

Jan Tore Solstad

The Distributional Aspect of Scarcity

Essays on the Economics of Natural Resources,
Institutions and Development

Thesis for the degree dr.polit.

Trondheim, October 2007

Norwegian University of Science and Technology
Faculty of Social Sciences and Technology Management
Department of Economics

 **NTNU**

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Chapter 1

The Distributional Aspect of Scarcity

**A Broad Perspective on the Economics of Natural Resources,
Institutions and Development**

The Distributional Aspect of Scarcity

A Broad Perspective on the Economics of Natural Resources and Institutions

by

Jan Tore Solstad
Trondheim Business School
Sør-Trøndelag University College
Jonsvannsveien 82
N-7004 Trondheim
(E-mail: Jan.Solstad@hist.no)

Abstract

This introductory essay serves as a synthesis of the thesis “The Distributional Aspect of Scarcity: Essays on the Economics of Natural Resources, Institutions and Development.” It accounts for the crucial role played by environmental and institutional conditions in economic development, motivates the research contribution of the thesis and discusses its methodological approach in a history of science perspective. The essay is organised around three fundamental concepts of economics; value, human behaviour and property rights. This makes it easier to reveal the basic underlying perspective on economics from which the thesis is conceived. Indeed, within this organising structure the essay identifies and accounts for the governing idea of the entire thesis - the “distributional aspect of scarcity.”

1 Introduction

Individuals do not choose between the alternatives offered by nature - they choose between the alternatives offered by owners (John R. Commons, 1934, p.199)

The present thesis addresses issues concerning the exploitation of natural resources. The aim is to add theoretical insight to the field of natural resource and environmental economics, and to contribute some new thoughts to the current debate on environmental matters. In this debate, the impression is frequently conveyed that there is a fundamental conflict between economic development and environmental concerns. However, as all economic activity ultimately depends upon the environmental resource base, the conception of such a conflict seems to be a false trail, probably originating from the confusing of economic development with economic growth. Rather, the basic conflict is to be found among the multitude of individuals having opposing interests and preferences over the diversity of mutually exclusive ways by which natural and environmental resources may be utilised. This is the perspective with which the present thesis enters the environmental debate.

The choice of perspective governs how problems are defined and approached. The way by which economists conceptualise the economy, the kind of problems they are absorbed by and the methodological tools by which they are equipped all have a decisive influence on their contribution to the policy debate and to the generation of knowledge in general. Although drawing heavily on the tools of neo-classical economics, the present thesis is inspired by institutional economics. Basically, this finds expression in the explicit focus on property rights in the analysis of natural resource and environmental management. As property is nothing but value, and a right to property is nothing but institutional behavior, the economics of property rights emerges out of the institutional understanding of value and behaviour. With this in mind, the thesis is organised around the three basic concepts - value, behaviour and property rights.

The essay is supposed to give a broad account of the underlying perspective on economics from which the thesis is conceived. Section 2 offers an argument for the crucial role played by environmental and institutional conditions in economic development. Turning to the economics of population, the important principle of scarcity is established in section 3. Section 4 identifies the underlying governing idea of the thesis, that is, the distributional aspect of scarcity, and together with sections 5 and 6, it offers a broad perspective of the economic concepts of value, behaviour and property rights.

2 The “Ultimate and Proximate Causes” of Economic Development

If superior creatures from space ever visit earth, the first question they will ask, in order to assess the level of our civilization, is: ‘Have they discovered evolution yet?’ (Richard Dawkins, 1989, p.1)

“History followed different courses for different peoples because of differences among peoples’ environments, not because of biological differences among peoples themselves.” In this way Jared Diamond (1998) sums up his book “Guns, Germs and Steel. A short history of everybody for the last 13, 000 years.” Diamond seeks to trace out the broad patterns of human history in terms of environmental geography and biogeography. To explain why wealth and power among the different regions of the world are so unequally distributed, he resorts to continental differences in the environmental conditions, as, for instance, in the starting materials for domestication. Before the rise of civilisation, some regions of the world happened to be rich on plant and animal species being highly suitable for domestication, while others were not. Thus, food production was more likely to emerge in those former regions. Moreover, some regions had a favourable geographical location with respect to the diffusion of domestication techniques, while others had not. Thus, by triggering domestication and enabling farmers to generate food surpluses, favourable environmental and geographical conditions gave some regions comparative advantages in terms of economic and military power. These conditions constitute the “ultimate causes” of the biased distribution of wealth and power among people of different regions (Diamond, 1998).

Based on the prevailing environmental and geographical characteristics, the domestication of plant and animal species has, throughout history, been triggered by effort-allocation decisions of human foragers. By seeking the highest return, for example in terms of calories and proteins, for the least effort used, people of some regions rationally remained hunter-gatherers, while others adopted food production. The reason why food production suddenly gained a competitive advantage over hunting gathering in the first place, may be found in factors like an increasing scarcity of wild foods, improved technologies for collecting, processing and storing food, or a rising population density. In any case, humans did not intentionally invent food production. Rather, it evolved as a by-product of many separate effort-allocation decisions made without awareness of their accumulated consequences. When first known, however, food production became not only a serious competitor for hunting-gathering, but, eventually, also its downfall. Indeed, more than being the preferred choice, food production gained by the very fact that the “denser populations of

food producers enabled them to conquer and displace hunter-gatherers by their sheer numbers” (Diamond, 1998, p.112).

The transition from hunting-gathering to food production constitutes a major turning point in human history, as it paved the way for the making of more advanced and complex technologies and institutions. The technological and institutional advantages constitute the “proximate causes” of the unequal distribution of wealth and power among people of different regions of the world. Those who got “a head start on food production” thereby gained a head start on technological and institutional development (Diamond, 1998, p.103). Moreover, the chain of causation between the two is expected to operate in both directions. That is, population densities increase with increased food availability, at the same time as higher population densities trigger technological and institutional innovation. Thus, “the adoption of food production exemplifies what is termed an autocatalytic process - one that catalyzes itself in a positive feedback cycle, going faster and faster once it has started” (Diamond, 1998, p.111).

Besides offering an interesting perspective on the evolution of human history, Diamond's work signifies the crucial role played by environmental and institutional conditions in economic development. The role he assigns to the notion of “ultimate causes” highlights the paramount importance of environmental conditions, while that of “proximate causes” illustrates, for better or worse, the immense power of institutions. In the terminology of resource economics, these refer to natural and man-made (physical and institutional) capital, respectively. The interaction between the two is the prime mover of economic development, and population growth constitutes a crucial connecting link between them. In the classical literature on resource economics, this brings us to the theory of Thomas Malthus (1798) and its alleged counter thesis, the work by Esther Boserup (1965).

3 Population Growth and Economic Development

[T]o urge man to further the gracious design of providence, by the full cultivation of the earth, it has been ordained, that population should increase much faster than food. (Thomas Robert Malthus, 1798, p.361)

Conventional wisdom assigns the main divergence between the theories of Malthus (1798) and Boserup (1965) to the *direction* of causality, that is, whether the means by which food is

obtained determine population growth, or the other way around. A conventional reading of Malthus suggests the former, that is, population growth is determined by the fixity of means available for obtaining food. As people basically are not able to adapt their reproduction behaviour to a limited resource base, rapid population growth is generated through increased fertility and reduced mortality *whenever* productivity is high and times are good. Given Malthus' assumption of scarcity and diminishing returns to scale, that is, a negative relationship between population growth and labour productivity, the resulting increase in the population necessarily reduces per capita consumption. As the living conditions deteriorates, "positive checks" slow down population growth until it settles down at the level of subsistence in the long term, that is, the well known "poverty trap." Hence, when a higher population density does not make people adopt more efficient methods of obtaining food, the scarcity of resources, in combination with the absence of voluntary restraint on birth control ("preventive checks"), inevitably results in poor living conditions for the great mass of people.

In contrast, Boserup (1965) treats population growth as given, and as the main factor determining the means by which food is obtained. Her argument basically hinges on the assumption that an increase in population pressure induces a shift to more labour-intensive production techniques. This opens new innovation possibilities, that is, the making of new and better technologies. Hence, even in a world of scarcity, there may be a positive relationship between population growth and labour productivity. In Boserup's (1965, p.75) own words, "a growing population will be faced with the need to improve the land and perform other investments in agriculture. It is nevertheless likely to experience diminishing returns to labour at least in the short run, and it may have to do longer and harder hours of agricultural work in order to avoid a fall in nutritional standards." This rather dismal conclusion is relaxed by Boserup's belief in the more positive long term effects of a gradually increasing population: "The gradual adaptation to harder and more regular work is likely to raise the efficiency of labour in both agricultural and non-agricultural activities; the increasing density of population opens up opportunities for a more intricate division of labour and - in some cases - a higher degree of urbanization results in improvements in agricultural productivity through the delivery to agriculture of better makes of tool, the provision of better administration, education, etc."

Boserup's (1965) work belongs to the tradition of *population-induced innovation models*. Firmly placed within the same tradition, Hayami and Ruttan (1985) explain invention and adoption of new technologies partly as a product of population growth through its effect

on relative prices. As population increases, land becomes scarcer and its price increases relatively to the prices of other factors, as for instance labour and land yield-increasing inputs (e.g. fertilizers). Hence, as pointed out by Cuffaro, “Technological change therefore moves in a land saving, labor using direction” (Cuffaro 1997, p. 1154). Another perspective within the same tradition, the “evolutionary theory of land rights,” as named by Platteau (1996, p.31), emphasises innovations in property rights. Its theoretical framework is rooted in various works by theorists associated with the so-called “property rights school” (Alchian and Demsetz, 1973; Coase, 1960; Demsetz, 1967; Johnson, 1972; Posner, 1992). Their focus is on the evolution from poorly defined (e.g. “open access”) to well defined property rights regimes.¹ As population grows, scarcity induces increased competition and a higher price of land. Thus, the externalities associated with poorly defined property rights, or no property rights at all as in “open access,” become more significant, and “property rights develop to internalize externalities when the gains of internalization become larger than the cost of internalization” (Demsetz, 1967, p.350). In this way, population growth induces a transition to more “efficient” land right structures (see section 6 below, for a fuller account of the economics of the “property rights school”).

As noted, conventional wisdom categorises the theories of Boserup and those sharing her views, as counter-Malthusian theories. However, although Malthus, quite contrary to Boserup, treats population growth endogenously, the basic feature of his theory is more in resemblance with that of the “population-induced innovation models” than is usually recognised. Traditionally, attention is directed solely towards Malthus’ “gloomy prediction ... that population growth would run up against the fixity of the earth’s resources and condemn most of humankind to poverty and recurring high death rates” (Birdsall, 1988, p.478. See also Cuffaro, 1997; Nerlove and Raut, 1997; Robinson and Srinivasan, 1997). According to Commons (1934, p.246), however, this is “only the materialistic basis of overpopulation developed in the first half of his book, whereas Malthus himself considered that his great contribution was his theory of Moral Evolution in the latter half.” Just like innovations in technology, knowledge and property rights, Malthus’ major concern, innovations in morality, emerges out of population pressure and scarcity. As in his own words, “Had population and food increased in the same ratio, it is probable that man might never have emerged from the savage state” (Malthus, 1798, p.364).

¹ Demsetz (1967) and Alchian and Demsetz (1973) are specifically referring to the transition from communal- to private property rights when formulating their theory of the evolution of “efficient” property rights. See e.g.

With this in mind, the conventional understanding of the work of Malthus and the population-induced innovation models as opposites is somewhat misleading. Indeed, from his principle of population, which Commons (1934, p.246) considers as none other than the “the biological foundation of the principle of Scarcity,” springs Malthus’ vision of “moral excellence” and the awakening of “social sympathy.” Likewise, from the principle of scarcity, springs Boserup’s (1965) belief in technological, educational and administrative progress, Hayami and Ruttan’s (1985) faith in the market as a means to achieve “efficient” innovation, Demsetz’s (1967) highly esteemed transition to private property rights, as well as Hobbes’ (1651) call for Leviathan and Hume’s (1739) notion of justice and property. They all confess to the principle of scarcity - the subject matter of economics.

4 Scarcity, Conflict and the Concept of Value

[W]e must renounce the theory, which accounts for every moral sentiment by the principle of self-love. We must adopt a more public affection, and allow that the interests of society are not, even on their own account, entirely indifferent to us. (David Hume, 1751, p.207)

Most problems of relevance to economics start with scarcity, unfold in conflict of interest, and must be evaluated with reference to some concept of value. Scarcity generates a multitude of trade-offs among a diversity of conflicting and, frequently, mutually exclusive objects of value. Basically, we are faced with two aspects of scarcity. Firstly, resources have a multitude of mutually exclusive alternatives of use. A parcel of virgin land may, for instance, either be preserved as habitat for wildlife and plants, or converted to agricultural land for food production. This points to the “allocative aspect of scarcity,” and is attached to the mutual exclusiveness of alternative uses of resources in a Robinson Crusoe economy. The different alternatives may be exposed to some unified standard of value, and on that basis, the “optimal” allocation of resources - the one generating the largest amount of value - may in principle be found. Broadly, this is the approach of mainstream welfare economics.

However, in the absence of a unified standard of value it is more problematic to identify the optimal allocation of resources. This brings us over to the second aspect of scarcity - that of distribution. The “distributional aspect of scarcity” concerns conflicting

Bromley (1991), Platteau (1996), Quiggin (1988), Runge (1981), Swaney (1990) and Wade (1987) for critical reviews of their line of reasoning.

interests among individuals in their utilisation of resources. This is the more fundamental aspect as it constitutes the *raison d'être* of institutions. As in the words of Commons (1934, p.6), drawing on Hume and Malthus, "out of scarcity derives not only conflict, but also the collective action that sets up order on account of mutual dependence." That is, property rights and institutions in general are social constructs invented for dealing with problems of scarcity and conflict of interest. After all, scarcity is the origin to the notion of property, and the idea of property is the basis of all institutions (Biddle, 1990; Commons, 1934). This points to the institutional perspective of environmental management, requiring a concept of value that pertains as much to the properties and qualities of institutions, as to material goods and environmental services *per se*.

The two aspects of scarcity are separable only in thought - not in reality. In any economic transaction they operate together and give meaning to the concepts of price, opportunity cost, externality and value. Still, conceptually they are very different. This finds its expression in the diverging methodological approaches of neo-classical welfare economics and institutional economics, the former from which mainstream natural resource and environmental economics draws heavily. The normative branch of natural resource and environmental economics, as represented by the extensive use of cost-benefit analysis, abstracts from distribution and concentrates on "allocative efficiency" (as defined by the potential Pareto improvement-criterion). Based on the compensation principle (Hicks 1939; Kaldor, 1939), any policy capable of generating a *net* benefit, that is, an increase in aggregate production, is ascribed a welfare improvement by this approach. However, the market- and estimated non-market prices used as inputs in the calculation of the aggregate production value inevitably reflect the existing institutional structure and the state of distribution. That is, unless the distribution of the status quo is uniformly accepted as the "appropriate" one by society at large, optimisation based on market prices will not be ethically neutral but biased in favour of the status quo. Indeed, "there is no meaning to total output independent of distribution" (Arrow, 1963, p.40). In general, it is difficult to make value comparisons between activities without resorting to specific distributional standards (Bergson, 1938; Samuelson, 1950). Moreover, by abstracting from problems of institutions, distribution and scale, the approach may not only be ethically biased, but also ignorant of many of the potential remedies for the most pressing social and environmental problems of today.

Basically, institutions are formed by individuals living in an environment of scarcity and conflict of interests. In their own best interest, people choose to subordinate themselves to common rules in order to obtain the mutual benefits of cooperation. That is, institutions are

the accumulated effect of a multitude of purposeful, institutional transactions among self-interested individuals. However, just as with the evolution of food production, institutions *evolve* as a by-product of many institutional transactions made *without* awareness of their full and accumulated consequences (see section 2 above). As in the words of Deblonde (2001, p.37; 38), inspired by the political philosophy of Hannah Arendt, “a societal organization - which is a manifestation of politics - is never ‘made’.” That is, the emergence of institutions are not “entirely determined by the categories of means and end.” Political events do not emerge from single political actions. Rather, they are formed in a “‘web’ of human relationships,” and cannot be traced back to any individual action (Arendt, 1958, p.183). Indeed, “one cannot think of political processes as a means to realize a particular end, since the end, i.e. the realization of human freedom, is revealed in the processes themselves (Deblonde, 2001, p.37).

Thus, disconnected from the preferences of any particular individual, institutions are carriers of values having their sole basis at the social level, as exemplified by the universal values of freedom and justice. Indeed, freedom and justice are nothing but institutions themselves. More than three centuries ago, Locke (1690) reminded us, that far from the liberty to do as one pleases, without being tied by any laws, “freedom of men under government is to have a standing rule to live by, common to every one of that society, and made by the legislative power erected in it” (Locke, 1690, p.17). Likewise, some decades later, Hume (1739, p.498) emphasised the institutional nature of justice, holding that “justice establishes itself by a kind of convention or agreement; that is, by a sense of interest, suppos’d to be common to all, and where every single act is perform’d in expectation that others are to perform the like.” Thus, freedom and justice both coincide with Commons (1934, p.73) definition of an institution, that is, with “collective action in *restraint, liberation and expansion* of individual action.”² Accordingly, it is by adding *security, ability and force*, to the group of individuals, that institutions become advantageous and carriers of social value (Hume, 1739, p.485). In any normative economic analysis, then, not only individual preferences over goods and services within a given institutional and distributional context, but the institutions themselves should be made subject to evaluation.

This is the underlying perspective of chapter 2, the paper “The Spatial Distribution of Benefits and Costs of Wildlife Management. Moose versus wolf in Norway.” The joint management of moose and wolf is evaluated both by efficiency criteria in terms of cost-

² Italics added.

benefit analysis, as well as by institutional criteria in terms of distributional conditions and the property rights structure. Although widely supported at the national level, the recolonisation of the Scandinavian wolf in Norway is in conflict with the interests of local farmers due to wolf predation on domestic livestock. To mitigate the livestock losses, the State grants compensatory awards. Thus, the presence of livestock in, or close to, wolf territories represents a cost for “society at large.” Another conflict of interest is attached to wolf predation on moose, as this may considerably lower the hunting income of local landowners. On the other hand, an abundant moose population causes large social costs in terms of moose-vehicle accidents. The spatial distribution and the institutional structure of the joint moose and wolf management are explored when all these benefits and costs are accounted for.

The paper concludes that today’s management of moose and wolf seems to serve local interests more than those of “society at large.” Moreover, the establishment of compensatory awards for livestock killed by wolf does not enhance social efficiency, but widens the distributional bias in favour of local interests. Furthermore, it is argued that property rights are not well specified or clearly defined, and that the mutual interference of various legal claims - as the prescriptive pasture rights of sheep farmers, the hunting rights of land owners, the public rights according to the Wildlife Act and biodiversity preservation, and the international rights according to various international conventions - constitutes a basic conflict within wildlife management. Hence, to reduce the conflict, the *legal assignment* of property rights should be changed. For instance, the State may buy out the pasture rights of local farmers, so that compensation is given for lost pasture rights rather than lost livestock. Future conflicts in terms of poorly defined property rights would then be reduced.

The “distributional aspect of scarcity” is not important only for our understanding of value. It matters much also for our understanding of human behaviour. Indeed, distributional scarcity triggers institutional behaviour. The next section proceeds with discussing the role of distributional scarcity in the shaping of individual behaviour.

5 Scarcity, Conflict and Institutional Behaviour

According to the historical analysis by Malthus, reason and moral character are a slow evolution out of overpopulation, conflict of interests, and the resulting necessity of having a government of law and order to regulate the conflict. (Commons, 1934, p.682)

Following Commons (1934, p.73), an institution is “collective action in restraint, liberation and expansion of individual action.” Institutional behaviour, then, is the performance of collective action, that is, individuals conforming to patterns of behaviour which promote the interests of the collective. Within mainstream resource and environmental economics, however, distributional scarcity often takes the form of strategical interaction among individuals having nothing but conflicting interests in their common exploitation of resources. Accordingly, conventional wisdom puts the problem of distributional scarcity on a par with the so-called “tragedy of the commons,” or, in game theoretic terms, the one-shot “prisoner’s dilemma” (Gordon, 1954; Hardin, 1968; Mesterton-Gibbons; 1993). Thus, the essence of the problem is represented by the failure of rational, self-interested individuals to act collectively and reach the most preferred, or “efficient,” outcome. Apparently, individual rationality is to blame for this rather dismal conclusion.

However, when time, communication and features of group cohesion in general are abstracted from, as in the static “prisoner’s dilemma” game, self-interested, rational individuals are actually deprived the opportunity to behave institutionally. Thus, the “prisoner’s dilemma” is to natural resource and environmental economics what the Hobbesian “state of nature” is to political philosophy: In the absence of a sovereign there is only destructive competition and no form of cohesion among individuals (Hobbes, 1651). As pointed out by Hume (1739, p.493), although “we may conclude, that ’tis utterly impossible for men to remain any considerable time in that savage condition, which precedes society; but that his very first state and situation may justly be esteem’d social, [this does not prevent] that philosophers may, if they please, extend their reasoning to the suppos’d *state of nature*; provided they allow it to be a mere philosophical fiction.” That is to say, by ignoring the presence and influence of the “institutionalized mind” (Commons, 1934), the “prisoner’s dilemma” has limited descriptive relevance to the problem of the commons. Rather, it is a theoretical polar case corresponding with the notion of “open access,” that is, unregulated access in the widest possible sense: absence of institutions both in the form of formal and informal property rights, social norms, or any other feature of group cohesion and identity.

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Recalling that “out of scarcity derives not only conflict, but also the collective action that sets up order on account of mutual dependence” (Commons, 1934, p.6.), the institutional framework should be made more realistic. As a minimum requirement, the institutional setting must be sufficiently advanced to give meaning to terms like cooperation and coordination. When this is in place, it can be demonstrated in several ways that collective action may be based on individually rational behaviour. Firstly, we may stick to the basic assumptions of the “prisoner’s dilemma” game, but abandon the static approach. In accordance with the “folk theorem,” it can then be shown that the dilemma may be eliminated by introducing dynamics to the game: If the “prisoner’s dilemma” is repeated an infinite or indefinite number of times, self-interested rational players may be guided towards “efficiency” if costs and benefits are not discounted too heavily (Fudenberg and Maskin, 1986). When time is considered explicitly, communication takes place in the form of mutual expectations of individual rationality. What is actually communicated is the expected response of a player to the different choices of another. As long as everyone acts according to individual rationality and expects the others to do the same, players may avoid the dismal outcome by coordinating their activities.

Secondly, we may modify the simplified institutional assumptions of the prisoner’s dilemma game. This approach is applied in chapter 3, the paper “Collective Action, Individual Rationality and Common Property Regimes.” The paper shows how cooperative incentives are generated among self-interested agents, even in the context of a “non-repeated” game adhering to the orthodoxy of individual rationality. By introducing the concept of a “unified purpose” which forms group cohesion and identity among individuals, the analysis shows how the problem of overexploitation is neutralised as cooperative incentives are generated - not by the aid of the “Hobbesian Sword” - but by individually rational choices of self-interested individuals.

The “unified purpose” is represented by the opportunity of the exploiters of a renewable resource to contribute a share of the resource yield towards a public good. The model is formulated as a two-stage sequential game, where the harvesting decisions are made at the first stage. After observing the resource yield, the choice of how much to provide for the public good is then made at the second stage of the game. The individual decision to refrain from opportunistic harvesting behaviour is interpreted as a form of strategic move in the paper.

Thirdly, we may resort to alternative concepts of rationality. This is the approach of contractarian theory. The typical point of departure of contractarians is the “state of nature, in which there are no institutions for defining and enforcing rights” (Sugden, 1993, p.17). Their

aim is to explain how rational and self interested individuals within a "state of nature" come to make bargains, and why they comply with them once they are made. Major contributions within this tradition are the works of Hobbes (1651), Locke (1690), Hume (1739), Rousseau (1762), Rawls (1971) and Gauthier (1986). Common to all is that they apply a concept of rationality quite at odds with that of orthodox game theory (Binmore, 1993; 1994).

Institutional behaviour, however, does not necessarily flow from outcome-oriented maxims of collective action. As pointed out by Basu (1996, p.739), "It is now more and more accepted that while a human being does choose and optimize, the feasible set from which she does so is determined not only by her budget constraint but also by social norms and custom." Social norms and custom are integral parts of the institutional environment in which individuals find themselves. Hence, to give a fuller account of institutional behaviour in the utilisation of natural resources, the influence of social norms and custom should be considered (Bardhan, 1993; Commons, 1934; Ostrom, 1990; Ostrom and Gardner, 1993; Rabin, 1998). Following Elster (1989, p.99), "One of the most persistent cleavages in the social sciences is the opposition between two lines of thought conveniently associated with Adam Smith and Emile Durkheim, between *homo economicus* and *homo sociologicus*." These are polar cases, the former in which individuals are guided by orthodox, instrumental rationality; and the latter in which individuals are dictated by social norms and behave like custom prescribes (Binmore and Samuelson, 1994; Elster, 1989).

There is no consensus on the "precise nature of *homo sociologicus*" (Binmore and Samuelson, 1994, p.46). Economists, however, typically "reduce norm-oriented action to some type of optimizing behavior" (Elster, 1989, p.99). Basically, they address the issue of social norms analytically, either by treating norms as "binding constraints limiting the choices of a maximizing self-interested individual" or by letting norms "play an important role in shaping individual preferences" (Baland and Platteau, 1996, p.116). In chapter 4, the paper "Exploiting a Local Common: Egoistic vs. Altruistic Behavior," the latter approach is applied. The role played by social norms is analysed by introducing altruistic preferences in the standard Gordon-Schäfer model of a fishery. Among other things, it is shown that altruism rooted in social norms reduces economic overexploitation as it neutralises the adverse effect of stock externalities.

