' = 0$, $G_{WW} = 0$ and $F'' < 0$, we always find this condition satisfied with $(q - B) \ge 0$. When $(q - B) < 0$, as for no harvesting value and $q = 0$, $\left|A''\right| \ge \left(q - B\right) F''$ must hold to meet the sufficiency condition.

With the specified functional forms, the weak Arrow sufficiency conditions for the sheep management problem and the wolf management problem read $\partial^2 H / \partial X^2 = -c \le 0$ and $\partial^2 L / \partial W^2 = -2r(q-b)/K - 2v \le 0$, respectively. The wolf management optimization problem therefore demands $r\left(q-b\right)/K + v \ge 0$. The geometric interpretation of this condition is that equation (6') for all $0 < k \le p$ should be downward sloping in the $X - W$ diagram (Figure 1).

The Hamiltonian of the social planner model writes

$$HL = ph_t - C(X_t) + qy_t - B(W_t) y_t + A(W_t) + \lambda_t (sX_t - G(W_t, X_t) - h_t) + \mu_t (F(W_t) - y_t).$$

Deriving the first order necessary conditions, we find that the golden rule conditions after some small manipulations may be written as $s - G_X(X, W) - \dfrac{C'(X)}{p} = \delta$, and

$F'(W) - \frac{B'(W)F(W) - A'(W) + pG_W(X,W)}{q - B(W)} = \delta$. When using the specific functional forms these equations read $s - \alpha W - cX / p = \delta$, and $r\left(1 - \frac{2W}{K}\right) - \frac{p\alpha X - (u - 2vW)}{(q-b)} = \delta$, respectively. They coincide with Eq. (4') with $k = 0$, and (6') with $k = p$, respectively.

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List of Figures

[1] First edition 1762.
[2] Kenneth Waltz (1959) provides a classical piece of political science discussing Rousseau's example in connection with international relations theory.
[3] Some would also add that without transaction costs institutions and rules will have no economic function, so there would be no institutions either (Papandreou, 1994).
[4] This is a prerequisite for having "externalities as non-market interdependency and inefficiency" in the first place.
[5] As the transaction costs of the victims in a bargaining situation is likely to be much higher than the transaction costs of state regulation, this seems to be a reasonable assumption (Vatn, 2005).
[6] This problem is obviously accentuated if different institutional settings cannot be compared with a single (e.g., monetary) value.
[7] Enforcement may be needed to ensure that *de jure* rights and duties become *de facto* rights and duties.
[8] More specificly, the Norwegian wildlife authority has established that the management goal is to have three successful wolf reproductions within the management area annually. This goal has been reached the last years (Norwegian Environment Agency).
[9] A possibly more realistic assumption is that the wolf per capita consumption increases at a decreasing rate, exemplified by the function $G(X_t, W_t) = [\alpha X_t / (\beta + X_t)]$. $\beta > 0$ is a shape parameter and $\alpha > 0$ is the maximum consumption per animal.