The above discussion illustrates the crucial importance played by institutional and behavioural assumptions in the economic modelling of natural resource exploitation. This brings us to the final topic; the economics of property rights.

6 Scarcity, Conflict and Property Rights

Nothing is property that is not expected to be scarce, and everything expected to be scarce is quickly brought by collective action within the meaning of property rights. (Commons, 1934, p.522)

According to Locke (1690, p.19), although God gave the world and its natural resources to mankind in common, “there must of necessity be a means to appropriate them some way or other before they can be of any use, or at all beneficial, to any particular men.” Indeed, Locke derives a principle of individual property rights as vested in the claimant’s inviolable rights to the securing of own sustenance and the produce of own labour (Locke, 1690). Thus, Locke’s theory of property rights, justifies private ownership based on physical or empirical possession. That is, the existence of a “natural” right to property prior to any notion of collective consent (Bromley, 1991; Williams, 1977).³ On this point, Locke was followed by succeeding generations of mainstream economists. As maintained by Randall (1978, p.1), both for classical, neo-classical and new-institutional economists “individual ownership and control of resources were essential in order to permit the decentralization of allocative decisions.” Moreover, as exemplified by modern welfare economics, relying extensively on the cost-benefit approach, the distribution of private property rights is treated as given, and receives minor attention from the “mainstream” economist. Indeed, a normative foundation for such a position is offered by “the property rights school.”

While Locke finds justification for his theory of private property in the “divine right of Labor” (Commons, 1934, p.25), his successors from “the property rights school” find it in the concept of “efficiency” (Alchian and Demsetz, 1973; Coase, 1960; Demsetz, 1967; Johnson, 1972; Posner, 1992). These theorists focus on the evolution of land rights as an “efficient” transition from communal- to private property rights. Based on an “open access” conception of communal ownership, the theoretical basis of the “property rights school” is neo-classical microeconomics exposed to the concepts of externalities and transaction costs. In broad terms, an externality occurs when an individual’s action affects the welfare of another individual, the latter having no influence over the actions of the former, and the former having no particular attention to the effect on the welfare of the latter (see Baumol and Oates, 1988, p.17). That is, due to atomistic decision making among self-interested individuals, there are negative externalities associated with the utilisation of scarce resources. A relevant example is the

stock externalities in the traditional Gordon-Schäfer harvesting model: One individual's harvesting increases the harvesting costs of another through the stock effect.

In general, externalities may be "institutionalised" (internalised) to eliminate the social costs associated with them. However, the establishment and enforcement of institutions are also subject to costs. These are named transaction costs. Whenever the value of externalities is low, as for instance when population pressure is low and scarcity is not severe, transaction costs tend to dominate the benefits arising from eliminating the externalities. In such cases of non-significant externalities, there will be no institutional change, that is, no transition from communal- to private property rights. However, when population pressure and scarcity of land increases, the gains of establishing institutions in order to eliminate significant externalities may come to dominate transaction costs. Thus, when resources subject to "non-institutionalised" utilisation (absence of private property rights) become scarce, and the gains arising from "institutionalising" the externalities become dominant over costs, voluntary negotiations among individuals will take place and induce an "efficient" transition from communal- to private property rights. Accordingly, the government's role in the evolutionary process is limited to enforcing the agreed upon property rights structure.

Thus, in sharp contrast to the Pigovian externality theory which allows for government intervention, the problem of externalities should be solved by the aid of the market mechanism. As in the words of Coase (1960, p.2), the problem of externalities is of a "reciprocal nature," that is, it is not a straightforward matter to identify who is responsible for causing the externality.⁴ In other words, it is not straightforward to identify the "appropriate" distribution of property rights. However, following Coase, the identification of the responsible party is actually superfluous, as, indeed, the "problem is to avoid the more serious harm." As argued by Coase (1960), in the absence of transaction costs, resources will be allocated "efficiently" whatever is the initial distribution of property rights.⁵ If only property rights are clearly defined, distribution does not matter, as voluntary bargaining between opposing parties will, either way, lead to the abandoning of the activity of lower value to give room for

³ As pointed out by Commons (1934, p.32), Locke's "natural right of property does not arise from scarcity, but from abundance." That is, Locke's concept of property rights is of minor relevance to a world of distributional scarcity.

⁴ The identification of the responsible party is a prerequisite for the Pigovian approach.

⁵ In a survey of the critics of the Coasean line of reasoning, Dick (1976) points out that even in a world of zero transaction costs, optimal resource allocation will be independent of the initial distribution of property rights only in the absence of income effects and non-separable cost and damage functions.

that of higher value.⁶ In the literature, this is referred to as the “Coase theorem.” The resemblance of the argument with the compensation principle of mainstream welfare economics (see section 4 above) is striking: The economist does not need to take distribution into account - his only concern should be to maximise the value of aggregate production.

Under the assumption of increasing scarcity, then, the transition from communal- to private property rights are justified by the aid of economic “efficiency.” Once again we recognise the “allocative aspect of scarcity” as a guiding principle: The quest for “efficiency” is simply blind to distributional issues. Accordingly, the “property rights school” is subject to the same criticism as the compensation principle and cost-benefit analyses (see section 4 above). Moreover, whenever “efficient” institutional change is to take place, the abstraction from distributional concerns implies that those whose interests are not protected by the existing property rights will always be expected to compensate those whose interests are protected. That is, those without property rights must always compensate those with property rights in order to induce “efficient” institutional change. As in the words of Quiggin (1988, p. 1076), “The more severe ethical objections relate to the initial ‘constitutional’ stage. In the absence of universal consent for the initial allocation of rights, a consensual process for subsequent changes has no special moral status. Moreover, as one generation dies and another is born, the validity of any prior arrangement comes into question. In practice, it is difficult to see how the constitutional stage can be anything more than a fiction to justify the *status quo*.” It seems we need some alternative guiding principle for institutional change. As a first step on the way, the basic concepts of property and property rights should be elaborated.

“The first essential of ownership is scarcity” (Commons, 1934, p.253). Scarcity of resources induces conflict of interest, and the notion of property is the institutional response to this conflict. More specifically, property refers to a benefit stream and a property right to the capacity to control current and future appropriation of a benefit stream (Bromley, 1991; Demsetz, 1967). Thus, the essential feature of property rights points to the future rather than the past. As with materials in general, natural resources “do not exist as ownership or value for human beings until, from the present point of time, futurity is attributed to them” (Commons, 1934, p.406). Correspondingly, to have a right to property means to be in the position to call upon the collective to secure current and future appropriation of a benefit stream from external interference (Bromley, 1991). Thus, in accordance with Kant’s

⁶ It should be noted, however, that in a world of zero transaction costs, there can really be no externalities as they will all be eliminated by “efficient” bargaining solutions (Bromley, 1991; Dahlman, 1979; Dick, 1976). As maintained by Dick (1976, p.194), “Assume away transaction costs and you assume away the problem.”

understanding of property, property rights are social constructs vested in nothing but the consent of the collective (Bromley, 1991; Williams, 1977). Hence, "property ... involves three separable concepts, namely scarcity, futurity, and the rights, duties, liberties and exposures created by collective action" (Commons, 1934, p.522).

"While the engineer is the specialist in efficiency, and the business man is the specialist in scarcity, the banker is the specialist in futurity" (Commons, 1934, p.512). That is to say, to grasp the essential features of property, futurity also included, we should turn to the investment perspective of natural resource and environmental management. In the context of renewable resources, this may be achieved by applying the capital theoretic approach to natural resource and environmental exploitation. Within this approach, bioeconomic modelling is a powerful tool. With the aid of optimal control theory and the combining of biological growth models with those of standard neo-classical optimisation, bioeconomics maximises present values of net benefits arising from resource utilisation (Clark, 1990). Considering natural resources as biological assets, the "optimal" level of investment is determined by the capacity of natural resources to generate yields competitive with those of other assets (Clark, 1973a; 1973b; 1990; Hotelling, 1931; Swanson, 1993).

The yields of natural resources comprise net harvesting value (consumptive utilisation) and net stock value (non-consumptive utilisation).⁷ For a given return of alternative assets, as represented by a fixed rate of discount, the level of investment in a renewable resource thus depends on expectations of future net consumptive- and non-consumptive benefits. In the traditional sole-owner model of Clark (1990), where prices are fixed, the competitiveness of a natural resource is determined by the relation between the natural growth rate, (consumptive yield), the stock size (non-consumptive yield), and the rate of discount (yield of alternative assets). In so far as the harvesting value of a resource may be transferred into alternative investment opportunities, a relatively high rate of discount will discourage resource investment. As explained by Clark (1990, p.47), in the context of the fishery, "the 'capital' that the sole owner has invested in the fish stock itself possesses an opportunity cost in terms of the revenue foregone by not transferring its value to the most profitable alternative investment opportunity." Indeed, when the discount rate approaches infinity, Clark (1990) shows that the sole owner's optimal investment in the resource coincides with the overexploitation scheme of the static "open access" model of Gordon (1954). Thus, biological overexploitation is not only a "problem of the commons" - it may just as well occur under

⁷ The stock value is analogous to the "wealth effect" in capital theoretic models of optimal growth (Kurz, 1968).

sole ownership (Clark, 1973a; 1973b; 1990).⁸ With this in mind, the discount rate may be given an alternative interpretation: A high rate of discount may simply indicate that property rights are not properly secured and protected.⁹ That is, because of insecurity and imperfect protection of property rights, the “owner’s” expectations of future benefits from current investment are low. This, of course, applies to any property regime.

Indeed, more than a problem of identifying the most “efficient” property rights regime, the basic problem of disinvestment may be traced back to the distribution of de jure and de facto property rights. In a world of scarcity and conflicts of interests, environmental problems are typically characterized by various stakeholders having incompatible opinions about the declining resources. That is, benefits and costs of environmental management will be unevenly distributed among various stakeholders. For a given property rights structure, there will always be those who find a certain utilisation of a resource valuable without having the requisite property rights to realise its value. Inevitably, some individuals must be deprived of rights to property in order for others to have rights.

The uneven distribution of costs and benefits gives rise to quite distinct investment incentives among various stakeholders. Accordingly, the level of investment in natural and environmental resources relies extensively on who is, de jure or de facto, in the position to control the level of investment in natural resources. That is, the distribution of property rights is of paramount importance in the management of natural resources. Irrespective of the objectives for environmental policy, then, a main challenge for natural resource and environmental economics is to analyse and reveal the incentive structure among various interested parties in environmental conflicts. Moreover, due to the insecurity and imperfect protection of property rights, the economist must look beyond the de jure property rights to reveal the de facto property rights structure. Not until the incentives of those de facto in control of the resource are surveyed, a thorough analysis of environmental policy can be offered. This is one of the aims of chapter 5, the paper “The Political Economy of Wildlife Exploitation.”

The institutional setting of the paper is a conflict over property rights to wildlife between a wildlife agency and a group of local peasants practicing agricultural production outside the area. The agency has the legal rights to exploit the wildlife, while the local people

⁸ From the individual owner’s point of view, however, the sole ownership situation is one of *economic* optimality, while that of open access is one of economic overexploitation.

⁹ Hotte (2001, p.9), for instance, makes use of such an interpretation. In his model, the insecurity of a settler’s property rights to land is accounted for by introducing a probability of eviction. In his own words, “The effect of

have no legal rights to the wildlife, or its habitat, but are inclined to hunt illegally within a setting of imperfect law enforcement. The incentives of the local people to hunt illegally is analysed and modelled explicitly in the paper, and takes the form of a reduced illegal harvesting function. The crucial variables of the illegal harvesting function are related to the economic conditions in the alternative agricultural production, the law enforcement activity of the agency, the population pressure, and to the ecological conditions. The incentives of the agency to hunt and to use effort in the enforcement activity are modelled as a problem of optimal control, where the illegal harvesting function of the local peasants is included. Having accounted for the incentives of the stakeholders, it is then shown how the existing *de jure* property rights structure appears in different forms of *de facto* property rights structures, depending on the prevailing economic and ecological conditions. Measured against the objective of having a viable wildlife stock, it is shown in a next step how the different forms of *de jure* and *de facto* property rights structures affect the expediency of various policy alternatives (see chapter 5).

Recalling that property is a benefit stream, and a property right is the capacity to control and appropriate the benefit stream, it also becomes apparent that environmental policy is nothing but a redistribution of property rights. This is exemplified in chapter 6, the paper "Investing in Wildlife: Can Wildlife Pay its Way?" The main purpose of the paper is to analyse mechanisms determining investment in wildlife. The context is pastoral exploitation of semi-arid African rangeland. A group of pastoralists practice cattle herding and wildlife harvesting within a fixity of land. As there is competition for grazing land, livestock and wildlife interact with each other. Moreover, the biological interaction between the livestock and the wildlife translates into an economic interdependency. Thus, to analyse the economics of the system, a bioeconomic model is formulated, and the incentives of the pastoralists to invest in wildlife are traced out. Based on these, various policies aimed at securing the wildlife are analysed. In particular, the policy recommendation of the Convention on International Trade in Endangered Species (CITES) is addressed.

The CITES recommendation consists in restricting trade with wildlife products in order to reduce the profitability of wildlife harvesting by lowering net off-take prices. Thus, the CITES policy implies a restriction of the property rights to wildlife of local hunters in order to grant property rights to wildlife to the international community. However, although their *de jure* property rights are restricted, the local hunters may still be *de facto* in the position to

introducing a probability of eviction which follows an exponential distribution amounts to increasing the *effective discount rate* of the settler by the value of the exponent."

control the stock of wildlife due to imperfect law enforcement. Hence, the CITES policy may work counterproductively as the investment incentives of the local hunters are still the decisive factor in determining the fate of wildlife. As future benefits from wildlife exploitation is reduced due to lower off-take prices, the competitiveness of wildlife, as compared to that of livestock, is reduced. Thus, as a response the local hunters may increase current wildlife harvesting, in order to convert wildlife “assets” into the now more profitable alternative assets. The consequences for wildlife may be devastating (see chapter 6).

In spite of differences in context, the two papers of chapter 5 and 6 both identify disinvestment and institutional failure as crucial factors determining the fate of wildlife. Indeed, a broad review of the economics of resource and environmental degradation in general, will demonstrate “that there are numerous avenues to resource degradation but only one underlying source” - the insufficiency of investment in appropriate institutional structures (Swanson, 1996, p.25).

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Chapter 2

The Spatial Distribution of Benefits and Costs of Wildlife Management

Moose versus Wolf in Norway

The Spatial Distribution of Benefits and Costs of Wildlife Management

Moose versus Wolf in Norway

by

Jan Tore Solstad
Trondheim Business School
Sør-Trøndelag University College
Jonsvannsveien 82
N-7004 Trondheim
(E-mail: Jan.Solstad@hist.no)

Abstract

The recent recolonisation of the Scandinavian wolf in Norway is widely supported at the national level, but is in conflict with the interests of local farmers due to wolf predation on domestic livestock. To mitigate the livestock losses, the State grants compensatory awards. Hence, the presence of livestock in, or close to, wolf territories also represents a cost for “society at large.” A less recognised but potentially more significant conflict of interest is attached to wolf predation on moose. This may considerably lower the hunting income of local landowners. On the other hand, an abundant moose population causes large social costs in terms of moose-vehicle accidents. The spatial distribution and the institutional structure of the joint moose and wolf management are explored when all these benefits and costs are accounted for. It is concluded that today’s management of moose and wolf seems to serve local interests more than those of “society at large.” Moreover, the establishment of compensatory awards for livestock killed by wolf does not seem to enhance social efficiency, but widens the distributional bias in favour of local interests. Alternatively, the State could buy out the pasture rights of local farmers, giving compensation for lost pasture rights rather than lost livestock.

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1. Introduction

Global experience indicates that wildlife conservation is successful only when wildlife resources generate enough revenue to cover the expenses of their own conservation (du Toit 1995). When wildlife generates revenues for people, e.g. in terms of subsistence hunting, trophy hunting or wildlife tourism, there will be incentives to invest in wildlife. Correspondingly, when wildlife resources generate net costs for people, e.g. in terms of crop damages or predation on domestic livestock, there will be incentives to exterminate wildlife, typically by means of habitat conversion or hunting (Eltringham, 1994; Swanson, 1993).

Moreover, in a world of scarcity and conflict of interest, environmental problems typically stem “from the asymmetry in perspectives on the declining resources, between the local and global communities” (Swanson, 1994, p.147). In the context of biodiversity conservation, Wells (1992) highlights the asymmetrical spatial distribution of benefits and costs of a resource management based on protected areas, like national parks.¹ Broadly speaking, economic benefits of protected areas “are limited on a local scale, increase somewhat on a regional/national level and then become potentially substantial on a transnational/global scale. The economic costs follow an opposite trend, from being locally significant, regionally and nationally moderate, and globally small” (Wells, 1992, p.237).

When local and national incentives to invest in wildlife are diverging, which is the appropriate spatial level of wildlife management? The Malawi principles of the UN Convention on Biological Diversity (CBD) establish that the management objectives are a matter of societal choice, and that management should be decentralised to the lowest appropriate level (Jaren et al., 2003). When deciding which is the lowest appropriate level, the Malawi principles suggest we should “move away from viewing resources in isolation from each other. The dominant paradigm is now to focus on whole ecosystems, not only from the point of view of a wider range of ecological processes, but also from that of a far wider range of stakeholders and interest groups” (Linell, 2005, p.7). Indeed, interaction among species transforms into economic interdependencies among various stakeholders both within and across spatial scales. This must be accounted for.

The case of wildlife management in Norway may serve as an illustration. Although generating significant benefits at the national/global scale in terms of existence value, there is a genuine local fear that the recent recolonisation of the gray wolf will undermine the

¹ Typically, the protected areas approach deprives local communities their traditional rights to utilise local resources, frequently without compensation, while the interests of agents at the national and global level are protected (Marks, 1984; Wells, 1992).

economic basis of communities lying in or close to wolf territories. It is often asserted that local communities are overruled by "society at large," and that local people alone have to bear the costs of wolf conservation (Skogen and Krange, 2003). The same applies to other large predators like bear, wolverine, lynx and eagle. However, does the same picture emerge when a wider range of wildlife and human stakeholders are considered? Taking the large herbivores, like the deer species, quite the contrary may be the case. The moose, for instance, is a highly valued game species in Norway which generate significant benefits to local landowners in terms of hunting. Moreover, the moose represent significant costs for "society at large" in terms of moose-vehicle accidents.

When a wider range of wildlife species and human stakeholders are included, it seems the above asymmetrical spatial distribution of costs and benefits of wildlife is not so evident. Moreover, the predator-prey relationship between some species makes the picture even more complex. To have a balanced analysis, then, both types of wildlife and their interaction must be accounted for, and all relevant human stakeholders must be included.

The choice of objectives and the appropriate spatial level of wildlife management is ultimately a political decision. The present paper seeks to improve the grounds for decision-making by analysing the political economy of wildlife management in Norway. The conflict of scale involved will be explored explicitly, and the most relevant benefits and costs of wildlife - as appropriated by and imposed on various stakeholders - are identified. Based on conventional welfare economics, optimising rules (efficiency criteria) for wildlife management is derived and discussed. Moreover, conflicts with wildlife are social conflicts. More than being conflicts between people and wildlife, they are conflicts between various human stakeholders (Skogen and Krange, 2003). Thus, the problem of wildlife management is institutional in nature and calls for an explicit focus on distribution and property rights.

As the wolf (*Canis lupus*) is by far the most controversial and debated of the large predators, and the moose (*Alces alces*) by far the most important game in terms of hunting, their joint management is chosen as a case. As the moose is the major prey for the wolf, this choice allows for an explicit focus on the challenges associated with interacting species. The next section reviews the institutional structure, the spatial distribution and the historical records and current status of moose and wolf management in Norway. In section 3 the ecological system and today's management practice is modelled. Section 4 describes the benefit and cost functions of moose and wolf, and identifies local and social optimising rules for the joint management. Applying a real world example from the county of Hedmark, the model is illustrated by numerical simulations. Specific functions and data are accounted for in

section 5, while results and discussions are offered in section 6. Finally, some conclusions are drawn in section 7.

2. The Institutional Structure, Spatial Distribution, Historical Records and Current Status of Moose and Wolf Management

In Mid- and Southern Norway, where the whole of the wolf population is located and about 90% of moose hunting takes place, more than 90% of the outlying land is privately owned (Arnesen, 2000). Nonetheless, there are a manifold of other interests and property rights attached to this land. Local farmers have gained prescriptive pasture rights for livestock, and these rights are extended by the establishment of full scale compensatory awards for livestock killed by predators, like wolf. Moreover, the Wildlife Act establishes that wildlife and wildlife habitats are to be managed in a way so that the productivity and biodiversity of nature is preserved. Thus, there are also public rights attached to privately owned outlying land. Furthermore, through various international conventions, as for instance the Bern-convention, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the CBD, there are international rights vested in Norwegian outlying fields as well.² Finally, the Norwegian Wildlife Act establishes that all wildlife in Norway belong to the State. Indeed, the location of wildlife habitats, wildlife stock sizes, and time, place, method and quotas of harvesting of game species are all under control of the State as affirmed by the Wildlife Act. Where hunting is allowed, however, local landowners have the sole hunting rights on their own land.

The above is the *de jure* property rights to wildlife and wildlife habitats. The *de facto* property rights, however, may differ from these due to imperfect law enforcement, to diverging practices, or to existing legal claims being in conflict with each other. In the Norwegian context, the latter two factors are most relevant. Indeed, in contrast to the directives of the Wildlife Act, today's moose management is in practice based on local administration at the municipality level as the hunting quotas are decided by locally elected boards (Olaussen, 2000; Storaas et.al 2001). Moreover, some of the legal claims to wildlife and wildlife habitats are surely in conflict with each other. Thinking of property as a benefit stream and a property right as the capacity to control current and future appropriation of the benefit stream (Bromley, 1991; Demsetz, 1967) - while keeping the duality of rights in mind, saying that what is a property right (*benefit*) for some, is a duty (*cost*) for others - we see, for

² The wolf is included in Appendix II both of the Bern-convention, which lists strictly protected species, and of CITES, which lists species in which trade may be permitted but must be strictly regulated.

instance, that the prescriptive pasture rights of farmers and the moose hunting rights of landowners both may be severely restricted by the legal claims of the public to have wolf in the same areas. Moreover, the public rights associated with the legal protection of the wolf are restricted by the establishment of compensatory awards to farmers for wolf predation on livestock.

When property rights are looked upon as the capacity to control the appropriation of benefit streams, the spatial distribution of benefits and costs and the trends and current levels of moose and wolf populations may together give us some information about the *de facto* institutional structure. The moose represents considerable local benefits in terms of hunting value accruing to local landowners.³ Indeed, the potential meat value of the moose is estimated to be above NOK 370 million annually in Norway (Storaas et.al, 2001).⁴ On the other hand, the moose generates significant social costs in terms of moose-vehicle accidents. These have been estimated to range somewhere between NOK 200-300 million annually (Kastdalen, 1996).

The benefits of the wolf are distributed widely throughout the country. In a national survey, close to 80% express that they are in favour of having a viable wolf population in Norway as long as wolves are no closer than 10 km's from where they live. The same study also concludes that people's willingness to pay for having a viable wolf population in Norway far exceeds the known costs (Dahle et.al, 1987). A more recent survey reports that a majority of all Norwegians agreed (59%) or partly agreed (19%) that the wolf has a right to exist in the country (Linnell and Bjerke, 2002).⁵ Together with the international conventions, this suggests that the recovery of the wolf has significant support both at the national and international level. This is the non-use or existence value of the wolf.⁶

The costs are imposed on local farmers by wolf killing domestic livestock, primarily sheep, grazing in outlying fields. Moreover, having moose as the main prey, wolves may inflict significant costs on local landowners in terms of reduced hunting income. In addition, wolves kill hunting dogs. Furthermore, although the risk of being attacked by wolf is very low in Scandinavia (Linnell and Bjerke, 2002), it is maintained that the fear of living close to

³ Hunting is the main source of income obtained from moose in Norway, and the landowner both holds the right to hunt and to the net income of hunting (Gundersen, 2003; Storaas et.al, 2001).

⁴ NOK 1 ~ USD 0.15 in 2006.

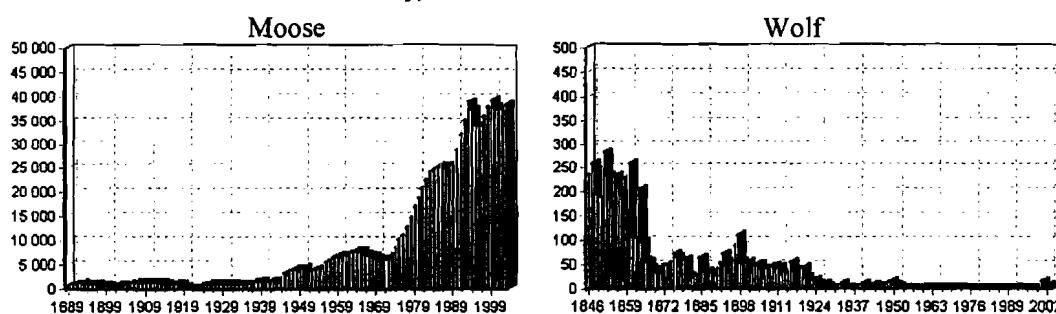
⁵ Only 23%, however, would accept that wolves live within a distance of 10 km from where they live (Linnell and Bjerke, 2002).

⁶ Here, existence value is understood as the value of natural resources that generates utility other than personal use, thus including bequest value (Bishop and Welsh, 1992). Krutilla (1967) was the first to address the notion of existence value in economics. An overview and discussion of valuation methods is offered by Larsson (1993) and Nunes and van den Bergh (2001).

wolves represents a reduction of local people's quality of life. Indeed, among people living in or close to wolf territories, 31% express a clear concern about the safety of being outdoors (Bjerke and Kaltenborn, 2000).

Broadly speaking, then, the moose generates net benefits locally and net costs nationally, while the wolf generates net costs locally and net benefits nationally and globally. Interestingly, harvesting statistics indicate a quite contrasting picture also when it comes to the trends and current levels of moose and wolf populations (see Figure 1).

Figure 1 Hunting statistics (number of harvested animals per year).
Source: Statistic Norway, 2007.



In the 19th century the moose stock was kept relatively low, and in some areas actually driven to extinction.⁷ Primarily, this was due to excessive human harvesting along with a relative abundance of large carnivores. However, mainly as a result of the decline of large carnivores, changes in forestry regimes, and new harvesting strategies, the moose population increased rapidly from the Second World War on (Andersen and Sæther, 1996). In the past few years, the Norwegian summer population of moose has been around 120000, providing a basis for an annual harvesting close to 40000 animals (Statistics Norway, 2007).

In contrast, the first half of the 19th century is considered the last great wolf period in Norway (Pedersen et al. 2003).⁸ By the end of the century the population declined. The relatively low number of wolves continues through the first half of the 20th century and shrinks even more in the 1950s and 60s. The same pattern is seen in Sweden. In the period 1964-1978 no wolf reproduction was registered and the species was functionally extinct both in Norway and in Sweden (Pedersen et al., 2003; Persson and Sand, 1998; Wabakken et al, 2001).⁹ Eventually the negative trend changed, and 1978 is regarded as the starting year of

⁷ The moose was protected by law in large parts of Norway in the 1920s (Andersen and Sæther, 1996).

⁸ Wolves in Norway belong to a joint Scandinavian wolf population.

⁹ As a response, the wolf was protected by law in Sweden in 1966 and in Norway in 1972.

wolf recovery in Scandinavia. Since 1983 there has been successful breeding almost every year in the Scandinavian Peninsula and in 1991 the Scandinavian wolf population started increasing and expanding (Pedersen et.al, 2003; Wabakken et.al, 2001). The estimation of the Scandinavian wolf population in the winter 2006 is 141-160 animals, of which 15-17 are in Norway. Moreover, 24 wolves were located using both sides of the national border between Norway and Sweden (Wabakken et.al, 2006).

During the past 150 years, then, Norway has experienced a dramatically increasing population of moose and a dramatically declining population of wolf. Thus, in a broad historical sense it seems hard to say that wildlife is managed more in accordance with "society at large" than with local interests. In any case, Norwegian authorities have carried out policy measures in order to mitigate the negative impacts the recolonisation of the wolf has on local interests. First of all, the State grants full scale compensatory awards supposed to cover the monetary costs associated with wolf predation on domestic livestock.¹⁰ With respect to wolf killing of sheep, such compensatory awards amounted to an annual average of NOK 2.1 million over the period from 2004-2006 (Directorate for Nature Management Norway, 2007). Moreover, in December 2004 the Norwegian Government legalised licensed hunting of wolves. This means that local hunters with a license are permitted to participate in the hunt.¹¹ In January 2005 the law was applied for the first time when the Norwegian Government decided to have five wolves killed in Hedmark County. The outtake represented 42% of potentially breeding resident wolves in Norway (Wabakken et al. 2005).

3. Ecology and a Model of Today's Management Practice

As the Norwegian wolf population is so low, so strongly influenced by immigrants from Sweden, and under such a strict regulation of the Norwegian wildlife authorities, it does not make much sense to formulate a natural growth function for the wolf stock.¹² This means that the moose-wolf interaction is assumed to be one sided. There is a functional response, meaning that the wolf stock affects the population dynamics of the moose, but the effect of the moose on the wolf population dynamics is ignored. In ecological terms, the wolf stock is thus exogenously given.

¹⁰ Compensatory awards are also granted for bear-, wolverine-, lynx-, and eagle predation on domestic livestock in Norway.

¹¹ The central wildlife authorities determine hunting quotas and the specific area and time period for which the hunting may take place

¹² Due to the strict regulation, the wolf is not able to respond numerically to variations in the moose population (Nilsen et.al, 2005). To account for this, the regulation of the wolf stock will be treated without explicit reference to harvesting and a harvesting function. Thus, the modelling of the moose and wolf population is asymmetrical.

Corresponding with today's management practice, the harvesting quota and the stock of moose are decided locally. The harvesting is assumed to be determined as a fixed fraction of the moose stock (proportional harvesting).¹³ The wolf population, however, is regulated directly by the central wildlife authorities, as affirmed by the Wildlife Act. In biological equilibrium, then, today's actual moose and wolf management in Norway is described by:

$$(1) \quad \frac{dX}{dt} = F(X) - G(Y, X) - M(X) - \alpha X = 0$$

$$(2) \quad Y = Y^0,$$

where X and Y are the size of the moose and wolf stocks (as measured in the number of 'normalised' animals), respectively, at time t (the time index is omitted). $\frac{dX}{dt}$ is the rate of change, $F(X)$ the natural growth function in the absence of wolf predation, $G(Y, X)$ the predation term, $M(X)$ the mortality caused by moose-vehicle accidents, and α is the locally chosen harvesting rate of moose. The natural growth function is supposed to be density dependent following a humped curve increasing to a peak value for an intermediary value of the own stock size. That is, $\frac{dF}{dX} = F_x(X) > 0$ for X less than X^{msy} , and $\frac{dF}{dX} = F_x(X) \leq 0$ for X equal to or above X^{msy} , while $\frac{d^2F}{dX^2} = F_{xx}(X) < 0$ for all X .¹⁴ The wolf predation on moose increases with the number of wolves, $\frac{\partial G}{\partial Y} = G_y(Y, X) > 0$, and is non-decreasing with the number of moose, $\frac{\partial G}{\partial X} = G_x(Y, X) \geq 0$. Moreover, $\frac{\partial^2 G}{\partial X^2} = G_{xx}(Y, X) \leq 0$ and $\frac{\partial^2 G}{\partial Y \partial X} = G_{xy}(Y, X) \geq 0$ is assumed to hold. The number of moose killed in moose vehicle accidents increases with the population size, $\frac{dM}{dX} = M_x(X) > 0$. The sign of $\frac{d^2M}{dX^2} = M_{xx}(X)$ is in general ambiguous, but is assumed to be zero in the numerical analysis. Finally, Y^0 is the number of wolves as decided by the central wildlife authorities.

¹³ See Skonhøft (2006) for a discussion of various moose harvesting schemes.

¹⁴ X^{msy} represents the maximum sustainable yield stock.

Equation (1) defines the isocline of the moose stock, and is assumed to be downward sloping.¹⁵ This implies that $G(Y, X) + M(X) + \alpha X$ intersects with $F(X)$ from below, and thus ensures dynamic stability. In biological equilibrium, an increase of the wolf stock and the human harvesting rate will both unambiguously reduce the stock of moose,

$$\frac{dX}{dY^0} = \frac{G_Y}{F_X - G_X - M_X - \alpha} < 0 \text{ and } \frac{dX}{d\alpha} = \frac{X}{F_X - G_X - M_X - \alpha} < 0.$$

4. Benefits, Costs and Optimising Rules

4.1 The local and social net benefit functions

The benefit and cost terms of moose and wolf hit various stakeholders in various ways. Here, it is distinguished between the local and the social per household benefit and cost of moose and wolf management.¹⁶ Some benefits and costs are shared evenly between local and non-local people, while some accrue to local people alone. The hunting income of moose, ph , where h is the steady-state harvesting and $p > 0$ the corresponding fixed net harvesting price of moose, accrue to local people alone.¹⁷ So do the cost of moose in terms of forest damage, $CM^f(X)$, and the cost of wolf predation on domestic livestock, $CW(Y)$.¹⁸ Moreover, by reducing the hunting income of moose, wolf predation on moose is also a cost solely imposed on local people. Stock benefits in terms of existence value of moose and wolf, $BM(X)$ and $BW(Y)$,¹⁹ and the cost of moose-vehicle accidents, $CM^a(M(X))$,²⁰ accrue, however, to both groups. Thus, letting s represent the local proportion of the total human population, equation (3) gives the local net benefit for $0 < s < 1$ and the social net benefit for $s = 1$.

$$(3) \quad U = ph - CM^f(X) - CW(Y) + s(BM(X) - CM^a(M(X)) + BW(Y)).$$

¹⁵ This means that $\frac{dX}{dY} = \frac{G_Y}{F_X - G_X - M_X - \alpha} < 0 \Rightarrow F_X - G_X - M_X - \alpha < 0$ must hold in equilibrium.

¹⁶ Social benefits and costs pertain to the aggregation over all inhabitants in Norway (both locals and non-locals). Moreover, both local and social net benefits, as measured in monetary terms, are weighted equally over all households. The distinction between locals and non-locals is very broad. In the real world, benefits and costs of moose and wolf are unevenly distributed among various local as well as non-local sub-groups. For example, due to seasonal migration of moose, it is often the case that those landowners appropriating most of the hunting income of moose are not the same ones as those paying most of the costs in terms of forest damage (Skonhøft and Olaussen, 2005; Storaas et al., 2001). Such distributional concerns are ignored in the present paper.

¹⁷ Secondary income for the local community as generated by the hunting activity is ignored (for a discussion, see for instance Storaas et al., 2001).

¹⁸ The granting of compensatory awards to local farmers by the State is not accounted for here.

¹⁹ The income from non-consumptive use, for instance in the form of wildlife viewing, are typically quite low in Norway and is left out of the analysis (Storaas et al., 2001).

²⁰ Only accidents in which the moose is killed are accounted for in the present analysis.

Although the existence value pertains to the mere existence of a species - and thus could be treated as a binary variable reflecting either existence or non-existence - it is assumed to be continuous here. For an endangered species the existence value is assumed to increase gradually - at a decreasing rate - with the size of the stock (Bishop and Welsh, 1992). This is so because the existence value is assumed to be positively related to the probability of survival (viability), and that the probability of survival is supposed to increase with the size of the stock. For a viable species, however, a further increase in the stock will have a negligible effect on the probability of survival and thus no effect on the existence value. In the general case it follows that $BM_x \geq 0$, $BW_y \geq 0$, $BM_{xx} \leq 0$ and $BW_{yy} \leq 0$. The cost of moose in terms of forest damage and of wolf in terms of predation on domestic livestock are both assumed to increase with the respective stocks, $CM^f_x > 0$ and $CW_y > 0$, while the sign of CM^f_{xx} and CW_{yy} is in general ambiguous (but assumed to be zero in the numerical analysis below). Moreover, the cost of moose-vehicle accidents is assumed to increase at a constant rate with the number of accidents, so that $CM^a_M > 0$ and $CM^a_{MM} = 0$.

4.2 Local and social optimal management

Based on the above benefit and cost functions, the optimal management from both the local and the social perspective is identified by the aid of optimal control theory. The harvesting quota of moose, and the moose and wolf stocks are then endogenous variables being determined by dynamic optimisation of the net benefits. Here, $0 < s < 1$ and $s = 1$ define the case of local and social optimisation, respectively. In both cases, the optimal stocks of moose and wolf are found by maximising the present value of the net benefit of equation (4), subject to the ecological constraint of equation (1). δ is the rate of discount. All benefits and costs are measured in monetary units.

$$(4) \quad PV = \int_0^{\infty} (ph - CM^f(X) - CW(Y) + s(BM(X) - CM^a(M(X)) + BW(Y))) e^{-\delta t} dt.$$

The current value Hamiltonian of the problem is $H = ph - CM^f(X) - CW(Y) + s(BM(X) - CM^a(M(X)) + BW(Y)) + \mu(F(X) - G(Y, X) - M(X) - h)$, with h and Y as the control variables, X as the state variable and μ as the shadow price (costate variable) of the moose. An interior solution implies strictly

positive stock sizes and a positive moose offtake at the steady-state. Assuming an interior solution, the first order conditions in terms of the reduced form steady-state equilibrium are given by:²¹

$$(5) \quad p(F_X - G_X - M_X) + sBM_X = p\delta + CM^f_X + sCM^a_M M_X$$

$$(6) \quad sBW_Y = CW_Y + pG_Y.$$

In general, equations (5) and (6) determine simultaneously the equilibrium moose and wolf stocks X^* and Y^* (superscript $*$ denotes the case of an interior solution). The steady-state equilibrium moose offtake then follows as $h^* = F(X^*) - G(Y^*, X^*) - M(X^*)$ when $\dot{X} = 0$. As the Hamiltonian is linear in the control variable h , the dynamics will typically be of the Most Rapid Approach Path (Clark, 1990). This means that when the moose stock is above the steady-state optimum, one should harvest as much as possible in order to attain optimality as fast as possible. By the same reasoning, harvesting should stop when below the steady-state optimum.

For a relatively low moose stock, where the internal rate of return of the stock is above the external rate of return ($F_X - G_X - M_X > \delta$), the left hand side of (5) is the marginal cost of taking one additional moose out of the stock. The first term, where the expression within the bracket represents the marginal growth rate of moose net of wolf predation and mortality caused by moose-vehicle accidents, is the negative effect on the steady-state offtake of moose evaluated at the net harvesting price, p .²² The second term represents the loss in existence value associated with reducing the stock, and is given less weight in the local as compared to the social optimum. The right hand side of (5) is the marginal benefit of taking one additional moose out of the stock. The first term is the opportunity cost of capital (Clark, 1990), that is, the gain obtained by transferring the resource's value to the most profitable alternative investment opportunity, here as represented by the discount rate, δ . The second and third term represent the gain obtained by removing a potentially noxious animal, that is, moose

²¹ If the population dynamics and harvesting of the wolf were formulated explicitly, the reduced form steady-state equilibrium would coincide with that of equations (5) and (6) in the case of a wolf shadow price (costate variable) of zero. In other words, equation (5) and (6) may be interpreted as the optimising rule under the assumption of a zero net harvesting price of wolf.

²² This term represents a benefit when the initial stock is higher and $F_X - G_X - M_X < \delta$.

responsible for forest damage or involved in vehicle accidents. The benefit from reduced moose-vehicle accidents is given less weight in the local as compared to the social optimum.

The left hand side of (6) is the marginal cost of reducing the wolf stock. This loss reflects a reduction in the existence value of the wolf, and is given less weight by the local as compared to the social planner. The right hand side of (6) is the marginal benefits of reducing the wolf stock. The first term is the benefit of removing noxious animals, that is, wolves killing domestic livestock. The second term is the interaction effect. Evaluated at the net harvesting price of moose, this term represents an additional benefit as a lower wolf stock increases the steady-state harvesting of moose.

The second order conditions and the comparative statics of the model when there is an interior solution are outlined in Appendix 1. These give the local and social optimal response to various changes in the external environment. An increase in the rate of discount, for instance, unambiguously reduces the optimal stock of moose and increases the optimal stock of wolf in both of the optimising models. Hence, the familiar result of a single-species harvesting model with a positive net harvesting price applies to the moose (Clark 1990). As the higher discount rate reduces the optimal moose stock, the marginal benefit of reducing the wolf stock in terms of less predation on moose, decreases. That is, for the initial wolf stock, the marginal benefit of increasing the wolf stock will now be higher than the marginal cost. Accordingly, it is optimal to increase the stock of wolf when the discount rate increases.

An increase in the harvesting price of moose has an ambiguous effect on the optimal stock of moose in both of the optimising models. First of all, we have the direct effect associated with the first order condition of equation (5), which is similar to the familiar mechanism of a single-species harvesting model. When the harvesting price increases, the relative importance of the net stock value is reduced as the profitability of harvesting increases. Thus, if the marginal net stock value is negative initially, meaning that the internal rate of return of the stock is larger than the external, $F_x - G_x - M_x > \delta$, the optimal stock of moose increases with a higher harvesting price. Moreover, the marginal cost of wolf preying on the moose increases relatively with the harvesting price of moose. Thus, the direct effect on the moose is strengthened by the interaction effect: To account for the higher marginal cost of wolf, the optimal stock of wolf is reduced. As with the direct effect, this increases the profitability of harvesting - but now through a higher marginal net growth rate of moose - and thus works in the direction of a higher optimal stock of moose. When, however, the marginal

net stock value is positive, $F_x - G_x - M_x < \delta$, the effect on the optimal stocks of moose and wolf is ambiguous.

The effect of a change in s is derived to find how local as compared to social optimisation affects the optimal management of the species. The result is ambiguous, however, and depends on the relative sizes of the marginal cost of the moose in terms of moose-vehicle accidents ($CM^a_M M_x$) and the marginal benefit in terms of the existence value (BM_x). This part of the moose economy is shared equally between local and non-local households, while the rest is entirely a local matter. Thus, if $CM^a_M M_x > BM_x$ the local planner will - in social terms - underestimate a net *cost* component of the moose stock, and choose a stock of moose that is too large. In the opposite case, the local planner will underestimate a net *benefit* component of the moose stock, and choose a stock of moose that is too small. As the marginal existence value of moose presumably will be low for an abundant population, the marginal cost in terms of moose-vehicle accidents will dominate when the number of moose is relatively large. In accordance with externality theory, local optimisation then implies a larger stock of moose and a lower stock of wolf as compared to social optimisation.

5. Specific Functions and Data

The model is applied to the case of Hedmark County. Hedmark is located in the south-east of Norway. It has a human population of about 190 000, constituting 4% of the total number of people in Norway. Covering a total of 27 388 km², Hedmark has roughly 25 000 km² of outlying land after subtracting densely populated areas (0.4%) and farmland (7.6%). Parts of this outlying land serve as habitat for moose and wolf populations, and as Hedmark borders on Sweden, the recovery of the wolf in Norway has in the main taken place here. Consequently, Hedmark is also encumbered with the bulk of the livestock damage caused by wolves in Norway. Indeed, during the period 2004-2006 about 65% of the total number of sheep killed by wolf in Norway was killed in Hedmark (Directorate for Nature Management, 2007).²³ Moreover, Hedmark is the leading forest and moose county in Norway (about 20% of the total Norwegian harvest of moose takes place here) and has the highest number of moose-vehicle accidents (Statistics Norway, 2007).

²³ The Norwegian Parliament agreed on a new wolf management zone in Norway in 2004. Of a total of 22 municipalities in Hedmark, 9 are included in the current wolf management zone. The zone also includes the Counties of Akershus, Oslo and Østfold.

5.1 Specific Functions

The numerical model is represented by a specific natural growth function for moose without wolf predation, a wolf functional response, and a function of moose mortality caused by moose-vehicle accidents as by:

$$(7) \quad F(X) = rX \left(1 - \frac{X}{K} \right)$$

$$(8) \quad G(Y, X) = \begin{cases} \beta XY & \text{for } X < \tilde{X} \\ \beta \tilde{X} Y & \text{for } X \geq \tilde{X} \end{cases}$$

$$(9) \quad M(X) = \gamma X$$

The natural growth function for moose without wolf predation obeys the law of logistic growth, where $r > 0$ is the intrinsic growth rate and $K > 0$ the carrying capacity. With wolf predation, and for relatively low moose densities where $X < \tilde{X}$ for a given habitat area, the functional response is represented by a positive linear function of the moose stock, βXY .²⁴ Empirical evidence suggests, however, that although the wolf kill rate (the number of moose killed per wolf per year, βX) increases with moose density, it flattens out at relatively low densities (Hayes and Harestad, 2000; Pedersen et.al, 2005; Solberg et.al, 2003). Thus, the functional response is independent of the moose stock and given as $\beta \tilde{X} Y$ for $X \geq \tilde{X}$. Finally, the number of moose killed by vehicles is assumed to increase proportionally with the population size at the rate $\gamma > 0$.

Applying the specific functions of equations (7) - (9) in the general moose population dynamics of equation (1), the equilibrium solution of the model will be stable when $r > \beta Y + \gamma + \alpha$ for $0 < X < \tilde{X}$, and when $\frac{K}{r}(r - \gamma - \alpha)^2 > 4\beta \tilde{X} Y$ for $X \geq \tilde{X}$.

The marginal probability of extinction is assumed to decrease with the size of the stock. When the minimum viable population is reached, however, a further increase has no effect on

²⁴ Except from the term representing the mortality caused by moose-vehicle accidents, the model complies with the generalized predator-prey model of Tu and Wilman (1992).

the probability of extinction.²⁵ Thus, the functional forms of the stock benefits of moose and wolf of equations (10) and (11) are chosen to reflect that the existence value increases - at a decreasing rate - with the size of the stock, and reaches its maximum at the minimum viable population level. At or above this level, the marginal existence value is zero.²⁶

$$(10) \quad BM(X) = \begin{cases} (\rho_1 - \rho_2 X)X & \text{if } X < X^{mvp} \\ \rho_1^2/4\rho_2 & \text{if } X \geq X^{mvp} \end{cases}$$

$$(11) \quad BW(Y) = \begin{cases} (\sigma_1 - \sigma_2 Y)Y & \text{if } Y < Y^{mvp} \\ \sigma_1^2/4\sigma_2 & \text{if } Y \geq Y^{mvp} \end{cases}$$

X^{mvp} and Y^{mvp} are the minimum viable population of moose and wolf, and $\rho_1 > 0$, $\rho_2 > 0$, $\sigma_1 > 0$ and $\sigma_2 > 0$ are parameter values reflecting the decreasing marginal existence value and the maximum existence value of the moose and wolf. The maximum existence values of moose and wolf are attained at or above the minimum viable population, and are given by $\rho_1^2/4\rho_2$ and $\sigma_1^2/4\sigma_2$, respectively.

Cost functions are given by equations (12)-(14). Linear cost functions are applied for both species (Boman, 1997). (12) gives the cost of forest damage as a function of the moose stock, (13) the cost of moose-vehicle accidents as a function of the number of accidents where moose are killed and (14) the cost of wolves preying on domestic livestock as a function of the wolf stock, where $\tau > 0$, $\nu > 0$ and $\phi > 0$ are the respective average costs.

$$(12) \quad CM^f(X) = \tau X$$

$$(13) \quad CM^a(M(X)) = \nu \gamma X$$

$$(14) \quad CW(Y) = \phi Y.$$

²⁵ The minimum viable population denotes "the population size below which the probability of extinction is unacceptably high, but at or above which the probability of extinction is reduced to an acceptable level over a given period of time" (Snaith and Beazley, 2002, p.193-94).

²⁶ This assumption is supported by a Swedish contingent valuation study which concludes there is no marginal willingness to pay for stocks beyond the minimum viable population (Boman, 1997). The same study concludes that the willingness to pay for a minimum viable population is independent of the number of wolves for which the minimum viable population is defined.

5.2 Data

Most of the parameter values are based on empirical studies. However, the carrying capacity is fixed in order to fit the harvesting in Today's management with that of the 2006 moose harvesting statistics of Hedmark, while the interaction parameter is fixed to get the wolf kill rate in accordance with empirical findings for the Scandinavian wolf population as a whole.

The notion of viability is usually applied to the Scandinavian wolf population as a whole. However, by signing the UN Convention on Biological Diversity, both Norway and Sweden have agreed to promote the maintenance of viable wolf populations in their natural surroundings (Nilsson, 2003). A mining of the wolf population in Norway thus violates the agreement and undermines the joint responsibilities in the conservation of the Scandinavian wolf. Together with the fact that a relatively large proportion of Norwegians is of the opinion that the wolf has a right to exist in the country, and that their willingness to pay for having a viable wolf population in Norway is relatively large, this substantiates the application of a minimum viable population for the Norwegian wolf alone. As a first approach, the minimum viable population of the wolf is put on a par with the prevailing management goal for wolf in Norway. This means that government failure is assumed away in the baseline case. In section 6.3 below, this assumption is modified. Based on empirical findings and genetic analysis of the Scandinavian wolf population as a whole, a higher minimum viable population is suggested there.

Several studies conclude there are significant differences in the attitudes towards and the willingness to pay for the large predators between people living inside and outside predator areas (Bjerke and Kaltenborn, 2000; Broberg and Brännlund, 2006; Chambers and Whitehead, 2003). Based on these studies, the existence value of wolf for a local household is assumed to be $\frac{1}{4}$ of that of a non-local. The lower value among locals may capture the fear of living close to wolves and the culturally based local resistance to wolf preservation in general (Bjerke and Kaltenborn, 2000; Skogen and Krangle, 2003). To my knowledge, there are no available data on the existence value of moose. In the present analysis, the per household existence value of moose is assumed to be the same among locals and non-locals, and equal to the non-local per household willingness-to-pay for wolf.

A zero discount rate is applied. Thus, the opportunity cost effects are ignored and the externality mechanisms are cultivated. In this case it also makes sense to compare the net benefits of the optimisation models with that of today's management model. If a positive discount rate were used, the equilibrium number of moose would be (equally) reduced in the two optimisation models.

The baseline parameter values are applied to solve the optimising models. The difference between local and social optimal management depends solely on the local (Hedmark) proportion of the total (Norway) number of households. All baseline parameter values are given and accounted for in Appendix 2.

6 Results and Discussion

Table 1 gives the numerical steady-state equilibrium solutions of today's management model and the local (Hedmark) and social (Norway) optimisation models. The table shows solutions for the stock sizes (X and Y), the harvest of moose (αX in today's management model, h in the optimisation models), the number of moose killed by wolf ($\beta \tilde{X}Y$), and the number of moose killed in moose-vehicle accidents (γX). Today's management has a wolf population of 21 animals, which is also supposed to represent the minimum viable population of the wolf (see Appendix 2). The number of moose is 20811, which implies a moose density slightly above 1 per km².²⁷ The annual human harvest of moose is equal to the actual harvest in Hedmark in 2006, that is, 7284 animals (Statistics Norway, 2007). Moreover, wolves and moose-vehicle accidents kill respectively 420 and 520 moose annually. In equilibrium, the above mortality factors imply an annual moose population growth of about 40%.²⁸

The moose stock equilibrium solutions of the optimisation models are in both cases above the level of the flattening out of the wolf kill rate and the minimum viable population. This implies a fixed wolf kill rate of 20 and a zero marginal existence value of moose.²⁹

Table 1. Steady-state equilibrium solutions when $Y^{min} = 21$

	Today's Management	Local Optimisation	Social Optimisation
Y	21	10	21
X	20811	42765	16596
$\alpha X, h$ *	7284 (0.35)	10908 (0.26)	6078 (0.37)
$\beta \tilde{X}Y$	420	200	420
γX	520	1069	415

* Numbers in parentheses are the corresponding equilibrium harvesting rates.

The steady-state equilibrium solutions of Table 1 serve as a basis for estimating various local, non-local and social benefit and cost terms of moose and wolf. In section 6.1, the case of today's management is analysed and discussed. Here, the hypothetical absence of the wolf

²⁷ The average moose density is estimated to be about 0.9 per km² in Hedmark (Solberg et.al, 2003).

²⁸ The mean population growth rate of moose is estimated to be about 40% in Hedmark (Pedersen et al., 2005).

²⁹ Technically, this means that BM_x and G_x are both zero (see section 4.2, equation (5)).

and wolf predation ($Y = 0$) is also considered. Section 6.2 addresses the cases of local and social optimisation, and discusses the management problem in light of externality theory. In section 6.3 the case of government failure is introduced, and the analysis is carried out under the assumption of a higher minimum viable population of the wolf. Indeed, the minimum viable population of the wolf plays a key role in the analysis, and it works solely through the existence value of the wolf. Some notes on the existence value are therefore offered in section 6.4. Finally, the role of property rights is addressed in section 6.5. The State's granting of full scale compensatory awards to local landowners to cover the monetary costs associated with wolf predation on domestic livestock is not accounted for in any of the tables below.

6.1 The Distributional Bias and Conflict: Today's Management Model

Table 2 shows the local, non-local and social benefit and cost estimates of the steady-state solutions of the today's management model. Today's joint moose and wolf management generates a net annual social benefit of about NOK 992 million. Distinguishing between spatial levels, the net annual per household benefit of wolf and moose is NOK 954 locally and NOK 467 non-locally. Thus, we have a ratio of 2 between local and non-local households.³⁰ The distributional bias in favour of local households is first of all due to the landowners' income from moose hunting, amounting to about NOK 64 million annually. By accounting for the establishment of compensatory awards to local farmers for wolf predation on livestock, sharing the costs of NOK 1.7 million equally among local and non-local households, the distributional ratio is slightly increased.

Table 2. Today's Management Model. Local, non-local and social net benefits.

	Local		Non-local		Social	
	Million NOK	NOK per household	Million NOK	NOK per household	Million NOK	NOK per household
Moose	76.7	914	431.0	221	507.7	249
<i>hunting income</i>	64.2	765	0.0	0	64.2	32
<i>existence value</i>	20.6	245	479.4	245	500.0	245
<i>vehicle accidents</i>	-2.1	-25	-48.4	-25	-50.5	-25
<i>forest damage</i>	-6.0	-72	0.0	0	-6.0	-3
Wolf	3.3	40	481.0	246	484.3	238
<i>existence value</i>	5.0	60	481.0	246	486.0	239
<i>livestock killing</i>	-1.7	-20	0.0	0	-1.7	-1
Total	80.1	954	912.0	467	992.1	487

³⁰ If the costs (in terms of killed sheep) of bear, wolverine, lynx and eagle are also included, constituting an average of about NOK 11.5 million annually in Hedmark in 2004-2006 (Directorate for Nature Management Norway, 2007), the net per household benefit locally is reduced to NOK 817, giving a ratio of 1.7.

Under the present assumption of a fixed annual harvesting rate, wolf predation implies both a lower stock and harvesting of moose. If the wolf is exterminated and wolf predation comes to an end ($Y = 0$), it can be shown that the moose population and the annual moose harvest increase by 4008 and 1402, respectively. The corresponding changes in local and social net benefits are reported in Table 3.

Table 3. Today's Management Model. Changes in local, non-local and social net benefits if the wolf is exterminated.

	Local		Non-local		Social	
	Million NOK	NOK per household	Million NOK	NOK per household	Million NOK	NOK per household
Moose	10.8	129	-9.3	-5	1.5	1
<i>hunting income</i>	12.4	147	0.0	0	12.4	6
<i>existence value</i>	0.0	0	0.0	0	0.0	0
<i>vehicle accidents</i>	-0.4	-5	-9.3	-5	-9.7	-5
<i>forest damage</i>	-1.2	-14	0.0	0	-1.2	-1
Wolf	-3.3	-40	-481.0	-246	-484.3	-238
<i>existence value</i>	-5.0	-60	-481.0	-246	-486.0	-239
<i>livestock killing</i>	1.7	20	0.0	0	1.7	1
Total	7.5	89	-490.3	-251	-482.8	-237

Wolf extermination will increase the annual hunting income by NOK 12.4 million and reduce the annual cost of wolf killing sheep by NOK 1.7 million. The loss in moose hunting income as caused by the presence of wolves is thus more than 7 times the cost in terms of lost sheep. As the size of the moose population will increase if the wolf is exterminated, social costs will increase in terms of more moose-vehicle accidents, amounting to NOK 9.7 million annually. Moreover, the annual cost of forest damage is increased by NOK 1.2 million. Hence, for the moose economy alone, the social net benefit associated with exterminating the wolf is only NOK 1.5 million. This means that it would take a wolf existence value of only NOK 3.2 million to make wolf extermination socially unprofitable. In any case, wolf extermination would generate an increase in the local net benefit of NOK 7.5 million, a decrease in the non-local net benefit of NOK 490.3 million, and thus an increase in the distributional ratio from 2 to 4.8.

6.2 Efficiency and Conflict: The Optimisation Model

Table 1 illustrates the severe conflict between local and social interests with respect to moose and wolf management. Local optimality implies a moose stock of about 2.5 times higher than what is optimal from the social perspective. Moreover, social optimality implies a wolf

population more than 2 times that of local optimality. The corresponding annual net benefit terms of the local and social optimal solutions are reported in Table 4 and 5.

Table 4. The Local Optimisation Model. Local, non-local and social net benefits.

	Local		Non-local		Social	
	Million NOK	NOK per household	Million NOK	NOK per household	Million NOK	NOK per household
Moose	100.1	1193	380.0	195	480.1	236
<i>hunting income</i>	96.2	1146	0.0	0	96.2	47
<i>existence value</i>	20.6	245	479.4	245	500.0	245
<i>vehicle accidents</i>	-4.3	-51	-99.4	-51	-103.7	-51
<i>forest damage</i>	-12.4	-148	0.0	0	-12.4	-6
Wolf	2.8	34	349.0	179	351.9	173
<i>existence value</i>	3.6	43	349.0	179	352.7	173
<i>livestock killing</i>	-0.8	-10	0.0	0	-0.8	0
Total	103.0	1227	729.0	373	832.0	408

Table 5. The Social Optimisation Model. Local, non-local and social net benefits.

	Local		Non-local		Social	
	Million NOK	NOK per household	Million NOK	NOK per household	Million NOK	NOK per household
Moose	67.7	807	440.8	226	508.5	250
<i>hunting income</i>	53.6	639	0.0	0	53.6	26
<i>existence value</i>	20.6	245	479.4	245	500.0	245
<i>vehicle accidents</i>	-1.7	-20	-38.6	-20	-40.2	-20
<i>forest damage</i>	-4.8	-57	0.0	0	-4.8	-2
Wolf	3.3	40	481.0	246	484.3	238
<i>existence value</i>	5.0	60	481.0	246	486.0	239
<i>livestock killing</i>	-1.7	-20	0.0	0	-1.7	-1
Total	71.1	847	921.8	472	992.9	487

In monetary terms, a change from a hypothetical local planner to a hypothetical social planner implies an annual loss of about NOK 32 million locally, an annual gain of about NOK 193 million non-locally, and a net annual gain of about NOK 161 million nationwide.³¹ Under the local planner, the local landowners' hunting income net of forest damage is almost NOK 43 million higher than under the social planner. Moreover, under the social planner, the non-local costs in terms of moose-vehicle accidents is almost NOK 61 million lower and the non-local existence value of wolves almost NOK 132 million higher than under the local planner.

³¹ It is assumed that local landowners retain the right to the income from moose hunting when the resources are under the control of the social planner.

Modern welfare economics identifies *efficient* management with the solution of the social planner, that is, the maximisation of *net* value, where the net benefits are weighted equally for all inhabitants. Table 1 indicates that today's moose management represents a moose stock which is about 25% higher than what is optimal from the social point of view, and heads in the direction of local optimality.³² This is not surprising since the moose in practice is under local management in Norway. Given a zero discount rate, conflict is first of all associated with the concept of externalities as applied to local moose management. The hunting income from moose devolves solely on local landowners. However, being spread over the entire population, a large fraction of the costs is external to local managers. Thus, local management generates a stock of moose that is too large in terms of social optimality.³³

However, although differing significantly in terms of the number of moose, the social net benefit of today's management model is not much lower than that of social optimality. Indeed, only NOK 0.8 million can be gained in equilibrium by realising the social optimal solution.³⁴ In efficiency terms, then, there seems to be no strong reason to alter the status quo. In terms of spatial distribution, however, a realisation of the social optimal solution will reduce the local net benefit by NOK 9 million and increase the non-local net benefit by NOK 9.8 million. This illustrates that the concept of "efficiency" is blind to distributional issues.

As the wolf stock is assumed to be under direct regulation and control of the State, and as any form of government failure and illegal activity is assumed away, there are obviously no externalities to internalise with respect to the wolf stock. This follows directly from the model formulation. In this setting, compensatory awards for lost livestock have only distributional effects, which widen the net benefit gap between locals and non-locals. In the next section, the assumption of no government failure is modified.

6.3 The Role of the Minimum Viable Population

The approach of putting the minimum viable population on a par with the current number of wolves may be questioned. Indeed, the current goals for the Scandinavian wolf population are preliminary and only stages on the way to a viable population (Nilsson, 2003). By signing the Bern Convention and the CBD, Sweden and Norway have agreed to promote the maintenance

³² The conclusion is sensitive to the choice of the harvesting rate and the carrying capacity (see appendix 3).

³³ A positive discount rate, representing an opportunity cost of moose, would make it optimal to keep a lower stock of moose. The gap between today's management and the social optimal solution would thus increase. For instance, a discount rate of 0.04 would give a social optimal moose stock of about 12600 animals.

³⁴ This is because the marginal net benefit of moose is relatively small over a relatively large interval. This indicates that the model is quite sensitive to some of the parameter estimates. Indeed, an increase of about 16% in the harvesting price, or a decrease of about 15% in the unit cost of moose-vehicle accidents, would imply that today's management of moose is socially efficient.

of viable populations of species in their natural surroundings. Hence, the estimation of the minimum viable population plays a key role in wolf management. A lower bound for the minimum viable population of wolves is estimated to be 400 individuals by Nilsson (2003).³⁵ This is about 2.5 times higher than the current Scandinavian wolf population. Assuming a fixed geographical distribution of the wolf, the corresponding number of wolves in Hedmark will be about 50. The corresponding solutions of the optimising rules are shown in Table 6.

Table 6. Steady-state equilibrium solutions when $Y^{mp} = 50$

	Today's Management	Local Optimisation	Social Optimisation
Y	21	0	49
X	20811	42765	16596
$\alpha X, h$ *	7284 (0.35)	11102 (0.26)	5509 (0.33)
$\beta \tilde{X}Y$	420	0	980
γX	520	1069	415

* Numbers in parentheses are the corresponding equilibrium harvesting rates.

The higher level of the minimum viable population implies a widening of the gap between local and social optimal levels of the wolf population. Indeed, while social optimisation will give a number of wolves close to the minimum viable population, extermination of the wolf will be the optimal strategy from the local perspective in this case. This is because it now takes a lot more wolves to safeguard the population, so that the marginal existence value of wolves will everywhere be significantly lower than before. Indeed, the marginal local cost of wolf predation on moose and livestock now dominates the marginal local existence value for all stock sizes. Obviously, this implies a much higher level of conflict. Moreover, there is now a deviation of the actual and socially preferred size of the wolf population. In addition to the externality problem associated with the local monitoring of the moose, we now have government failure as an additional channel of inefficiency.

According to this scenario, the Government's decision to hunt down the five wolves in Hedmark in February 2005 moved the number of wolves even farther away from the social optimal stock. Indeed, in terms of lost existence value, the annual social cost of the wolf hunt was NOK 51.5 million.³⁶ By way of comparison, only NOK 0.4 million was gained annually in terms of reduced wolf predation on sheep. Moreover, there are some distributional and efficiency effects working through the moose-wolf interaction. Under proportional harvesting,

³⁵ A recent reporting of a severe inbreeding depression in the Scandinavian wolf population by Liberg et al. (2005), suggests that this number may be considerably higher. See also Wabakken et al. (2001).

³⁶ Calculated as $BW(26) - BW(21)$ under the assumption of $Y^{mp} = 50$.

the wolf hunt increased the equilibrium stock of moose, thus carrying local moose management even farther away from the social optimum. It can be shown that when the economic effects of the increase in the moose stock are all accounted for (increased hunting income and increased costs in terms of more moose-vehicle accidents and forest damage) the social annual net benefit loss of the wolf hunt was about NOK 50.6 million, while the distributional ratio increased from 2.2 to 2.4. Both in efficiency and distributional terms, then, the wolf hunt may have increased rather than reduced the level of conflict of Norwegian wildlife management.

Obviously, the assumption of the minimum viable population plays an important role in the present analysis, and its relevance originates solely from the existence value of the wolf.

6.4 The Role of the Existence Value

Existence values are less tangible than direct use values. Moreover, when aggregated over the entire number of households in a country, they may often be quite large. Among other things, this makes the measuring of existence values for use in public policy questions quite controversial. Indeed, in 1986 the U.S. Department of the Interior issued regulations on the procedures for environmental damage assessment that prohibited the use of existence value unless for the specific cases where direct use values were not measurable (Portney, 1994).

Still, existence values are just as real as any other values. Indeed, rather than asserting that the adding of all inhabitants' individual existence values generates too large a number on the benefit side, it is just as reasonable to claim that, when compared to the existence value, the costs of wolf predation on livestock are almost negligible at the social level (see Table 2). In other words, there seems to be quite a potential for obtaining legitimacy for compensating local people (in some form or other) if only the net benefit of the wolf is optimised at the social level. The social cost is simply so small compared to the willingness to pay for having a viable stock of wolves. If the minimum viable wolf population is 50, the total willingness to pay for securing the wolf stock is about NOK 163 million.³⁷ By way of comparison, the corresponding extra costs imposed on local farmers would be NOK 2.2 million.³⁸ Thus, in this case there should be a fair chance to solve the distributional conflict and obtain a less confrontational wildlife management. In the search for such a solution, however, the role of property rights must be addressed more thoroughly.

³⁷ Calculated as $BW(49) - BW(21)$ under the assumption of $Y^{mv} = 50$. See equation (11) and Table 6.

³⁸ Calculated as $CW(49) - CW(21)$. See equation (14) and Table 6.

6.5 Property Rights and Conflict: The Institutional Approach

The practice of local monitoring of the moose population constitutes an extension of the *de facto* property rights to wildlife of local people. Thinking of property rights as the capacity to control current and future appropriation of benefit streams (see section 2 above), a net annual benefit of moose of about NOK 32 million may potentially be gained locally by having local control of the moose stock (comparing Table 4 with Table 5), of which NOK 9 million are realised today (comparing Table 2 with Table 5). All the same, this benefit is negatively affected by the legal claims of others to have wolf in the same areas, thus limiting the *de facto* property rights of local people. Indeed, according to Table 3, the hunting income of local landowners is reduced by NOK 12.4 million annually due to wolf predation.

Also the prescriptive pasture rights of local farmers are affected negatively by the legal claims of others to have wolf in the same areas. However, the pasture rights are currently protected by full scale compensatory awards. This means that non-locals must pay NOK 1.7 million annually for having wolves on outlying land (Table 2). Indeed, compensatory awards inflict costs on “society at large” and reduce the benefits obtained from the legal protection of biodiversity and endangered species. This represents a shift of *de facto* property rights from non-local to local people.

The most dramatic deviation of *de facto* from *de jure* property rights, however, pertains to the case of government failure. If the minimum viable wolf population is 50 rather than 21, the legal protection of the wolf as an endangered species is by no means fulfilled by today’s management. Indeed, in this case, today’s management practice reduces the benefits obtained from the legal protection of the wolf as an endangered species by NOK 163 million (cf. footnote 37).

More than anything else, the above paragraphs point to the problem that property rights are not well specified or clearly defined. Indeed, the mutual interference of the various legal claims constitutes a very basic conflict within wildlife management. This conflict is surely not reduced by compensatory awards for lost livestock, as the mutually exclusive legal claims are then still present. By this line of reasoning, conflict can be reduced only by making some changes in the *legal assignment* of property rights. As for the case of sheep versus wolf, a straightforward policy recommendation would be for the State to buy out the pasture rights of local farmers. Compensation, then, would pertain to lost pasture rights rather than lost livestock. Of course, it would still be a question of distribution of benefits and costs between the opposing parties. However, when the level of compensation is first agreed on, future conflicts in terms of poorly defined property rights would surely be reduced.

When it comes to the hunting rights of local landowners as affirmed by the Wildlife Act, these are not themselves in conflict with other legal rights. However, today's practice of local moose management may generate externalities in terms of moose-vehicle accidents. If so, a restoration of a policy in compliance with the property rights structure as specified in the Wildlife Act, saying that the control of deer species is to be vested at the level of the State, renders possible a reduction of the moose stock in order to reduce the social costs of moose-vehicle accidents. In this way, the *de jure* property rights are restored and moose management is brought in compliance with social preferences rather than the sectional interests of local landowners. That is, externalities are neutralised and conflict is reduced.

7. Conclusion

The paper analyses the asymmetrical spatial distribution of benefits and costs of wildlife management in Norway along the local - social dimension. The analysis indicates that the net per household benefit of today's joint moose and wolf management are considerably higher for the average local household as compared to the average non-local household. First of all, this is due to the large income that local landowners appropriate from moose hunting. The conclusion is not changed when the local costs in terms of predation by bear, lynx, wolverine, and eagle are included in the account.

Moreover, an abundant stock of moose is more in compliance with a management based on local rather than social optimisation. The explanation may be found with reference to the well known problem of externalities: As local people gain the entire benefits, but pay only a fraction of the costs, there will be local incentives to have a larger stock of moose than what is desirable from a social point of view. As the moose in practice is under local management in Norway, it should come as no surprise that today's number of moose seems to be too high as compared to social optimality. The result is, however, quite sensitive to parameter estimates.

Recent research establishes that the current Scandinavian wolf population is vulnerable and threatened. It has been suggested that the minimum viable population of the Scandinavian wolf is at least 400 animals. Keeping the geographical distribution of wolves fixed, viability thus requires about 50 wolves in Hedmark. If we accept this number, and keep in mind the significant support there is among Norwegians to have a viable wolf population in Norway, the current low number of wolves seems to be more in compliance with local rather than social interests. This may indicate that local stakeholders have a significant influence on wolf management in Norway.

The present paper identifies conflict in three dimensions. Firstly, conflict is associated with the distributional bias between local and non-local households. Secondly, conflict is associated with the extent of externalities and government failure, that is, the deviation between the social optimal management and today's actual management. Thirdly, conflict is associated with vaguely defined property rights, that is, the mutual interference of legal claims among different groups of people, as represented by local landowners, local farmers, and "society at large." Compensatory awards to local farmers, the strict regulation of the wolf population and the practice of local moose management are policies that do not reduce the distributional gap between local and non-local people, do not bring actual management any closer to what is efficient from the social perspective and do not clarify the property rights structure within wildlife management. On the contrary, these may be measures that may intensify conflict rather than reduce it.

An alternative path would be for the State to buy out the prescriptive pasture rights of local farmers in wolf territories. As the aggregated willingness to pay among Norwegians for having viable populations of carnivores seems to be high compared to the local cost of wolf predation on livestock, there should be scope for raising generous compensation for local farmers' loss of pasture rights. This would reduce the conflict between local farmers and "society at large" for the future. Moreover, the State could take more active control of moose management and reduce the number of moose in order to limit social costs in terms of moose-vehicle accidents. This may bring the management closer to what is efficient from the social perspective, and reduce the distributional bias between local and non-local households. Local landowners would still have the sole hunting rights of moose, but the hunting quotas would be determined centrally. There should be no legitimacy problem of such a policy as it complies with the property rights structure as approved by the Wildlife Act.

Appendix 1. Comparative Statics.

In the following $0 < s < 1$ and $s = 1$ correspond with local and social optimisation, respectively. 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. This implies that

$$p(F_{xx} - G_{xx} - M_{xx}) + sBM_{xx} - CM^f_{xx} - sCM^a_M M_{xx} \leq 0,$$

$$(p(F_{xx} - G_{xx} - M_{xx}) + sBM_{xx} - CM^f_{xx} - sCM^a_M M_{xx})(sBW_{yy} - CW_{yy} + pG_{yy}) - (pG_{xy})^2 \geq 0$$

and $sBW_{yy} - CW_{yy} + pG_{yy} \leq 0$. The comparative statics are found by taking the total differential of (6) and (7);

$$(A1) \begin{bmatrix} p(F_{xx} - G_{xx} - M_{xx}) + sBM_{xx} - CM^f_{xx} - sCM^a_M M_{xx} & -pG_{xy} \\ -pG_{yx} & sBW_{yy} - CW_{yy} + pG_{yy} \end{bmatrix} \begin{bmatrix} dX \\ dY \end{bmatrix} \\ = \begin{bmatrix} p & \delta - (F_x - G_x - M_x) & CM^a_M M_x - BM_x \\ 0 & G_y & -BW_y \end{bmatrix} \begin{bmatrix} d\delta \\ dp \\ ds \end{bmatrix}$$

The determinant of the matrix of the left hand side of (A1) ,
 $D = (p(F_{xx} - G_{xx} - M_{xx}) + sBM_{xx} - CM^f_{xx} - sCM^a_M M_{xx})(sBW_{yy} - CW_{yy} + pG_{yy}) - (pG_{xy})^2$
, will be positive in optimum due to the second order conditions for maximum, that is, $D > 0$.

We then obtain;

$$\frac{\partial X^*}{\partial \delta} = \frac{(sBW_{yy} - CW_{yy} + pG_{yy})p}{D} < 0, \quad \frac{\partial Y^*}{\partial \delta} = \frac{p^2 G_{yx}}{D} \geq 0,$$

$$\frac{\partial X^*}{\partial p} = \frac{(sBW_{yy} - CW_{yy} + pG_{yy})(\delta - (F_x - G_x - M_x)) + pG_{xy}G_y}{D} \begin{cases} > 0 \text{ if } F_x - G_x - M_x \geq \delta \\ = ? \text{ if } F_x - G_x - M_x < \delta \end{cases}$$

$$\frac{\partial Y^*}{\partial p} = \frac{(p(F_{xx} - G_{xx} - M_{xx}) + sBM_{xx} - CM^f_{xx} - sCM^a_M M_{xx})G_y + pG_{yx}(\delta - (F_x - G_x - M_x))}{D} \\ \begin{cases} < 0 \text{ if } F_x - G_x - M_x \geq \delta \\ = ? \text{ if } F_x - G_x - M_x < \delta \end{cases}$$

$$\frac{\partial X^*}{\partial s} = \frac{(sBW_{yy} - CW_{yy} + pG_{yy})(CM^a_M M_x - BM_x) - pG_{xy}BW_y}{D},$$

$$\frac{\partial Y^*}{\partial s} = \frac{pG_{yx}(CM^a_M M_x - BM_x) - [p(F_{xx} - G_{xx} - M_{xx}) + sBM_{xx} - CM^f_{xx} - sCM^a_M M_{xx}]BW_y}{D}$$

Appendix 2. Data

In the numerical simulations the intrinsic moose growth rate is given as $r = 0.5$. This is slightly above the rate applied by Olausen (2000) and Skonhøft and Olausen (2005). Moreover, for the given harvesting rate (see below), the carrying capacity is set as $K = 99270$ in order to get the number of moose harvested in today's management model equal to the actual harvest in 2006. Applying 19420 km² as the total habitat area for moose in Hedmark (based on area set aside for hunting in the 2003 hunting quota assignment: Statistics Norway, 2007), this represents a moose density of 5.1 animals per km². Sæther et al. (1992) estimate the carrying capacity for moose in four Norwegian municipalities. The arithmetic mean of these was about 7.6 animals per km². One of the municipalities, Åsnes, is located in the county of Hedmark, and may as such be more representative (e.g. in terms of vegetation) for the present analysis. As the Åsnes estimate was clearly the lowest (1.3 animals per km²), it makes sense to have a lower value for the carrying capacity here. Moreover, Skonhøft (2006) applies a carrying capacity occurring at a moose density of 5.8 animals per km² for the Koppang area of Hedmark. However, as this area is much smaller (600 km²) and well suited for the moose, a lower carrying capacity for the total moose area of Hedmark is reasonable.

The minimum viable moose population is given by $X^{mvp} = 5000$. Snaith and Beazley (2002) refer to empirical findings and genetic analysis which together indicate that 500-5000 breeding individuals are required to ensure a viable moose population in the long term, and they maintain that 5000 individuals should be the minimum target population size for long term conservation efforts. For the wolf, however, the minimum viable population is put on a par with the prevailing management goal for the wolf in Norway. Agreed to by the Norwegian Parliament in May 2004, this goal says that Norway shall have at least three annual wolf breedings within its borders. While the goal was reached in 2004, counts indicate only 2 wolf breedings in 2005 and 2006, all taking place within the borders of Hedmark (Pedersen et al. 2005; Wabakken et al. 2004; 2005; 2006). Since the wolf management zone extends Hedmark, the prevailing number of wolves in Hedmark may be in compliance with the prevailing national management goal. Hence, as a baseline, the wolf winter population of 2006 is taken to represent the minimum viable population. Counts indicate a population of 13 resident wolves in Hedmark by April 2006. Moreover, 16 resident wolves in Hedmark were located on both sides of national (Sweden) and county borders (Wabakken et al. 2006). Letting resident wolves located entirely within the county borders count as one, and the others

as a half, 21 is an approximation for the number of wolves in Hedmark by April 2006. Thus, the minimum viable wolf population for Hedmark is given by $Y^{mv} = 21$.

The annual growth rate of moose in Hedmark is about 40% (Pedersen et al., 2005). Assuming a stable moose population, the sum of the rates of harvesting, moose-vehicle accidents and wolf predation should equal the growth rate. Reports on moose hunting and registered non-harvested mortality of moose - over the hunting seasons from 2003/2004-2005/2006 - are used to estimate the harvesting rate and the mortality caused by moose-vehicle accidents for Hedmark (Statistics Norway, 2007). Together with information about the number of wolves and the wolf kill-rate (see below), these reports indicate harvesting and moose-vehicle collision rates of $\alpha = 0.35$ and $\gamma = 0.025$, respectively.

The mortality of moose also depends on wolf predation. In Scandinavia, the wolf population is low and the moose density is high. Empirical data suggest that variations in the moose population size then do not have much effect on the wolf kill rate (Pedersen et.al, 2005; Solberg et.al, 2003). The flattening out of the wolf kill rate seems to occur at a density of 0.2-0.4 moose per km² (Solberg et.al, 2003). In a Yukon study the estimated number was 0.26 moose per km² (Hayes and Harestad, 2000). Applying the Yukon estimate, while keeping in mind that the total moose habitat area in Hedmark is 19420 km², $\bar{X} = 5000$ is taken to represent the moose population level at which the wolf kill rate flattens out. The interaction parameter applied here is $\beta = 0.004$. This implies a wolf kill rate of 20, which is equal to the estimation of the average wolf kill rate in Scandinavia (Solberg et.al, 2003).

The unit net harvesting price reflects the first-hand purchase value (meat value) of the moose. This value may be appropriated by the landowner by either harvesting the moose him/herself or by hiring out hunting rights to others. The meat value may be seen as the opportunity cost of hiring out hunting rights. In a work by Henriksen and Storaas (1999) the hunting fees are reported to be in the range NOK 30-50 per kg meat. In other works, the first-hand purchase value of moose meat is set down as NOK 60 (Fremming, 2000; Solbraa, 1998) and NOK 70 (Grefsrud and Overvåg, 2004). Adjusting for inflation (Statistics of Norway, 2007) and applying the arithmetic mean, we arrive at NOK 63 per kg (in 2006 prices). Using an average slaughter weight of 140 kg per animal (Fremming, 2000; Grefsrud and Overvåg, 2004), we arrive at a unit net harvesting price of $p = 8820$ (NOK in 2006 prices).

The lower bound estimates of the mean willingness-to-pay per household for a viable wolf population in Sweden (Boman, 1997), for the joint preservation of bear, wolf and wolverine in Norway (Dahle et al., 1987) and for the bear, lynx, wolf and wolverine in

Sweden (Broberg and Brännlund, 2006), are applied to estimate the existence value of wolf. By adjusting for inflation and calculating the arithmetic mean, we arrive at a mean willingness-to-pay for a wolf stock equal to or above the minimum viable population of NOK 238 per household per year in 2006 prices. As the local willingness-to-pay for wolf is assumed to be ¼ of the non-local, local willingness-to-pay per household is given as NOK 61. Based on the number of households in Hedmark and Norway (see below), the aggregate local and social existence value of a viable wolf population are given as $\bar{\sigma}_1^2/4\bar{\sigma}_2 = 5$ and $\hat{\sigma}_1^2/4\hat{\sigma}_2 = 486$ (both in million NOK in 2006 prices), respectively. As we assume no spatial difference in the willingness-to-pay for moose, and that the per household existence value of moose is identical to the per household willingness-to-pay for wolf by non-locals, amounting to NOK 245, we arrive at a social existence value of a viable moose population of about $\rho^2/4\rho_2 = 500$ (million NOK in 2006 prices).

Hence, for a minimum viable population of moose of $X^{mvp} = 5000$ and of wolf of $Y^{mvp} = 21$, the parameters reflecting the decreasing marginal existence value are given by:
 $\bar{\sigma}_1 = 2BW(Y^{mvp})/Y^{mvp} \approx 0.476$ (million), $\bar{\sigma}_2 = BW(Y^{mvp})/(Y^{mvp})^2 \approx 0.011$ (million),
 $\hat{\sigma}_1 = 2BW(Y^{mvp})/Y^{mvp} \approx 46.286$ (million), $\hat{\sigma}_2 = BW(Y^{mvp})/(Y^{mvp})^2 \approx 1.102$ (million),
 $\rho_1 = 2BM(X^{mvp})/X^{mvp} = 200000$ and $\rho_2 = BM(X^{mvp})/(X^{mvp})^2 = 20$.

Annual forest damage caused by moose is estimated to be in the range of NOK 20-40 million (Solbraa, 1998. See also Storaas et.al, 2001). Adjusting for inflation and calculating the arithmetic mean, while assuming a total Norwegian moose stock of 120 000 (Andersen and Sæther, 1996; Gundersen, 2003), we arrive at an average annual cost in terms of forest damage of about $\tau = 290$ (NOK in 2006 prices).

Mysen (1996), Stikbakke and Gaasemyr (1997) and Wahlstrøm (1998) estimate the average cost of moose-car collisions to be NOK 162 600, 85 000 and 110 000, respectively. Moreover, in Jaren et al. (1991) the average cost estimate of moose-train collisions is about NOK 15 000 when the meat and recreational value of hunting is subtracted.³⁹ Adjusting for inflation and calculating the arithmetic mean, we arrive at average costs of moose-car collisions and moose-train collisions of NOK 147 000 and NOK 22 000, respectively (both in 2006 prices). Over the period from 2003/2004-2005/2006, about 60% of the moose-vehicle accidents were moose-car collisions (Statistics Norway, 2007). Thus, the weighted average cost of a moose-vehicle accident is given as $\nu = 97000$ (NOK in 2006 prices).

³⁹ Costs in terms of lost meat- and recreational value of the moose are left out of all these estimates.

In 2004, 2005 and 2006, NOK 15.7, 10.9 and 12.4 million was paid in compensatory awards to farmers in Hedmark for sheep killed by carnivores, respectively (Directorate for Nature Management, Norway, 2007). As wolves were responsible for 28.1, 7.7 and 0.9% of these killings, about NOK 4.6, 0.9 and 0.1 million was paid in compensatory awards for wolf-predation, respectively. Using the same counting method as above, the estimated number of wolves in Hedmark for 2004, 2005 and 2006 is 24, 21 and 21, respectively (Wabakken, P. et.al, 2004; 2005; 2006). This gives a cost per wolf of about NOK 192 000, 43 000, and 5 000 (all in 2006 prices) for 2004, 2005 and 2006, respectively. By calculating the arithmetic mean, we arrive at an annual cost per wolf in terms of compensatory awards for predation on sheep of about $\varphi = 80000$ (NOK in 2006 prices).

A zero discount rate is applied in the numerical analysis, $\delta = 0$. This is done to be able to compare the equilibrium net benefit flows of the optimisation models with that of today's management model. Finally, based on population statistics of 2006, the number of households in Hedmark and Norway is given as 83 945 and 2 036 900, respectively (Statistics Norway, 2007). That is, $s = 0.0412$ when representing the local economy.

Table A1. Baseline parameter values.

Parameter	Description	Value
r	Intrinsic growth rate	0.5
K	Carrying capacity	99 270 (animals)
\bar{X}	The moose stock size by which the wolf kill rate flattens out	5000
X^{mvp}	Minimum viable moose population	5000
Y^{mvp}	Minimum viable wolf population	21
α	Moose harvesting rate	0.35
β	Interaction parameter	0.004
γ	Rate of moose-vehicle accidents	0.025
p	Unit net harvesting price of moose	8820 (NOK)
$\bar{\sigma}_1$	Parameter 1 of the local wolf existence value function	0.476 (million)
$\bar{\sigma}_2$	Parameter 2 of the local wolf existence value function	0.011 (million)
$\hat{\sigma}_1$	Parameter 1 of the social wolf existence value function	46.286 (million)
$\hat{\sigma}_2$	Parameter 2 of the social wolf existence value function	1.102 (million)
ρ_1	Parameter 1 of the moose existence value function	200 000
ρ_2	Parameter 2 of the moose existence value function	20
τ	Average cost of moose in terms of forest damage	290 (NOK)
u	Average cost of moose-vehicle accidents	97 000 (NOK)
φ	Average cost of wolf in terms of killing sheep	80 000 (NOK)
δ	Discount rate	0
s	Local share of the total human population	0.0412

Appendix 3 Sensitivity Analysis

Effects on the equilibrium solutions of a change in the harvesting rate. The value of the carrying capacity is adjusted to have the annual harvest of moose equal to the baseline case.

- A 5% increase in the harvesting rate: $\alpha = 0.3675$ and $K = 114820$:

Table A2. Steady-state equilibrium solutions when $Y^{opt} = 21$

	Today's Management	Local Optimisation	Social Optimisation
Y	21	10	21
X	19820	49464	19195
$\alpha X, h$ *	7284 (0.3675)	12647 (0.2557)	7095 (0.3696)
βXY	420	200	420
γX	496	1237	480

* Numbers in parentheses are the corresponding equilibrium harvesting rates.

The corresponding moose density and moose density at the carrying capacity in Today's management model are 1.0 and 5.9, respectively.

- A 5% decrease in the harvesting rate: $\alpha = 0.3325$ and $K = 88820$:

Table A3. Steady-state equilibrium solutions when $Y^{opt} = 21$

	Today's Management	Local Optimisation	Social Optimisation
Y	21	10	21
X	21908	38263	14849
$\alpha X, h$ *	7284 (0.3325)	9739 (0.2545)	5394 (0.3633)
βXY	420	200	420
γX	548	957	371

* Numbers in parentheses are the corresponding equilibrium harvesting rates.

The corresponding moose density and moose density at the carrying capacity in Today's management are 1.1 and 4.6, respectively.

With a 5% higher harvesting rate, today's management of the moose almost complies with social optimality. On the other hand, if the harvesting rate is 5% lower, today's management of the moose comes closer to what is optimal from the local point of view. Based on the discussion of the estimates of the moose density at the carrying capacity in Appendix 2, it seems reasonable to assume that the harvesting rate and the carrying capacity lie between the two polar cases.

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Chapter 3

Collective Action, Individual Rationality and Common Property Regimes

Collective Action, Individual Rationality and Common Property Regimes

by

Jan Tore Solstad
Trondheim Business School
Sør-Trøndelag University College
Jonsvannsveien 82
N-7004 Trondheim
(E-mail: Jan.Solstad@hist.no)

Abstract

The problem of common property resource exploitation is traditionally associated with the dismal outcome of the static “prisoner’s dilemma game.” Having a one-sided focus on the conflict of interests among the co-owners, neglecting any form of group cohesion and identity, the institutional setting of this approach is severely simplified. The present paper adopts an institutional structure more in compliance with the nature of a common property regime. Appearing in the form of the joint provision of a public good, a unified purpose with which all co-owners act is introduced in the model. The model is formulated as a non-repeated two-stage sequential game, where the co-owners choose their harvesting strategy at the first stage. Then, after observing the resource yield, they choose how much to contribute to the public good at the second stage of the game. Without resorting to the folk theorem or to altruistic preferences, the paper concludes there need be no antagonism between individual rationality and cooperative behaviour in common property resource exploitation when the co-owners are given the opportunity and preferences to contribute some of the resource yield to a public good.

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1. Introduction

Under what conditions will cooperation emerge in a world of egoists without central authority? This question has intrigued people for a long time. And for good reason. We all know that people are not angels, and that they tend to look after themselves and their own first. Yet we also know that cooperation does occur and that our civilization is based upon it. But, in situations where each individual has an incentive to be selfish, how can cooperation ever develop? (Robert Axelrod, 1981, p.3)

The economic literature on common property regimes has traditionally identified the potential for overexploitation of natural resources as the conflict between individual interests within the commons (Gordon, 1954; Hardin, 1968). Scarcity and the ecological characteristics of the resources transform into economic interdependencies among individual exploiters. As these interdependencies are not taken into account, atomistic decision making among self-interested individuals “brings ruin to all” (Hardin, 1968). Along these lines, a typical game theoretic view has been that “the essence of the problem of managing a commons is captured by the prisoner’s dilemma” (Mesterton-Gibbons, 1993, p.106). In other words, in the spirit of Hardin’s (1968) “tragedy of the commons,” the problem of the commons has traditionally been represented by the failure of rational individuals to reach efficient outcomes (see also; Carpenter, 2000; Dasgupta and Heal, 1979; Larson and Bromley, 1990; Sen, 1967).

However, as dynamic considerations are neglected, as communication between players are not allowed, and as no kind of group cohesion and identity among the players are paid attention to, the static prisoner’s dilemma does not provide the players with an institutional setting that is appropriate for analysing rational decision-making in the context of common property regimes. Indeed, in a local common, individuals most often identify quite strongly with the groups in which they belong and do indeed communicate and interact with each other over time in specific, localized physical settings (Baland and Platteau, 1996; Ostrom, 1990; Ostrom, Gardner and Walker, 1994). Hence, in the real world the concept of individual rationality will be exposed to institutional settings of a far more complex nature. In fact, more complex institutional settings are needed to give meaning to terms like cooperation and coordination.

Today it is widely recognized that the “tragedy of the commons” approach refers to an open access regime rather than a common property regime. Accordingly, we are now more concerned with factors that may distinguish the commons from - rather than unite it with - open access. One way to accommodate the shortcomings of the traditional model has been to

abandon the static approach while sticking to the basic assumptions of the prisoner's dilemma game. By drawing on the dynamic concept of repeated non-cooperative games, the conventions on cooperation, like trust and patterns of reciprocity, can be integrated in the analysis. However, even in this case some rather strict assumptions have to be imposed on the model in order to establish that individual rationality complies with cooperative behaviour. For instance, in accordance with the "folk theorem" it is shown that individual rationality may guide players towards a Pareto efficient equilibrium only if the prisoner's dilemma game is repeated an infinite or indefinite number of times, and, then, only when the future benefits and costs are not too heavily discounted (Fudenberg and Maskin, 1986). Hence, even though individually rational players are given the opportunity to coordinate their strategies over time, they are able to overcome the dilemma only under some very strict assumptions.

Another approach is to emphasize the influence of social norms and custom on the utilisation of natural resources (Bardhan, 1993; Basu, 1996; Commons, 1934; Ostrom, 1990; Ostrom and Gardner, 1993; Rabin, 1998). Following Elster (1989, p.99), economists typically "reduce norm-oriented action to some type of optimizing behaviour." Sticking to the basic assumption of the maximising self-interested individual, economists often address the issue of social norms analytically by letting norms "play an important role in shaping individual preferences" (Baland and Platteau, 1996, p.116). In this way, social norms may be analysed by introducing altruistic preferences in a standard neo-classical utility function. Within such a context, it has been shown that individual rationality may generate an outcome which complies with the cooperative solution. Indeed, altruism rooted in social norms may reduce economic overexploitation of natural resources as it neutralises the adverse effect of stock externalities (Skonhøft and Solstad, 2001).

A quite different approach is offered by the contractarian enterprise. Attempting to refine the concept of rationality itself, analysts in this tradition argue that cooperative strategies flow from individual rationality constrained by an ethic, of which, according to some contractarians, itself is grounded in non-moral, rational premises (Sugden, 1993). Different authors have emphasized this aspect in different ways, as for instance Hobbes (1651), Hume (1739), Rousseau (1762), Rawls (1971) and Gauthier (1986), to mention some. Common to these is the application of a rationality concept quite at odds with that of orthodox game theory (Binmore, 1993; 1994).

The present approach takes yet a different route. Adhering to the orthodoxy of individual rationality and to self-interested behaviour, I assert that the rationality of - that is, the explanation for - cooperative strategies may be grounded in the presence of a unified purpose

with which individuals act (Larson and Bromley, 1990, p.235). The unified purpose has the potential to form group cohesion among the members of the commons. The very nature of a common property regime calls for such an emphasis as its two main features are the existence of: (1) a well-defined group of co-owners having the right to exclude others from its territory and the associated income or benefit stream; and (2) an internal structure of rights and duties coordinating individual behaviour within the group (Bromley, 1991; Ciriacy-Wantrup and Bishop, 1975). Larson and Bromley (1990) refer to the first of these the “composition axiom” and the latter the “authority axiom.” By introducing a unified purpose with which the co-owners act, I intend to show that the internal structure of rights and duties, coordinating individual behaviour within the commons, may in fact be the direct result of individually rational decision-making by self-interested co-owners.

The unified purpose is represented by the opportunity to make voluntary contributions to a public good benefiting all members of the commons (Ostrom, Gardner and Walker, 1994, p.8-15). It is assumed that the surplus the co-owners obtain from exploiting a resource may be used for appropriating private goods and/or for contributing to public goods. The decision problem of the individual co-owner then becomes to determine the optimal contribution to a public good as well as the optimal rate of resource exploitation.¹ The novelty of the present approach is that the two problems are treated together rather than separately. Moreover, the individuals are assumed to be utility maximising rather than maximisers of economic surplus. Within this setting, I will show that cooperative behaviour may be triggered under the assumption of individual rationality without resorting to the folk theorem or to altruistic preferences.

The model will be formulated as a two-stage sequential game. At the first stage, the exploitation of the natural resource (harvesting activity) takes place. Then, after observing the resource yield (harvesting surplus), the yield is used for buying private goods and/or contributing towards public goods at the second stage of the game. Each individual takes the (second stage) strategic effects of their own (first-stage) harvesting into consideration. As far as the resulting harvesting decision deviates from that without strategic effects, a strategic move is carried out. Being irreversible and observable, the strategic move acts as a means to influence the behaviour of other players at the second stage of the game (Tirole, 2003).

The standard model of common property resource exploitation is reviewed in the next section. Then, an extended harvesting model is formulated in section 3. Here, the presence of

¹ In Ostrom, Gardner and Walker's (1994) terminology, this relates to the “problem of provision” and the “problem of appropriation,” respectively.

a unified purpose, as represented by the provision of public goods, is introduced. The results are discussed in section 4. Finally, some concluding remarks are offered in section 5.

2. The standard model and “restricted open access”

Common property resource exploitation is traditionally modelled as a game in which each of the co-owners are individually rational players maximising own benefits from exploiting the resource without considering the stock externalities they impose on others (Gordon, 1954; Smith, 1968). The inclination to disregard the costs imposed on others is the dominant strategy among identical players of the game. In the context of a Gordon-Schäfer model of a fishery, Mesterton-Gibbons (1993) shows that the payoff matrix of such a game is similar to that of the prisoner’s dilemma game. Hence, the outcome, being Nash equilibrium, is inefficient as the co-owners do not capture the maximum economic surplus.

In the above scheme, the whole of the economic surplus will necessarily be dissipated if there are an infinite number of exploiters. However, within a common property regime there is a limited number of exploiters and, although inefficient, the regime will always yield a strictly positive surplus. This is illustrated in Figure 1 (for the special case of two co-owners), in which the appropriated economic surplus for co-owner 1 and 2 under biological equilibrium is measured along the coordinate axes.

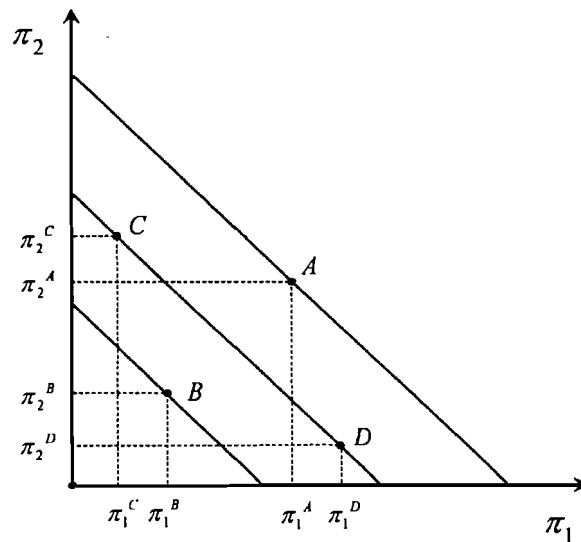


Figure 1 Capturing of economic surplus

Point *B* represents the suboptimal prisoner's dilemma equilibrium (both players defect from cooperation). As the coordinate axes constitute the boundaries in which individual surplus is zero, outcome *B* is seen to be in accordance with the capturing of a positive surplus. Thus, point *B* may be labelled the "restricted open access" equilibrium of the game (see Skonhøft and Solstad, 2001).² In this case we may say there are no internal structures of rights and duties, so that the "authority axiom" is violated while the "composition axiom" is fulfilled (Larson and Bromley, 1990).

The social optimal outcome (the Pareto efficient solution) is represented by point *A* in the figure, i.e., the case when both players choose to cooperate. In this case, we may say there is an internal structure of rights and duties over which the co-owners are in compliance. Hence, both features of a common property regime are fulfilled. Points *C* and *D* depict the case where one of the players defects while the other cooperates. Although yielding positive surplus for both in each case, point *C* represents the worst possible outcome for co-owner 1 and the best possible for co-owner 2, and vice versa for point *D*. The three negatively sloped straight lines running through *A*, *CD* and *B*, representing iso-surplus curves, reflect different distributions of individual gains given particular levels of total surplus. The outward-most iso-surplus curve represents the maximum level of total surplus, and the inward-most curve represents the minimum level of total surplus in the special case of two co-owners.

Figure 1 illustrates that pure defection is a dominant strategy for both players. Player 2 will improve his situation by defecting both when both players initially cooperate (going from *A* to *C*) and when player 1 initially defects and player 2 initially cooperates (going from *D* to *B*), and vice versa. Hence, neither *A*, *C* or *D* represent Nash-equilibrium outcomes. The only Nash-equilibrium is *B*, the suboptimal (Pareto-inefficient) outcome, in which both owners defect from cooperation and total economic surplus is at its lowest value.

For the general case of *n* co-owners, the harvesting game may be formulated mathematically as:

$$\text{Max}_{e_i} \pi_i = ph_i(e_i, e_{-i}) - c_i(e_i) \quad (1.1)$$

where π_i and e_i is the harvesting surplus and the harvesting effort of co-owner *i*, respectively ($i=1,2,\dots,n$). p is the fixed unit harvesting price, and $h_i(e_i, e_{-i})$ and $c_i(e_i)$ the harvesting

² The case of "restricted open access" is labelled "modified privatization" by Buchanan and Yoon (2001, p.398).

function and the effort cost function of co-owner i , respectively. The shape of the individual harvesting function depends on the biological properties of the resource and the harvesting technology. When each co-owner maximises own economic surplus under biological equilibrium and treats the effort of all the $(n-1)$ other co-owners as given so that the solution concept is of the Nash-Cournot type, we obtain the "restricted open-access" solution (corresponding to point B in the case of two co-owners in Figure 1).

The socially optimal (Pareto efficient) effort for co-owner i , however, is obtained when the total economic surplus of all n co-owners is maximised (corresponding to point A in the case of two co-owners in Figure 1):

$$\text{Max}_{e_i} \sum_{i=1}^n \pi_i = \sum_{i=1}^n (ph_i(e_i, e_{-i}) - c_i(e_i)). \quad (1.2)$$

3. The extended harvesting model

In the extended harvesting model co-owner i is supposed to allocate the harvesting surplus between the appropriation of a private good (y_i) and the contribution to a public good (z_i). In general, we may think of public goods in the form of e.g. defence and education here. As a special case, public good provision will be put on a par with the covering of the (transaction) costs of economic organisation.

The model is formulated as a two-stage game of complete but imperfect information: All co-owners simultaneously choose harvesting effort and then, after observing each others harvesting surplus, they simultaneously choose the amount to spend on the private and/or public good. Assuming that the whole harvesting surplus is spent, and letting prices equal one, the budget restriction of co-owner i becomes:

$$\pi_i = y_i + z_i. \quad (2.1)$$

While co-owner i 's consumption of private goods amounts to his own spending on private goods, i 's consumption of public goods equals the total provision of public goods by all of the co-owners. Suppose the n co-owners have identical non-separable utility functions as given by³:

³ The co-owners need not be identical with respect to harvesting technology. That is, the harvesting surplus may vary among the co-owners.

$$u_i(y_i, z) = Ay_i^\alpha z^\beta, \quad (2.2)$$

where $z = \sum_{i=1}^n z_i$. $A > 0$, $\alpha \geq 0$ and $\beta \geq 0$ are parameters of the utility function. When $\alpha > 0$ and $\beta > 0$, individual utility is increasing with both types of goods.⁴

Using backward induction, the second-stage Nash-equilibrium is derived for each feasible outcome of the first-stage game. Given the second-stage optimising behaviour, the Nash-equilibrium of the first stage is derived. That is, the individual co-owner anticipates his own and others optimal contribution to the public good at the second stage, and applies this to find the optimal harvesting effort at the first stage.

Given the budget restriction of equation (2.1), the individual utility of equation (2.2) is maximised with respect to the public good contribution, z_i , as in:

$$\text{Max}_{z_i} u_i = A(\pi_i - z_i)^\alpha z^\beta. \quad (2.3)$$

The first order condition for individual utility maximisation with respect to the public good contribution, given the harvesting surplus, is:

$$\frac{\partial u_i}{\partial z_i} = -\alpha A(\pi_i - z_i)^{\alpha-1} z^\beta + \beta A(\pi_i - z_i)^\alpha z^{\beta-1} = 0. \quad (2.4)$$

For a given harvesting surplus, then, the contribution to the public good resulting from individual optimisation at the second stage of the game reads:

$$z_i = \frac{1}{\alpha + \beta} (\beta \pi_i - \alpha z_{-i}). \quad (2.5)$$

The Nash-equilibrium contribution to the public good of individual i then becomes:

⁴ In this case, the provision of the public good is a prerequisite for obtaining utility from consuming the private good, and vice versa. This stems from the use of a non-separable utility function. However, the non-separable specification of the utility function is not essential for the conclusions of the analysis. Indeed, it can be shown that the use of an additive separable utility function, as for instance $u_i(y_i, z) = \ln(1 + \alpha y_i) + \ln(1 + \beta z)$, yields qualitatively the same results.

$$z_i^* = \frac{1}{n\alpha + \beta} \left(((n-1)\alpha + \beta)\pi_i - \alpha\pi_{-i} \right). \quad (2.6)$$

Thus, co-owner i has incentives to contribute more to the public good if his own harvesting surplus increases, and less if the surplus and the public good provision of others increase. This complies with standard public good theory.

Given the Nash-equilibrium solution of equation (2.6), individual utility is now maximised with respect to harvesting effort at the first stage:

$$\text{Max}_{e_i} u_i = A \left(\pi_i - z_i^* \right)^\alpha \left(z_i^* \right)^\beta. \quad (2.7)$$

Inserting z_i^* gives:

$$\text{Max}_{e_i} u_i = A \left(\frac{\alpha}{n\alpha + \beta} \sum_{i=1}^n \pi_i \right)^\alpha \left(\frac{\beta}{n\alpha + \beta} \sum_{i=1}^n \pi_i \right)^\beta. \quad (2.8)$$

Individual utility maximisation with respect to harvesting effort now complies with maximisation of the joint harvesting surplus as in equation (1.2). In other words, the Nash-equilibrium harvesting effort of the first-stage game coincides with social optimality (the Pareto efficient solution). Indeed, as long as it is optimal for the co-owners to contribute a positive amount of the harvesting surplus to the public good, individual utility maximisation generates Pareto efficiency in the harvesting game.⁵

The optimising rule says to allocate the surplus between private- and public good consumption so that the marginal utilities of consumption are equalised. Thus, the shape of the utility function determines the optimal contribution to the public good, z_i^* . Although there is no inefficient harvesting, there is still a free-rider problem in the provision of the public good.

⁵ It can be shown that this result also holds for the additive separable utility function in footnote 4.

Social optimality, or the Pareto efficient contribution to the public good, is derived by maximising the sum of individual utility over all n co-owners subject to the individual public good provision:

$$\text{Max}_{z_i} \sum_{i=1}^n u_i = \sum_{i=1}^n \left(A(\pi_i - z_i)^\alpha z_i^\beta \right). \quad (2.9)$$

Assuming that the co-owners are identical - both with respect to harvesting surplus and utility functions - the individual optimal public good provision of equation (2.5) and the solution of the social optimal public good provision derived from equation (2.9) are respectively:

$$z_i^* = \frac{\beta}{n\alpha + \beta} \pi_i \quad (2.10)$$

$$z_i^{so} = \frac{\beta}{\alpha + \beta} \pi_i. \quad (2.11)$$

The Nash-equilibrium public good provision (z_i^*) is unambiguously positive for a definite number of identical co-owners as long as $\beta > 0$. That is, as long as the public good generate some minimum of utility for the individual co-owner, there will be no inefficiency gap in the harvesting activity. However, the Nash-equilibrium public good provision will be smaller than what is socially optimal (the Pareto efficient solution z_i^{so}), and the inefficiency gap increases with the number of co-owners.

When $\alpha > 0$ and $\beta = 0$, the public good is neither utility generating nor a prerequisite for obtaining utility from private goods. Nothing will now be provided for the public good and the harvesting will be inefficient in the Pareto sense. In this case, the harvesting model comes down to the static prisoner's dilemma game. Hence, the traditional representation of the problem of the commons, as given by equation (1.1), is a special case of the extended harvesting model. In contrast, when $\alpha = 0$ and $\beta > 0$, meaning that a market for appropriating utility generating private goods is absent, it is both individually and socially optimal to contribute all the surplus to the public good. When the consumption of private goods is no option, self-interested behaviour and individual optimisation generate Pareto-efficiency in the provision of the public good as well as in the harvesting activity. In the

general case when α and β are both positive, and for a given $n > 1$, the inefficiency gap in the provision of the public good is smaller the lower α is as compared to β .

4. Discussion

When the two decision problems are combined, the inefficiency gap in terms of drawing too heavily on natural resources disappears as long as individuals prefer to contribute a minimum to the public good. In the case of two co-owners, this corresponds to solution A in Figure 1. The underlying mechanism is as follows: It is now in co-owner 1's best interest to act in a way so that the harvesting surplus of co-owner 2 increases. Firstly, this makes co-owner 2 contribute more to the public good. Secondly, co-owner 2's increased contribution to the public good means that co-owner 1 can contribute less to the public good, and thus spend more on the private good. Both effects add utility to co-owner 1. Moreover, as a higher surplus of co-owner 1 likewise induces co-owner 2 to contribute less to the public good, co-owner 1 should make some limitation on own surplus. Altogether, the maximisation of individual utility in the harvesting game requires that co-owner 1 put some weight on the harvesting surplus of co-owner 2 at the expense of own surplus. Indeed, individual incentives to increase the harvesting effort beyond what is socially optimal are completely removed. This result also holds for the general case of n co-owners.

Thus, incentives to cooperate are generated among the co-owners as they have a common interest - or a "unified purpose" - in the provision of the public good. The self-interested, rational individual executes forbearance in harvesting as their fellow co-owners appropriation of economic surplus matters in the provision of public goods.⁶

The decision to restrict own harvesting effort to the level of Pareto efficiency may be given an interpretation within the framework of strategic moves. In a two-stage model, a strategic move is an irreversible and observable "investment" carried out at stage one in order to influence the action of the players at stage two (Tirole, 2003). Within the field of industrial organisation, it has been developed a taxonomy of such strategies. These are based on whether the "investment" makes the investor tough or soft, whether the "investment" is supposed to deter or accommodate entry of rivals, or whether the decision variables of period two are strategic substitutes or strategic complements (Tirole, 2003).⁷

⁶ In Commons (1934, p.88) terminology, forbearance is the exercise of a limited degree of an individual's potential physical or economic power.

⁷ An investment that makes the investor tough/soft is one that affects the profit of competitors negatively/positively. Moreover, the decision variables are strategic substitutes when the reaction functions are negatively sloped and strategic complements when the reaction functions are positively sloped (Tirole, 2003).

Conveyed to the present context and in the case of two co-owners, we may consider the strategic move as co-owner 1 “investing” in the harvesting surplus of co-owner 2. That is, in the harvesting game, co-owner 1 acts in order to increase co-owner 2’s surplus at the expense of own surplus.⁸ This will increase the utility of co-owner 2. Hence, the “investment” makes co-owner 1 soft. Moreover, the decision variables at the second stage of the game, z_i , are strategic substitutes. This is so because co-owner 1 optimally reduces his own contribution to the public good when co-owner 2 increases his, and vice versa. That is, the reaction functions are negatively sloped. Finally, in the present context we must understand the strategic move as a strategy of accommodation.

Compared to a situation where co-owner 2 does not observe the strategic move of co-owner 1, it is evident that co-owner 1 should “invest” more in the surplus of co-owner 2. According to the strategic taxonomy, then, the strategic move may be considered a “Lean and hungry look” strategy (Tirole, 2003, p.327). Hence, the socially optimal outcome of the harvesting game is firmly based on the strategic considerations of self-interested and individually rational utility maximisers. There is no antagonism between collective and individual rationality. Indeed, the strategic move of a fully self-interested individual complies entirely with the harvesting behaviour of an individual with completely altruistic preferences (see Skonhøft and Solstad, 2001).

In the general case of $\alpha > 0$ and $\beta > 0$, a positive amount of each type of good is required in order to obtain utility from the other. This specification of the model may be given the following interpretation: To have an efficient market exchange of private ownership, a complex structure of rules and conventions are required to reduce the individual transaction costs. Being non-rivalous in consumption and non-excludable, such institutional arrangements have the characteristics of a public good (Bromley, 2006). Thus, to be at all able to make beneficial exchange of private goods at the market, a minimum of contributions to the institutional arrangements (the public good) is required. Indeed, “markets cannot possibly exist without an institutional structure in place” (Bromley, 2006, p.46). This is to say that the public good is essential for appropriating and enjoying any utility at all from private goods. Moreover, the public good itself generates utility only indirectly through the appropriation of private goods.

⁸ How this may be done depends on the characteristics of the harvesting model. If we assume a Gordon-Schäfer harvesting model in biological equilibrium, the choice of a harvesting effort of exploiter 1 below that of the Nash-equilibrium increases exploiter 2’s harvesting surplus and reduces that of exploiter 1. The net effect is, however, positive (see for instance Skonhøft and Solstad, 2001).

With this in mind, consider the standard neoclassical assumption of zero costs of operating competitive markets (Williamson, 1985). In the present model, this falls in line with the special case of $\alpha > 0$ and $\beta = 0$, where utility may be obtained from purchasing the private good without contributing anything to the public good. As shown above, the outcome of the harvesting game is then inefficient in the Pareto sense. This means that the neoclassical simplifying assumption of the institutional structure - as here in terms of the neglected costs of economic organisation - has a serious impact on the behavioural predictions of the model.

5. Concluding remarks

In this paper I have emphasized the institutional perspective of common property management. I have argued that the institutional context of common property management has an impact on the nature of interaction within the regime. By introducing the presence of a unified purpose with which the members of the common property regime act, here as represented by the joint provision of a public good, the paper adds new theoretical insight to the conventional understanding of common property resource exploitation. One specific aim of the paper has been to question the conventional wisdom that there is an antagonism between individually rational behaviour and cooperative behaviour in the context of common property management. The arguments have been put forward within the framework of non-cooperative game theory.

The main conclusion is that self-interested, rational individuals become less inclined to mine jointly exploited resources when they are given the opportunity and preferences to contribute some of the resource yield to a public good. A cooperative structure emerges in the harvesting game in the form of individual execution of forbearance of harvesting opportunities. The unified purpose transforms into an interaction between the members of the commons in which the mutual benefits of cooperation are realized. The emergence of a cooperative structure reveals itself as a performance of collective action, that is, individually rational agents conforming to patterns of behaviour which promote the interests of the collective.

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Chapter 4

Exploiting a Local Common: Egoistic vs. Altruistic Behavior

Exploiting a Local Common: Egoistic vs. Altruistic Behavior

ANDERS SKONHOFT

Norwegian University of Science and Technology

JAN TORE SOLSTAD

Sør-Trøndelag University College

Abstract *The paper analyzes the exploitation of a local common where the behavior is steered by altruism rooted in social norms. The analysis is illustrated by using the Gordon-Schäfer model of a fishery. We start by reviewing the standard results when all exploiters are purely egoists; i.e., when own utility depends only on own profit. Under the assumption of identical harvesting efficiency for all owners, we then introduce social norms and find the consequences for the resource utilization and welfare under various degrees of altruism. It is demonstrated that more altruism generally leads to less harvesting effort, less economic overexploitation of the resource stock, and increased resource rent. In a next step, we open up for differences in harvesting technology. It is shown that a high degree of altruism, in addition to a large efficiency gap among the owners, restricts the possibility of an exploitation scheme where all owners participate in the harvesting activity. The possibility of a two-channel efficiency improvement as a result of more altruism is also demonstrated.*

Key words Bioeconomic analysis, local commons, norms.

Introduction

Referring to the ‘conventional wisdom’ among economists about property rights, Bromley (1989, pp.186–87) notes that, “when resource destruction is observed in settings of joint ownership and control it is the institutional arrangements (joint responsibility) that is immediately said to be at fault.” Much in line with Ostrom (1990) he claims that, “in practice, ‘the tragedy of the commons’ metaphor deflects analytical attention away from the actual social arrangements able to overcome resource degradation and make common property regimes viable” (Bromley 1991, pp. 22–23). This flaw in the conventional economic analysis of common property resources can be traced back to the use of very simplistic behavioral and institutional assumptions where, among others, people are supposed to be individually and instrumentally rational, entirely self-interested, and totally unaffected by social norms and the particular institutional arrangement in place. However, empirical and experimental studies suggest that social norms and the prevailing institutional arrangement play a crucial role for individual motivation and behavior in local resource management

Anders Skonhøft is a professor in the Department of Economics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway, email: anders.skonhøft@sv.ntnu.no. Jan Tore Solstad is an assistant professor at Trondheim Business School, Sør-Trøndelag University College, N-7004 Trondheim, Norway, email: Jan.Solstad@aoa.hist.no. Anders Skonhøft was corresponding author. This research was supported by grants from the Norwegian Research Council through the Biological Diversity Program and the Man and Biosphere Program. We are grateful for constructive comments from two referees.

(Bardhan 1993; Ostrom and Gardner 1993; Ostrom 1990; Rabin 1998; Wade 1987).

In the following analysis, we aim to correct for this misconception. Social norms are, therefore, assumed to influence individual behavior. Hence, common property resource management is distinguished from that of the open access. Contextually, the sort of resource management settings we have in mind fall within Ostrom's (1990, p. 26) notion of small-scale, common-pool resources (CPRs), as for instance 'inshore fisheries, smaller grazing areas, groundwater basins, irrigation systems, and communal forests.' These resources are particularly essential for people living in the poor regions of the world (Dasgupta and Mäler 1995), and referring to FAO-statistics, Ostrom (1990, p. 27) maintains that about 90% of the world's fishermen and over half of the fish consumed each year are captured by the small-scale, inshore fisheries. Accordingly, improper understanding and policy failures attached to the management of these resources may have far reaching effects.

Two main features distinguish a local common property regime from open access. Firstly, there is a specified 'small' number of owners that, as a group, has the exclusive rights to appropriate the resource under consideration and, secondly, there is an institutional structure of individual rights and duties within the group of owners in which individual behavior is in compliance (Ciriacy-Wantrup and Bishop 1975; Bromley 1991). Hence, a local common is more than an accidental collection of independent individuals; it is a group of people in which the individual members relate to each other according to specific conventions on cooperation and coexistence, like social norms, group identity, trust, and patterns of reciprocity. These are all part of the social and institutional capital that accumulates over time within well-defined local commons (Baland and Platteau 1996; Ostrom 1990; Seabright 1993). In the same way, we hold that *altruism*, being rooted in these conventions, and in social norms in particular, is a result of the same historical process. Thus, by including altruism in the analysis, we acknowledge the crucial role played by norms and institutions in the economy of local common property management.

Social norms may trigger a variety of behavioral motivations. Our analysis is confined to those fitting along an egoism-altruism axis, on which complete egoism and complete altruism are the polar cases. Basically, there are two ways of addressing the issue of social norms analytically. Firstly, norms may be treated as 'binding constraints limiting the choices of a maximizing self-interested individual,' and secondly, they may 'play an important role in shaping individual preferences' (Baland and Platteau 1996, p. 116). We will adopt the latter in our treatment of altruism rooted in social norms, and the egoism-altruism distinction will be integrated in the preference structure of the individual agents. Based on this concept, our aim is to explore how the level and distribution of altruism among individuals may influence the economy of local common resource management. The various outcomes are evaluated in terms of effort use, resource utilization, and welfare, and the reasoning is illustrated by using the Gordon-Schäfer model of a fishery, where the solution concept all the time is of the Nash-Cournot one-shot game type.¹ We then analyze how the introduction of altruistic preferences eliminates inefficiencies in the resource management of the most pessimistic of all institutional settings, the one represented by static, non-cooperative games based on strict self interests.

As a background for the analysis, we start in the next section by reviewing the fairly standard results of the Gordon-Schäfer model when all exploiters are purely egoists, and we have what we will refer to as 'restricted open-access.' In the section that follows, we introduce social norms and analyze the resource exploitation under

¹ Hence, although conventions on cooperation are indirectly accounted for through the inclusion of altruism in the preferences of the individuals, the game theoretic concept adopted is entirely noncooperative.

various degrees of altruism. In the next section, the special case when the co-owners practice the same degree of altruism and, therefore, have the same preferences, are analyzed. Finally, we study what happens when the exploiters use different harvesting technologies and the harvesting efficiency is different.

The Standard Gordon-Schäfer Model

When the number of exploiters is explicitly considered, the basic relationships of the Gordon-Schäfer model (see, *e.g.*, Mesterton-Gibbons 1993) are given by:

$$dX/dt = F(X) - \Sigma h_j \quad (1)$$

$$F(X) = rX(1 - X/K) \quad (2)$$

and

$$h_i = qe_i X. \quad (3)$$

Equation (1) is the population dynamics of the resource (the fish stock) with X as the stock size at time t (the time index is omitted), $F(X)$ is the natural growth function and h_j is the harvesting of exploiter j , $j = 1, \dots, n$ and where n is fixed. The natural growth function [equation (2)] is of the logistic type, where r is the maximum specific growth rate, and K is the carrying capacity. Finally, equation (3) yields the Schäfer harvesting function with e_i as the effort and q as the catchability coefficient. Consequently, in the present setup, all owners are assumed to have identical catchability coefficients, thus being equally efficient in harvesting and homogeneous in endowment (see below). This assumption is relaxed later on.

The current profit of exploiter i is now $\pi_i = (ph_i - ce_i)$, where p is the given market price of the resource and c is the unit effort cost, also assumed to be given and fixed. Combining the above equations when $dX/dt = 0$, gives $X = K[1 - (q/r)\Sigma e_j]$. When substituting into the harvesting function [equation (3)], we obtain $h_i = qK[1 - (q/r)\Sigma e_j]e_i$. The profit, or the resource rent, of exploiter i under biological equilibrium is, therefore, $\pi_i = pqK[1 - b - (q/r)\Sigma e_j]e_i$, where $b = c/Kpq$. $b < 1$ must hold to secure a positive profit and hence, a positive harvesting activity.

When every fisherman maximizes profit under biological equilibrium and treats the effort of all the $(n - 1)$ other exploiters as given so that the solution concept is of the Nash-Cournot type, we obtain the open-access solution under the assumption of a fixed number of exploiters. The equilibrium effort of owner i is then given as:

$$e_i^{roa} = r(1 - b)/q(n + 1). \quad (4)$$

Equation (4) represents the *restricted open-access* effort (denoted by superscript 'roa'), emphasizing that the property relations between the exploiters are the same as in the traditional notion of open access, except from the constraint imposed on the number of agents. The total effort of the n fishermen follows as $E^{roa} = nr(1 - b)/q(n + 1)$. Substituted into the profit function, the profit of exploiter i reads $\pi_i^{roa} = Kpr(1 - b)^2/(n + 1)^2$, while the total profit is $\pi^{roa} = Kprn(1 - b)^2/(n + 1)^2$. Hence, contrary to the traditional concept of open access, there will always be a positive economic rent in the restricted open access case; *i.e.*, the rent will never be entirely dissipated. The equilibrium stock will be $X^{roa} = K(1 + nb)/(n + 1)$. For more details, see below.

The restricted open-access solution can be compared to the Pareto efficient solution when the total resource rent $\pi = \sum \pi_i$ is maximized so that the stock externalities are internalized. The effort use of exploiter i is then given by:

$$e_i^s = r(1 - b)/2qn \quad (5)$$

(superscript 's' denotes overall optimality). The total effort follows as $E^s = r(1 - b)/2q$, which is independent of n because the harvesting function is linear in the effort use. Moreover, we find that the total resource rent reads $\pi^s = Kpr(1 - b)^2/4$, and the equilibrium stock is $X^s = K(1 + b)/2$. E^s is below E^{na} for all $n > 1$, while X^s is above X^{na} , and the discrepancy increases when n shifts up because of more stock externalities. All these results are well known (see Mesterton-Gibbons 1993).

Exploitation Under Various Degree of Altruism

The above solution was obtained when the behavior of every exploiter was steered by strict egoism; own utility depends only on own profit. This is the restricted open-access solution because there are no social norms governing the individual exploitation of the resource. However, as discussed in the introduction, a local common property regime is characterized by having a structure of individual rights and duties within the group of owners in which the individual members relate to each other according to specific conventions on cooperation. These social norms are now embedded in the model by changing the assumption of purely egoistic behavior with altruistic behavior.²

The various degree of altruism will be reflected by the weight put on the well being of the others relative to own well being. The utility of owner i is, therefore, now a weighted sum of own profit and the profit of the other exploiters. We use the specific functional form $U_i = (1 - \mu_i)\pi_i + [\mu_i/(n - 1)]\sum \pi_j$, where $i = 1, \dots, n$ and $j = 1, \dots, i - 1, i + 1, \dots, n$. The (exogenous) weight μ_i is assumed to be in the domain $[0, (n - 1)/n]$ and a higher μ_i means more altruism. If the weight is equal to $(n - 1)/n$, we define owner i to be *completely altruistic*, and hence, $U_i = (1/n)\sum \pi_j$, where $i = 1, \dots, n$ and $j = 1, \dots, n$. On the contrary, the model coincides with the standard Gordon-Schäfer model when $\mu_i = 0$; *i.e.*, when there is *pure egoism* and the preferences are given by $U_i = \pi_i$.³

To obtain analytical results, we consider only two exploiters. The utility functions are then:

$$U_1 = (1 - \mu_1)\pi_1 + \mu_1\pi_2 \quad (6)$$

and

$$U_2 = (1 - \mu_2)\pi_2 + \mu_2\pi_1. \quad (7)$$

For owner 1, the utility writes $U_1 = pqK[1 - b - (q/r)(e_1 + e_2)][(1 - \mu_1)e_1 + \mu_1e_2]$ when using equations (1)–(3), and $U_2 = pqK[1 - b - (q/r)(e_2 + e_1)][(1 - \mu_2)e_2 + \mu_2e_1]$ for

² Becker (1976; 1981) and Kurz (1978), among others, discuss the underlying individual motives to act altruistically in other contexts (*e.g.*, within the family).

³ The possibility of 'overaltruism': *i.e.*, the case when μ_i is in the domain $(n - 1/n, 1]$ is therefore ruled out. Neither the case of masochism nor envy are considered (Stark 1995).

owner 2. It can easily be confirmed that the utility functions are strictly concave in own effort under the given restrictions on μ_i . Under the assumption of utility maximization, $\partial U_i / \partial e_i = 0$ ($i = 1, 2$), we obtain the best response functions as:

$$2(1 - \mu_1)e_1 + e_2 = r(1 - \mu_1)(1 - b)/q \quad (8)$$

and

$$e_1 + 2(1 - \mu_2)e_2 = r(1 - \mu_2)(1 - b)/q \quad (9)$$

where equation (8) is for owner 1 and equation (9) is for owner 2. See figure 1.

Solving, the Nash equilibrium comes out as:

$$e_1^* = r(1 - b)(1 - 2\mu_1)(1 - \mu_2) / [4(1 - \mu_1)(1 - \mu_2) - 1]q \quad (10)$$

and

$$e_2^* = r(1 - b)(1 - 2\mu_2)(1 - \mu_1) / [4(1 - \mu_1)(1 - \mu_2) - 1]q \quad (11)$$

Superscript '*' denotes the general case of altruism. The equilibrium will be unique except when both owners are completely altruistic and $\mu_1 = \mu_2 = 0.5$. The best response functions will then coincide and it will be an infinite number of equilibria. It is also seen that the problem has no interior solution when one of the owners is completely altruistic. Hence, when $\mu_1 = 0.5$ ($\mu_2 = 0.5$) and μ_2 (μ_1) is in the domain $[0, 0.5)$, the best response functions will intersect at the e_2 -axis (e_1 -axis) so the effort of owner 1 (2) is zero, $e_1^* = 0$ ($e_2^* = 0$). However, when μ_i is in the domain $[0, 0.5)$ and the problem has a unique interior solution, it can easily be confirmed that $\partial e_1^* / \partial \mu_1$

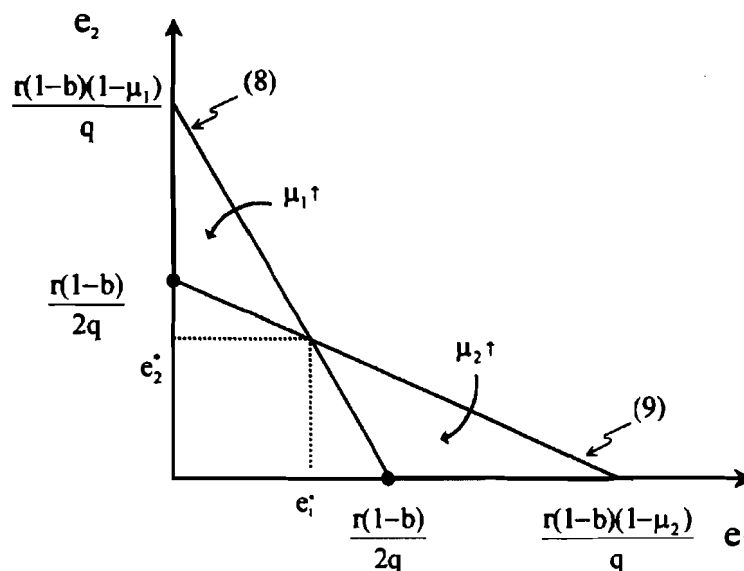


Figure 1. The Best Response Functions Under Various Degree of Altruism

< 0 and $\partial e_2^*/\partial \mu_1 > 0$, and $\partial e_2^*/\partial \mu_2 < 0$ and $\partial e_1^*/\partial \mu_2 > 0$ hold (see figure 1). Increased altruism works, as expected, in the direction of less own effort and more effort of the other owner. Combining the equilibrium conditions, it is also seen that $e_1^*/e_2^* = (1 - 2\mu_1)(1 - \mu_2)/(1 - 2\mu_2)(1 - \mu_1)$ holds; *i.e.*, the relative harvesting effort is only contingent upon the various degree of altruism.

Having characterized the equilibrium, we proceed to show how altruism influences the exploitation of the local common resource. From equations (10) and (11) it follows directly that the total effort will be $E^* = r(1 - b)[(1 - 2\mu_1)(1 - \mu_2) + (1 - 2\mu_2)(1 - \mu_1)]/[4(1 - \mu_1)(1 - \mu_2) - 1]q$, and E^* will be reduced when altruism increases, $\partial E^*/\partial \mu_i < 0$ ($i = 1, 2$). Less effort of one owner must, therefore, outweigh more effort of the other. Moreover, when there is some degree of altruism among at least one of the exploiters, $E^* < E^{max}$ must hold. Because the stock size of the resource is decreasing in the total effort use, $X^* = K(1 - qE^*/r)$, we will also have that $\partial X^*/\partial \mu_i > 0$ ($i = 1, 2$). A strengthening of social norms, leading to increased altruism, works unambiguously in the direction of less effort and less overexploitation of the resource.

The next question is, what happens to the resource rent when there is a movement in the direction of more altruism? The profit of owner 1 will be $\pi_1^* = pqK[1 - b - (q/r)E^*]e_1^*$, which after some rearrangements can be written as $\pi_1^* = Kpr(1 - b)^2(1 - \mu_1 - \mu_2)(1 - 2\mu_1)(1 - \mu_2)/[4(1 - \mu_1)(1 - \mu_2) - 1]^2$. It can be confirmed that $\partial \pi_1^*/\partial \mu_i < 0$ will hold. Finding the corresponding equilibrium profit of owner 2 and differentiating, we obtain $\partial \pi_2^*/\partial \mu_i > 0$. The total profit is $\pi^* = Kpr(1 - b)^2(1 - \mu_1 - \mu_2)[(1 - 2\mu_1)(1 - \mu_2) + (1 - 2\mu_2)(1 - \mu_1)]/[4(1 - \mu_1)(1 - \mu_2) - 1]^2$ and hence, $\partial \pi^*/\partial \mu_i > 0$. The total profit increases when one of the owners becomes more altruistic. The conclusion is that when individuals become more altruistic oriented, own effort and own profit will be reduced. At the same time, this ensures that total effort decreases and overall profit increases.

The above results were obtained when it was an interior solution for effort use. When owner 1 is purely altruistic and, therefore, indifferent to whether the resource rent is obtained through own harvesting activity or the activity of others, $\mu_1 = 0.5$, while μ_2 is in the domain $[0, 0.5)$. Equations (10) and (11) reduce to $e_1^* = 0$ and $e_2^* = r(1 - b)/2q$, respectively. In this case, the harvesting activity of owner 2 is independent of the degree of own altruism, and the effort use coincides with the total effort under overall optimality; *i.e.*, $e_2^* = E^*$. This result is obvious; when harvesting takes place by only one agent there will be no stock externalities.⁴ We will also have $\pi_1^* = 0$ and $\pi_2^* = \pi^* = \pi^1$, and the complete altruist renounces his personal profit. Hence, being indifferent about who obtains the profit, the complete altruist will keep away from own harvesting because the stock externalities are neutralized, and the total resource rent is maximized.

A Special Case: The Same Preferences of the Owners

We now look at the special case when the degree of altruism rooted in social norms is the same among the owners so that $\mu_1 = \mu_2 = \mu$ holds. The solution is then symmetric and the equilibrium effort will be:

$$e_i^* = r(1 - b)(1 - \mu)(1 - 2\mu)/[4(1 - \mu)^2 - 1]q; \quad i = 1, 2 \quad (12)$$

⁴ This is, however, not a general result. When there are three or more owners and just one is completely altruist, harvesting will take place by the other two. Stock externalities will, therefore, be present, and the total effort use will be above that of the overall optimum.

As above, the solution will obviously be as in the standard Gordon-Schäfer model when $\mu = 0$; $e_i^* = e_i^{roa}$ and $E^* = E^{roa}$. It also follows that $\partial e_i^* / \partial \mu < 0$; *i.e.*, the effort of each owner decreases when there is a general movement in the direction of more altruism. Moreover, by using L'Hopitals rule, it can be demonstrated that e_i^* approaches e_i^s ($i = 1, 2$), and hence, E^* approaches E^s , when μ approaches 0.5. When we are close to the strict altruistic case, each owner uses approximately the same effort as under overall optimality. See figure 2.

The equilibrium stock size can now be written as $X^* = K\{1 - 2(1 - b)(1 - \mu)(1 - 2\mu) / [4(1 - \mu)^2 - 1]\}$, while the total profit is $\pi^* = 2Kpr(1 - b)^2(1 - \mu)(1 - 2\mu)^2 / [4(1 - \mu)^2 - 1]^2$. Hence, more altruism means less ecological and economic overexploitation. In the limiting case when μ approaches 0.5, the stock size will also approach the stock size under overall optimality. This will also be so for profit. Being altruists, the owners maximize total resource rent and thus internalize the stock externalities; they reduce harvesting effort to avoid imposing high unit harvesting costs on their co-owners.

Differences in Efficiency

We now study what happens when there are differences in harvesting efficiency among the owners. According to Baland and Platteau (1996), the focus is then directed to the twin issues of group size and homogeneity. The conventional argument is that social norms are more likely to appear in homogeneous groups of small numbers. Moreover, it is supposed that homogeneity is more likely to be present in small groups, indicating that the effect of group size partly works through the homogeneity factor. Baland and Platteau (1996, p. 301), however, argue that, "too often, heterogeneity is blamed as a matter of principle without enough effort being devoted to spelling out the precise conditions under which it undermines collective action." To correct for this misconception, they separate between three main sources of hetero-

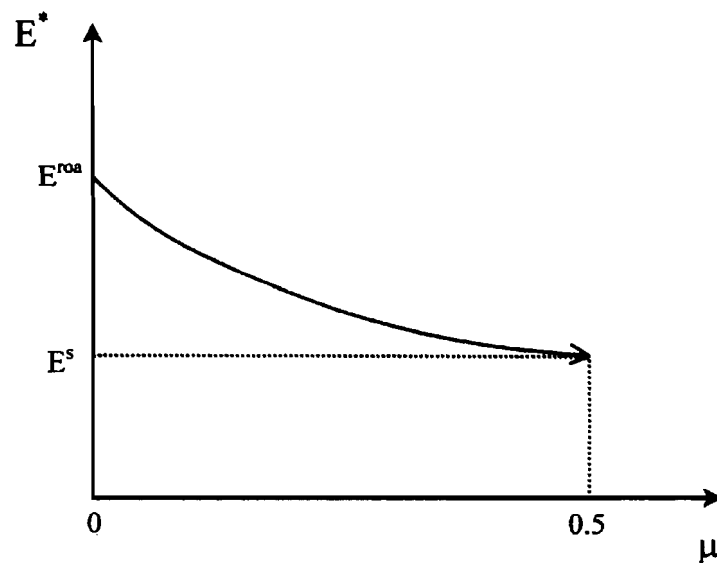


Figure 2. Overall Effort Use Under the Same Degree of Altruism

generosity; those of culture, interests, and endowments. From their empirical studies, they conclude that heterogeneity of endowments, quite contrary to those of culture and interests, may enhance co-operation and stimulate collective action. As skills are included in their endowments category, our notion of differences in efficiency falls within this category.

Hence, to analyze the above issues within the present setting, the assumption that technical skills or the efficiency in harvesting are identical, is relaxed. We still consider only two owners and restrict the analysis to the situation where the agents have the same weights in their utility functions, $\mu_1 = \mu_2 = \mu$. The utility functions under biological equilibrium when the catchability coefficient q varies are then $U_1 = (1 - \mu)pq_1K[1 - b_1 - (1/r)(q_1e_1 + q_2e_2)]e_1 + \mu pq_2K[1 - b_2 - (1/r)(q_1e_1 + q_2e_2)]e_2$ for owner 1, $U_2 = (1 - \mu)pq_2K[1 - b_2 - (1/r)(q_1e_1 + q_2e_2)]e_2 + \mu pq_1K[1 - b_1 - (1/r)(q_1e_1 + q_2e_2)]e_1$ for owner 2, and where $b_i = c/pq_iK < 1$ ($i = 1, 2$). Under the assumption of utility maximization and an interior solution, $\partial U_i/\partial e_i = 0$ ($i = 1, 2$), the Nash-equilibrium will now be given by:

$$e_1^* = r(1 - \mu)[2(1 - \mu)(1 - b_1) - (1 - b_2)]/[4(1 - \mu)^2 - 1]q_1 \quad (13)$$

and

$$e_2^* = r(1 - \mu)[2(1 - \mu)(1 - b_2) - (1 - b_1)]/[4(1 - \mu)^2 - 1]q_2. \quad (14)$$

To obtain an interior solution with positive harvesting efforts, more restrictions on the ecological and economic parameters have to be imposed. $e_1^* > 0$ will hold when $(1 - b_2)/(1 - b_1) < 2(1 - \mu)$, while $e_2^* > 0$ holds when $(1 - b_2)/(1 - b_1) > 1/2(1 - \mu)$. The feasible set for an interior solution is, therefore, determined by the relative efficiency together with the degree of altruism, and is represented by the shaded area in figure 3. The feasible set shrinks when the degree of altruism increases. Hence, a 'high' degree of altruism accompanied by a 'small' efficiency gap means that one of the owners will refrain from harvesting because of stock externalities, while the other one takes the total catch; say, $e_1^* = 0$ and $e_2^* = r(1 - b_2)/2q_2 = E^*$. The same happens under a modest degree of altruism accompanied by a large efficiency gap.⁵

The result that a large efficiency gap causes the most efficient (or the most efficient ones in a general setting with more agents) to take all the catch is earlier demonstrated by, among others, Mesterton-Gibbons (1993). What is new here, is that a similar outcome is generated under the assumption of a small efficiency gap if combined with a high degree of altruism. Altruism rooted in social norms adds a new channel to a more efficient exploitation of the common as it reallocates harvesting effort from the least efficient to the most efficient by making the least efficient owner stop fishing altogether, thus leaving only one owner left in the fishery. Hence, total rent of the fishery is increased, firstly, due to the elimination of stock externalities as only one owner will be left in the fishery and, secondly, due to the fact that

⁵ The present notion of relative efficiency should, however, be interpreted with care because the vertical axis on figure 3 refers to the ratio $(1 - b_2)/(1 - b_1)$, and not q_2/q_1 . The simplest way to illustrate this point is when altruism is absent. When $\mu = 0$, $e_1^* > 0$ if $(1 - 2a) + a/q_2 > 0$, and $e_2^* > 0$ if $q_2 > 2a(1 + a)$. b_i is here replaced, and we have $a = b_i q_i = c/pq_iK$. In addition, the catchability coefficient of owner two is normalized to one, $q_1 = 1$. Accordingly, we must have $a < 1$. Depending on the value of a , which can be interpreted as the cost-price ratio, it can be easily shown that the conditions for obtaining an interior solution are fulfilled for a wide range of values of q_2 . Hence, when $\mu = 0$, an interior solution can take place for small as well as large gaps in efficiency among the harvesters. This is also the case when $\mu > 0$.

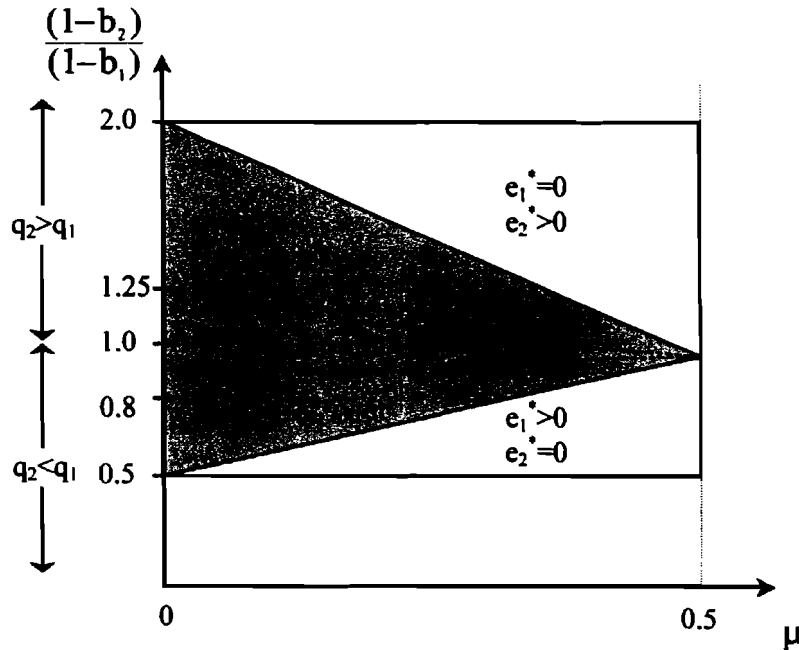


Figure 3. The Feasible Set for an interior Solution Under Different Degree of Altruism and Efficiency.

Note: Both owners harvest (the shaded area) and only one harvest (the non-shaded area). Outside the box, the least efficient is forced to leave harvesting regardless of the prevalence of altruism.

the one remaining will be the most efficient. Notice also that altruism triggers a voluntary withdrawal from harvesting, compared to a coerced withdrawal in the conventional model; that is, withdrawal and reduction in the number of exploiters take place because individual preferences are more in accordance with the interests of the collective. The co-owners of the local common can then reap the fruit of labour division, where the most efficient fishermen harvest, while the least efficient find alternative work at the prevailing opportunity cost, c . Our theoretical reasoning on heterogeneity fostering cooperation is, therefore, in line with the above mentioned empirical findings of Baland and Platteau (1996).

When there are interior solutions and both owners harvest, a changing degree of altruism yields:

$$\frac{\partial e_1^*}{\partial \mu} = r \{ 4(1 - \mu)(1 - b_1) - [5 - 4\mu(2 - \mu)](1 - b_2) \} / [4(1 - \mu)^2 - 1]^2 q_1 \quad (15)$$

and

$$\frac{\partial e_2^*}{\partial \mu} = r \{ 4(1 - \mu)(1 - b_2) - [5 - 4\mu(2 - \mu)](1 - b_1) \} / [4(1 - \mu)^2 - 1]^2 q_2 \quad (16)$$

We have the suspected result $\frac{\partial e_1^*}{\partial \mu} < 0$ when $(1 - b_2)/(1 - b_1) > (1 - \mu)/[5/4 - \mu(2 - \mu)]$, and $\frac{\partial e_2^*}{\partial \mu} < 0$ when $(1 - b_2)/(1 - b_1) < [5/4 - \mu(2 - \mu)]/(1 - \mu)$. This case is given in the middle of the shaded area in figure 3. Hence, as long as there is a small

initial degree of altruism and a small efficiency gap, we obtain the same result as in the previous section. On the other hand, if there is a large initial degree of altruism or a large efficiency gap, we obtain other results and only the least efficient owner will reduce harvesting, while the most efficient, in fact, will increase harvesting effort. These cases take place in the upper part of the shaded area when owner 2 is most efficient, $\partial e_2^*/\partial\mu > 0$ and $\partial e_1^*/\partial\mu < 0$, and in the lower part when 1 is the most efficient harvester, $\partial e_1^*/\partial\mu > 0$ and $\partial e_2^*/\partial\mu < 0$.

A general movement in the direction toward more altruistic behavior when the efficiency gap is large (but small enough to secure an interior solution) so that the harvesting activity of the most efficient increases, while the activity of the other shrinks, leads to a major reallocation of effort use. However, for the outcomes taking place in the upper and lower parts of the shaded area, we demonstrate that total effort will decrease, ensuring a reduction of the economic overexploitation of the resource stock and an increase in the total resource rent, $\partial E^*/\partial\mu < 0$, $\partial X^*/\partial\mu > 0$ and $\partial\pi^*/\partial\mu > 0$.⁶ More altruism promotes more efficient exploitation through a neutralization of the stock externalities. However, under these regimes an additional channel for efficiency improvement is present as the harvesting activity of the most efficient expands, while the activity of the least efficient shrinks. Efficiency improvement is achieved through redistribution of the harvesting shares as well.

Concluding Remarks

In this paper, we have studied the exploitation of a local common natural resource with a structure of individual rights and duties within the group of co-owners in which individual behavior is in compliance. Sharply in contrast to conventional economic analysis, the study is based on the assumption that the behavior of each owner is steered by altruism rooted in social norms. By introducing altruistic preferences, the role played by social and institutional capital are acknowledged. We have also used the term 'restricted open access,' pertaining to the traditional notion of open access, except with the assumption of a limited number of agents.

The analysis has been illustrated by using the Gordon-Schäfer model of a fishery, and where the exploitation takes place through a one-shot game with an equilibrium concept of the Nash-type. The main results can be summarized as follows. More altruism leads to less harvesting effort, less economic overexploitation of the resource, and a higher rent. In the limiting case when all owners are completely altruistic, the exploitation of the common takes place as under overall optimality; *i.e.*, as in a situation where the stock externalities are internalized. The present one-shot game model with altruistic behavior produces qualitatively the same results as the Nash equilibrium of an infinitely repeated game using trigger strategies and where individual utility is based strictly on self interests; *i.e.*, own utility depends only on own profit (the so-called Folk-theorem, see Gibbons 1992). More importantly, we have demonstrated that when there are differences in harvesting efficiency among the exploiters, altruism combined with efficiency gaps restricts the possibility of obtaining an exploitation scheme where all owners participate in the harvesting activity. Altruism in combination with efficiency gaps adds a new channel for efficiency improvement as it reallocates effort from the less efficient to the more efficient harvesters. In the boundary solution where exploiters voluntarily withdraw from exploitation due to altruistic preferences, our analysis also concludes that heterogeneity,

⁶ We have not been able to show these results analytically. They are confirmed by numerical experiments.

indeed, may stimulate collective action. This conclusion challenges the conventional belief that group homogeneity is unambiguously positive for common property management, and it applies to the case of heterogeneity in technological skills.

As long as the owners are not completely altruistic, the model presented in the paper joins conventional theory in concluding that economic inefficiencies are less severe when the group of owners is small. More importantly, however, the model indicates that the presence of social and institutional capital may be more crucial for the well functioning of common property regimes than the size of the group. In fact, it is shown that the adverse effects of large numbers may be partly or completely neutralized by social norms either through a coordinated internalization of stock externalities or through a voluntary withdrawal from harvesting in the case of heterogeneity in efficiency and skills.

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Chapter 5

The Political Economy of Wildlife Exploitation

The Political Economy of Wildlife Exploitation

Anders Skonhoft and Jan Tore Solstad

ABSTRACT. *In this paper we analyze the exploitation of wildlife in a Third World context. In the model there are two agents: an agency managing a habitat area of fixed size and a group of peasants. The agency managing the habitat area has the legal right to exploit the wildlife, while the local people hunt illegally. Introducing the concept of relative harvesting dominance, we demonstrate that the stock utilization depends crucially on the prevailing economic and ecological conditions. It is also shown that the existing property-rights regime appears in different forms depending on these conditions. (JEL Q26)*

I. INTRODUCTION

There are three identified basic driving forces behind the threat of extinction of animal species. First of all, economic and biological overexploitation has been emphasized. The earliest analysis discussed open access harvesting (Gordon 1954). However, even when the harvesting is perfectly controlled (exclusive ownership) by a long-term profit-maximizing resource owner, Clark (1973) showed that a high opportunity cost of the capital, a high price/cost ratio of the yield, and a low natural growth rate of the species could make extinction an optimal economic policy. See also the contribution by Spence (1975). As is well known, Gordon, Clark, and Spence were analyzing marine resources.

Secondly, disinvestment in the biological resources has been focused on. Typically, this approach stresses the importance of competition for land, for example, conversion of natural habitats to agricultural land (Brown et al. 1993; Swanson 1994; Schulz and Skonhoft 1996). Thus, rather than being overexploited, species are undercut according to this line of reasoning (Hanna and Munasinghe 1995). Analyses based on the disinvestment approach are usually formulated in the context of terrestrial resources. Contrary to marine resources, terrestrial resources are subject to competition for land-

based "niches": that is to say, their habitats may be converted to alternative uses. Thus, the opportunity cost of land is an important factor determining the degree of exploitation of the species (Brown et al. 1993; Swanson 1994; Skonhoft 1995).

Thirdly, we have the institutional dimension of resource management. This approach stresses the specification and functioning of property rights as the basic factor determining to what extent biological resources can be exploited in a sustainable way. So, what matters is the presence of "a well-specified property rights regime and a congruency of that regime with its ecological and social context" (Hanna and Munasinghe 1995, 4).

This last view will be the point of departure in the present study when analyzing factors affecting the degree of exploitation of wildlife in a Third World perspective. When considering natural resources in the form of wildlife in developing countries, central issues are the behavior of the rural people living close to the wildlife and the interaction between the rural people, the wildlife, and the agency managing and having the property rights of the wildlife (Marks 1984; Kiss 1990; Swanson and Barbier 1992; Kothari, Suri, and Singh 1995; Naughton-Treves and Sanderson 1995). Often, this interaction represents conflicting interests; both the legal owner of the wildlife—the State or large private landowners—and the rural people claim their rights to exploit and manage the wildlife resources. As maintained by this type of "institutional approach," these conflicts,

The authors are with, respectively, the Department of Economics and the Centre for Environment and Development, Norwegian University of Science and Technology, Dragvoll, Norway. This research was supported by a grant from the Norwegian Research Council through the Biological Diversity Program. An earlier version of the paper was presented at the Annual Conference of the European Association of Environmental and Resource Economists (EAERE) in Lisbon, June 1996, and benefited from discussions there. We are also grateful for comments from an anonymous referee.

rooted in the prevailing property structure and its functioning, have serious implications for the degree of resource exploitation and, thus, on the management of the wildlife in general.

In what follows, property and property rights are therefore central issues. Bromley understands property as a *benefit stream* and a property right as "the capacity to call upon the collective to stand one's claim to a benefit stream" (Bromley 1991, 15). Possession of inviolable property rights presupposes that the rights are authorized by law and that the law is effectively enforced by the state. Effective protection from the state is either attributed to perfect physical or economical governmental protection, or to perfect fulfilment of the duty on the part of all others not to interfere with the right holders' appropriation of the benefit stream (Bromley 1991). Thus, a well-functioning property regime is characterized by, firstly, legally *well-defined* property rights and, secondly, effectively *protected* property rights.

The existence or nonexistence of these two factors defining the functioning of the property structure can be used to classify three different types of regimes. First of all, we have the situation where there is legally well-defined ownership and perfect state protection (exclusive rights, perfect law enforcement). This setting is in accordance with the above-mentioned Clark (1973) model. Secondly, we have the case where the ownership is legally well defined but not adequately enforced by the government. Under such a scheme, often due to lack of societal recognition of the property rights in place, the management is likely to be affected by conflicting property rights claims. An important factor here is also obviously the peoples' response to the formal legal system. In Africa, for instance, rural people often lack adequate knowledge of the legal system, and those who are familiar with it often disregard it (Martin 1992). Finally, we have the case where there is no legally defined ownership; that is, the open access regime (Gordon 1954).

The second type of these regimes will be the starting point in our modeling, but, as will be demonstrated, the two others can be

considered as special cases of the general model. The focus will be on the conflicting interests between a private agency managing and owning both the wildlife and its habitat, and the local people living in the vicinity of the habitat.¹ The habitat is of fixed size, and by law the local people are not allowed to hunt the wildlife or enter the park with their production activities. However, they harvest the wildlife population illegally inside the habitat area. Alternatively, or complementarily, they hunt the wildlife when it roams outside the habitat area. In the bioeconomic model to be formulated, the main issue is therefore subsistence poaching and its influence on the degree of exploitation of the wildlife stock when the legally defined owner also harvests. The present analysis extends those of Milner-Gulland and Leader-Williams (1992) and Skonhoft and Solstad (1996).²

In the model, there are therefore two agents, a resource owner and a group of local people. In Section II we start by formulating the illegal harvesting function of the local people. Their harvesting strategy is based on short-term behavior because of the property rights scheme, and two basic motives behind the poaching are captured. In Section III the benefits of the resource owner are outlined. The solution of the model is analyzed in Section IV where an important underlying assumption is that the resource owner, in contrast to the local people, has incentives to

¹ Our definition of a private owner also includes state ownership if the governmental agency managing the wildlife and its habitat area behaves just as a private agent, that is, maximizes profits from the wildlife and excludes others from utilizing the resources.

² Milner-Gulland and Leader-Williams analyze the interaction between law enforcement, the economic incentives to poach for a group of subsistence hunters, and the rate of hunting. The poachers are considered short-term utility maximizers and are the only agents in their model. The degree of law enforcement is therefore exogenous. In what follows, the antipoaching activity is determined within the model. As in the present study, Skonhoft and Solstad introduce a resource owner. However, the underlying motives behind the poaching activity are not analyzed explicitly in that study. Moreover, the Skonhoft and Solstad analysis deals basically with conservation issues. Consequently, in contrast to the present study, there is no harvesting by the resource owner.

invest in the stock of wildlife. In Section V we study special cases of the model. These are distinguished from the general model by introducing the concept of *relative harvesting dominance*.

II. THE POACHING ACTIVITY OF THE LOCAL PEOPLE

As noted, we start by constructing a formal model to explain how the local people harvest the wildlife stock under conditions where they have no legal rights to harvest but where enforcement of regulations is costly and imperfect. Throughout we will think of the local people as a homogeneous group of peasants living in the proximity of a wildlife habitat.³ They are involved in two different production activities: agricultural and illegal harvesting of the wildlife. All agricultural production takes place outside the wildlife habitat. There will be a constraint on the total effort used in these two activities; a trade-off between harvesting and agricultural production is therefore present. In the model, as in reality, there are two basic motives behind poaching. First of all, there is hunting for meat or, occasionally, for trophy. Second, harvesting takes place to get rid of "problem" animals that stray outside the wildlife habitat, destroying crops and agricultural products. This is the nuisance motive (Marks 1984).⁴

These two motives are included in equation [1] which gives the total benefits of the local people at a given point of time (the time index is omitted). The first term G represents the benefit due to agricultural production, while the term bf represents the harvesting benefit. The benefit functions are fixed through time.

$$U = G(N, X; a) + bf(L, X). \quad [1]$$

We assume that G is an increasing function of effort used in agriculture N , but at a decreasing rate, so that $\partial G/\partial N = G_N > 0$ and $G_{NN} < 0$ holds. The stock of wildlife is represented by X and gives the nuisance effect on the agricultural production. More wildlife means more damage and shifts the benefit and marginal benefit down, $G_X < 0$ and

$G_{NX} < 0$. Conversely, a higher price a of the agricultural products shifts the function up, $G_a > 0$ and $G_{Na} > 0$.

In the second term of equation [1], f represents the illegal offtake with b as the fixed marginal valuation of the offtake. f is an increasing function of the harvesting effort L , but at a decreasing rate, $f_L > 0$, $f_{LL} \leq 0$. Moreover, for a given effort, a higher stock of the wildlife means a higher offtake, $f_X > 0$, and the marginal productivity of the harvesting effort increases with a higher stock, $f_{LX} > 0$. We will also obviously have that $f(0, X) = f(L, 0) = 0$. It is seen that if $f_{LL} = 0$, these assumptions are in line with the Schaefer harvesting function.

Equation [2] gives the resource constraint of the local people. That is to say, the total labor effort T , which also can be interpreted as the total human population living in the vicinity of the wildlife habitat, is the sum of the effort used in the two production activities.

$$N + L = T. \quad [2]$$

³ It is therefore assumed that there are no conflicting interests among them. Hence, prevalence of individual conformity to group norms is assumed to be present. In line with traditional reasoning, it is assumed that the elders are in charge of the group's activities (Marks 1984).

⁴ These are the direct motives for their illegal activity. However, as already indicated, there are some more *fundamental* causes of their disposition to act illegally. Taking South-Saharan African countries as an example, today's conflicting interests have a long history. Earlier days' balanced resource management schemes, often under highly informal local community institutions, have changed in a dramatic way. Nationalization and privatization of wildlife habitats have alienated the local people from the wildlife. Today, local people often find only problems in having an abundant wildlife community in their neighborhood. Traditional harvesting has been subject to severe restrictions, and anti-poaching laws have turned the old practice of subsistence hunting into a crime. Moreover, people are often prevented from eliminating "problem" animals to protect their crops and their livestock. This process has generally evolved without regard to the social, cultural, and economic consequences imposed on rural people. They have seldom received any compensation for their loss of access to land and natural resources on which their subsistence once relied. All these factors have worked toward destroying the incentives of the local people to care for the wildlife and obey wildlife laws (Marks 1984; Kiss 1990).

Equations [1] and [2] give a well-defined allocation problem. However, the allocation of effort between the two production activities will also be influenced by the fact that the harvesting is illegal according to the property rights scheme. The offtake of wildlife will therefore also be affected by the level of antipoaching effort, E , put in force by the resource owner. This effect works, first of all, through the probability of being detected when hunting illegally and, secondly, through the imposed fine when detected.⁵ The fine is supposed to be fixed, while the probability of being detected, θ , is given by equation [3]. θ is assumed to be an increasing function of the level of antipoaching effort (the level of law enforcement) and the time (effort) spent on the illegal activity so that $\theta_E > 0$ and $\theta_L > 0$. In addition, it will also be assumed that the marginal probability of being detected increases with the level of antipoaching effort; that is, $\theta_{LE} > 0$. Finally, we obviously also have that $\theta(0, L) = 0$ and $\theta(E, 0) = 0$ must hold.⁶

$$\theta = \theta(E, L). \quad [3]$$

If the fine is denoted by Q , the expected benefit at time t will be $(1 - \theta)U + \theta(U - Q)$. The allocation of labor between the two activities and, thus, the illegal harvesting function, can then be found. As already mentioned, it will be assumed that the behavior of the local people is based on *short-run* maximization of the expected benefit. A myopic behavior seems reasonable for them because they obtain no legal benefits from the wildlife. For them, it therefore makes sense to harvest as much as possible this year, because next year they may be effectively prevented from harvesting due to more efficient law enforcement. Consequently, the local people have few, if any, incentives to base their harvesting activity on intertemporal considerations. In addition to the level of the antipoaching effort E , they therefore also take the stock of wildlife X as given when deciding their offtake. Assuming risk neutrality, the allocation of effort following from maximizing $(1 - \theta)U + \theta(U - Q) = G(N, X; a) + bf(L, X) - Q\theta(E, L)$ subject to constraint [2] is then given by equation [4]

when agricultural production always takes place.

$$G_N(N, X; a) \geq bf_L(L, X) - Q\theta_L(E, L). \quad [4]$$

The optimal effort used on harvesting is labeled L^* . If $L^* > 0$, equation [4] holds as an equality and if $L^* = 0$, [4] holds as an inequality. So when $L^* > 0$, the harvesting effort will be a function of the stock size X and the antipoaching effort E , together with the parameters reflecting the economic environment of the peasants, $L^* = L^*(X, E; a, b, Q, T)$. Substituted into the harvesting function $f(L, X)$, the *reduced-form* illegal harvesting function is therefore obtained as in equation [5].

$$h = \begin{cases} 0 & \text{when } L^* = 0 \\ f(L^*(X, E; a, b, Q, T), X) \\ = h(X, E; a, b, Q, T) > 0 & \text{when } L^* > 0. \end{cases} \quad [5]$$

Figure 1 depicts the illegal harvesting function. There will be no harvesting up to a certain level X_0 of the stock. This stock size reflects the maximum level of the stock that keeps the local people away from poaching for a given level of the antipoaching effort and the economic environment. X_0 can be seen as a measure of the *poaching pressure*. When the stock is equal to or below this level, it is therefore unprofitable for the local people to use labor effort on hunting, so $L^* = 0$. On the other hand, a stock size above X_0 means $L^* > 0$ and $h > 0$ accompanied by $h_X > 0$. h_X will be positive because a higher stock size will shift the marginal benefit curve of agricultural production G_N downwards through the nuisance effect, while the marginal net benefit curve of harvesting ($bf_L - Q\theta_L$) will shift upwards for obvious reasons (for details, see Appendix

⁵ In other words, while the poachers are assumed to be detected by the legal resource owner, they are punished by a governmental authority.

⁶ The present formulation builds, to some extent, on the fishery model of Sutinen and Anderson (1985). However, contrary to our model, Sutinen and Anderson assume that the amount of labor used in illegal harvesting is affecting the level of the *fine if detected* rather than the *probability of being detected*. We feel that our formulation better fits the present problem.

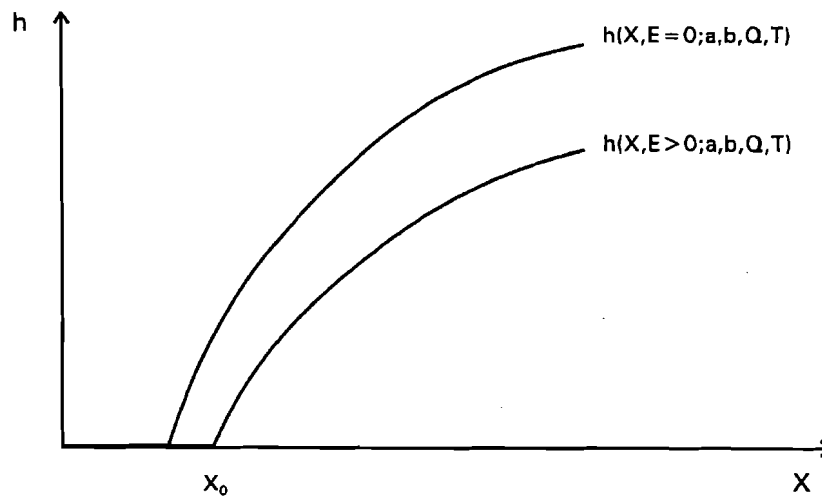


FIGURE 1

THE REDUCED FORM ILLEGAL HARVESTING FUNCTION. THERE WILL BE NO HARVESTING UP TO THE STOCK LEVEL X_0 FOR THE GIVEN ECONOMIC ENVIRONMENT WHEN $E > 0$.

1). Thus, more effort will be allocated to the harvesting activity for a higher size of the wildlife stock. In addition, a higher stock size will by itself increase the harvesting activity.

More antipoaching effort increases the possibility of being detected, so as E increases θ_L will increase and shift the $(bf_L - Q\theta_L)$ schedule downwards. Less labor will therefore be used on harvesting. Consequently, the poaching function as depicted in Figure 1, shifts outwards when E increases so $h_E < 0$ when $X > X_0$. If there is no antipoaching effort at all, the second term of the right-hand side of equation [4] vanishes. So for a given economic environment, X_0 will be at its lowest level. As will become clear below, a crucial question is how the slope of the reduced-form illegal harvesting function changes as the antipoaching effort changes. It can be demonstrated (see Appendix 1) that the sign of h_{XE} in general will be ambiguous when $X > X_0$. However, as argued, it seems reasonable to study two situations. First of all, we have the case when h_{XE} as an approximation is equal to zero, and, secondly, when the effect is negative, but small in magnitude (see also Appendix 2).

In addition to the stock size and the enforcement activity, the economic environ-

ment will also affect the reduced-form harvesting function. An increased fine induces a negative shift in the marginal expected benefit of the harvesting activity and will therefore work in the direction of reducing the optimal illegal hunting effort. h will therefore shift outwards, so X_0 increases and $h_Q < 0$ for $X > X_0$. An increased valuation of the agricultural products will shift the curve G_N upwards. Consequently, we will also have that $h_a < 0$. The effect of an increased marginal valuation of the offtake will be of the opposite; $h_b > 0$ holds therefore for $X > X_0$. Finally, we have the effect of an increased effort constraint which, as already noted, can be interpreted as an increased human population pressure. The result will be more effort used in both production activities, so the reduced-form illegal harvesting function shifts upwards, $h_T > 0$.

Summing up, we have demonstrated that below a "small" stock size, there will be no illegal harvesting and no poaching pressure because there is a positive alternative cost of poaching. The opportunity cost depends, in general, on the antipoaching effort and on the economic environment. Improved economic conditions relating to agricultural production will increase the opportunity cost and, hence,

reduce the poaching pressure, while an increased marginal valuation of the wildlife and increasing population pressure (more total effort) will cause an opposite effect.

III. THE BENEFITS OF THE LEGAL RESOURCE OWNER

Having established the reduced-form poaching function of the local people, we are now ready to introduce the harvesting activity of the resource owner, that is, the agency having the legal rights to the benefits of the wildlife and its habitat. It will generally be assumed that the agency reaps the legal and economic benefits from the wildlife through two channels, namely, through harvesting and through a non-consumptive use of the resource. On the other hand, the resource owner must control and secure his benefits by using antipoaching efforts. Equation [6] represents profit per unit of time.

$$\pi = py + W(X) - qE. \quad [6]$$

The first term py is the harvesting profit. For simplicity, it is assumed that the stock does not affect the harvesting costs. It is also assumed that the costs are linear in the off-take y . Analytically, these two assumptions come down to the same as assuming that there is costless harvesting, so p can be interpreted as the market price of the off-take. Moreover, also for simplicity, the market price is assumed to be fixed and independent of the off-take. The justification for these assumptions can be that the resource owner is selling hunting licenses of a fixed price.

The second term gives the non-consumptive profit from the wildlife related to the stock size. $W(X)$ can typically reflect benefits from wildlife tourism (traditional wildlife viewing and safari tourism). Generally, this non-consumptive value of the stock is assumed to be positive and concave with $W(0) = 0$, $W_x > 0$ and $W_{xx} \leq 0$. This means that the present stock effect is quite parallel to the so-called "wealth effect" in models of optimal growth (Kurz 1968).

As already noted, the resource owner

holds the legal rights to totally prevent the local people from harvesting the wildlife. However, he is offered no physical or economic protection by the government and has to fund the enforcement effort himself (usually resulting in imperfect and costly law enforcement). The term qE represents this cost, where q is the fixed unit effort (say personnel) cost.

Both the off-take y of the resource owner and the illegal off-take h of the local people are constrained by the population dynamics of the wildlife as given by equation [7]. As already indicated, we let one stock of wildlife represent the whole game population and $F(X)$ is the natural growth function related to the fixed size of the habitat. It is a humped curve increasing to a peak value for an intermediate value of the stock. In the following we will think of $F(X)$ as a logistic function with $F(0) = F(K) = 0$ and $F(X) > 0$ in the domain $(0, K)$, where K is the carrying capacity, so that $F_{xx} < 0$.

$$dX/dt = F(X) - (y + h). \quad [7]$$

IV. THE DEGREE OF EXPLOITATION UNDER IMPERFECT PROTECTION

Equations [5]–[7] are the basic equations of the model which we now are ready to analyze. In contrast to the group of local people, the harvesting activity of the resource owner will be steered by long-term considerations because he has the legal right to exploit the wildlife. Under such a scheme, there is a strategic interdependency between the agents. The interdependency is, however, of the *asymmetric* type because the local people have to adjust their activity to the enforcement use of the resource owner. In a first stage, the resource owner maximizes present-value profit, taking into account the illegal harvesting function of the local people. In the next stage, the illegal hunting activity follows from the optimal choice of E and y .

Technically, when the resource owner enforces an optimal antipoaching control, the solution is found by maximizing of equation [8], where $\delta > 0$ is the resource owner's rate

of discount, subject to the population dynamics [7] and equation [5].

$$PV = \int_0^{\infty} [py + W(X) - qE]e^{-\delta t} dt. \quad [8]$$

The current value Hamiltonian of the problem is $H = py + W(X) - qE + \mu[F(X) - y - h(X, E; a, b, Q, T)]$ with y and E as the control variables, X as the state variable, and μ as the shadow price of the wildlife. When an interior solution is assumed to be present, the first-order conditions will be $\partial H/\partial y = 0$, $\partial H/\partial E = 0$ and $d\mu/dt = \delta\mu - \partial H/\partial X$. This yields $p - \mu = 0$, $-q - \mu h_E = 0$ and $d\mu/dt = \delta\mu - W_X - \mu F_X + \mu h_X$, respectively. An interior solution implies a strictly positive stock size together with a strictly positive legal offtake and effort use at the steady-state. A positive antipoaching activity also implies a positive illegal offtake. If not, the antipoaching activity would have been wasted effort. Equations [9] and [10] give the reduced-form long-term equilibrium.

$$q = -\mu h_E(X, E; a, b, Q, T) \quad [9]$$

$$F_X(X) + W_X(X)/p = \delta + h_X(X, E; a, b, Q, T). \quad [10]$$

Equation [9] says that the resource owner should use antipoaching efforts up to the point where the marginal cost of the antipoaching effort q is equal to the marginal benefit of the antipoaching effort $-\mu h_E$. Equation [10] is the present version of the Clark-Munro rule (Clark and Munro 1975), where h_X reflects the marginal cost of increasing the stock due to the poaching activity. $W_X(X)/p$ is the marginal non-consumptive value of the wildlife evaluated at the market value of the legal offtake. The left-hand side of [10] is therefore the resource owner's marginal benefit of increasing the stock while the right-hand side is the marginal cost of doing so.

Generally, equations [9] and [10] determine simultaneously the equilibrium stock X^* and the antipoaching E^* (superscript * denotes the general case, that is, where there is an interior solution). The equilibrium illegal offtake follows then as $h^* = h(X^*, E^*; a, b, Q, T)$. In the next stage, when $dX/dt = 0$, equation [7] determines the equilibrium offtake of the resource owner, $y^* = F(X) - h^*$. Figure 2 depicts the solution. We can see that the stock will be more heavily exploited as compared to a situation with le-

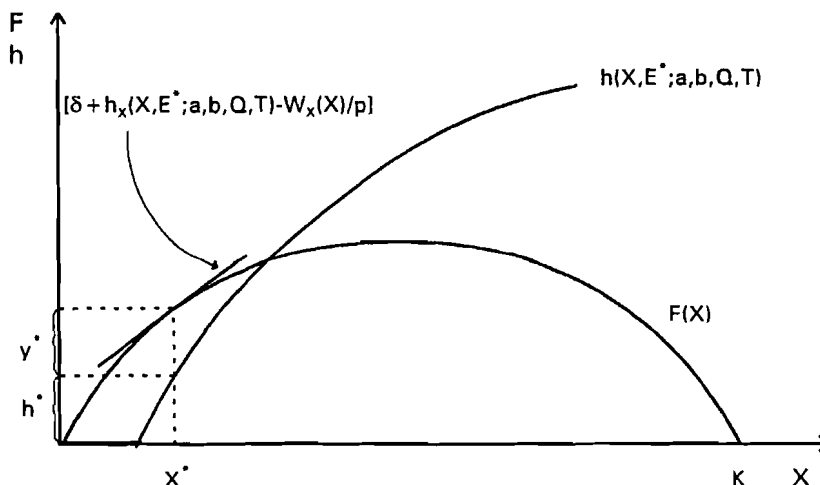


FIGURE 2
THE LONG-TERM EQUILIBRIUM SOLUTION WHEN THERE IS AN INTERIOR SOLUTION
(THE GENERAL CASE).

gally defined ownership and perfect state protection (i.e., the Clark 1973 model) because of the presence of the stock externality $h_x > 0$ in equation [10]. This implies that the resource conflict itself depresses the stock size. Moreover, the optimal stock will be located to the left of the biomass representing the maximum sustainable yield (X^{msy}) if h_x , together with δ , dominates W_x/p . Consequently, when the illegal harvesting function is quite responsive to an increased stock size so that the marginal stock externality is strong and the marginal benefit ratio of the resource owner is low, the stock will be well below what corresponds to X^{msy} . In what follows, this "threat-of-extinction case" is generally assumed to be present.

Having seen the basic mechanism determining the long-run equilibrium when there are strictly positive offtake rates and enforcement use, we now proceed to study how permanent changes in the economic environment influence the degree of stock exploitation. In what follows, it will be useful to distinguish between two cases. First of all, we have the case where the cross effect in the poaching function is weak and negligible so that $h_{xE} = 0$ when $h > 0$ (see Section II and Appendix 1). The steady-state conditions [9] and [10] are then two independent equations where [9] determines E^* and [10] determines X^* . As a consequence, δ and the marginal stock-value W_x have no influence on the optimal antipoaching effort, while q has no effect on the stock size. Secondly, we have the case where h_{xE} is negative. Equations [9] and [10] then simultaneously determine the stock size and the enforcement use.

When $h_{xE} = 0$ as an approximation holds, it can be shown that a permanently higher market price of the offtake will result in a smaller long-run stock, $\partial X^*/\partial p < 0$ (see Appendix 2). The effect is therefore just as in the traditional Clark (1973) model, but in the present setup it works through lowering the marginal benefits of the non-consumptive value of the wildlife. Moreover, an increased p will increase the antipoaching effort, $\partial E^*/\partial p > 0$. This result follows intuitive reasoning as it lowers the price ratio q/p . As a consequence, the reduced-form illegal harvesting function will shift to the right meaning

that the offtake of the resource owner will increase, $\partial y^*/\partial p > 0$, while the illegal offtake will decrease, $\partial h^*/\partial p < 0$. The effect of a permanent shift in the non-consumptive stock value W_x , say, as a result of an increase in the demand for tourism services, will have an opposite stock effect to that of p . In addition, because the optimal antipoaching effort is unaffected, there will also be a redistribution of the offtake in favor of the local people.

As already noted, $\partial X^*/\partial q = 0$ will hold when $h_{xE} = 0$. However, in line with intuitive reasoning, the optimal antipoaching effort will decrease, $\partial E^*/\partial q < 0$. As a consequence, the reduced-form illegal harvesting function will shift inward so that $\partial h^*/\partial q > 0$, while the offtake of the resource owner will decrease by the same amount $\partial y^*/\partial q = -\partial h^*/\partial q$. The above stock effect is quite interesting in that it contrasts with intuitive reasoning. In view of this effect, governmental intervention designed to both secure the resource owner's property and safeguard a threatened wildlife stock by reducing q through a subsidy will not increase the long-term wildlife stock. There will only be a redistribution of the offtake between the resource owner and the local people. Notice also that the result $\partial X^*/\partial q = 0$ also implies that the wildlife population will stay at the same size whether or not the resource owner uses antipoaching efforts, suggesting that $y^* > 0$ still holds.

A permanent increase in the rate of discounting by the resource owner (perhaps as a result of a more myopic view of the future) will reduce the relative difference of discounting between the local people and the resource owner and will decrease the equilibrium stock, $\partial X^*/\partial \delta < 0$. Because the antipoaching effort will be unaffected by this change, $\partial E^*/\partial \delta = 0$, the poaching function will not change; the result will also be $\partial h^*/\partial \delta < 0$. Again, referring to Appendix 2, the opposite will happen for the long-term legal offtake, $\partial y^*/\partial \delta > 0$. Because this result holds also when X^* is located to the left of X^{msy} , the effect generally contrasts with the Clark (1973) model.

Changes in the economic environment underlying the illegal harvesting activity will

TABLE 1
COMPARATIVE STATICS OF THE STEADY-STATE WHEN THERE IS AN
INTERIOR SOLUTION (THE GENERAL CASE) (NO BRACKETS, $h_{XE} = 0$;
IN BRACKETS, $h_{XE} < 0$ WHEN THE RESULTS DIFFER)

	p	q	a	Q	T	b	δ	γ
X^*	-	0 (-)	+	+	-	-	-	+
E^*	+	-	0 (+)	0 (+)	0 (-)	0 (-)	0 (-)	0 (+)
y^*	+	- (?)	?	?	?	?	+	- (?)
h^*	-	+	?	?	?	?	- (?)	+
$(h^* + y^*)$	-	0 (-)	+	+	-	-	-	+

Notes: The effects on the total harvest ($h^* + y^*$) are calculated when the stock is below that of the X^{ov} . γ is a shift-factor representing the marginal stock value, W_x .

also influence the stock size and the harvesting activity. Appendix 1 shows that permanent improvement in the profitability of agricultural production will not influence the effect of enforcement efforts on the poaching activity so $h_{Ea} = 0$. Under this assumption, it should be clear that $\partial E^*/\partial a = 0$ when $h_{XE} = 0$. The same happens when b , Q , and T shift. Consequently, the reduced-form illegal harvesting function shifts only as a result of direct effects, that is to say, changes in the parameters, a , b , Q , and T , and not through changes in E .

Appendix 1 also indicates that the effects of these parameters on h_x will be different from zero. More specifically, the slope of the poaching function shifts downward when the marginal valuation of the agricultural products increases; that is, $h_{xa} < 0$ when there is a positive offtake. The same happens when the imposed fine of detection Q increases, while the effect of an increased marginal valuation of the offtake b and an increased human population pressure T (increased total effort) will be the opposite. As a consequence, a permanent increase in profitability of agricultural production (triggered by perhaps a subsidy on agricultural products or through less protectionism in agricultural trade, shifting the producer prices of agricultural products up) will work in the direction of reducing the exploitation pressure on the wildlife stock, $\partial X^*/\partial a > 0$. This result is in line with the reasoning of Brown et al. (1993), but opposite to that of Schulz and Skonhott (1996). The mechanism here is quite different from the Schulz-Skonhott model because the possibility of land-use

conversion and reduced habitat size is assumed away. We obtain also a positive effect on the stock as a result of a changing fine so $\partial X^*/\partial Q > 0$, while the effects of an increased population pressure and marginal valuation of the offtake by the local people will be of the opposite sign so $\partial X^*/\partial T < 0$ and $\partial X^*/\partial b < 0$, respectively. The effects on the offtake rates of these changes will in general be unclear (again, see Appendix 2). The results are summarized in Table 1.

Table 1 also summarizes the results for the case when $h_{XE} < 0$ holds. As already noted, equations [9] and [10] simultaneously determine X^* and E^* when this cross effect is present so there will be some differences compared to the above results (for details, see Appendix 2). Most notable is that higher unit enforcement costs will tend to reduce the equilibrium stock size, $\partial X^*/\partial q < 0$. Under the present assumption, the effect of reduced antipoaching activity therefore spills over to the stock size. Moreover, changes in the economic environment affecting the production activities of the local people will now influence the optimal use of antipoaching efforts.

V. RELATIVE DOMINANCE: PERFECT PROTECTION AND OPEN ACCESS

We now look at special cases where the economic and ecological environment is such that there is no longer any fully interior solution of the model. When harvesting takes place by only one of the agents, the concept of *relative harvesting dominance* becomes

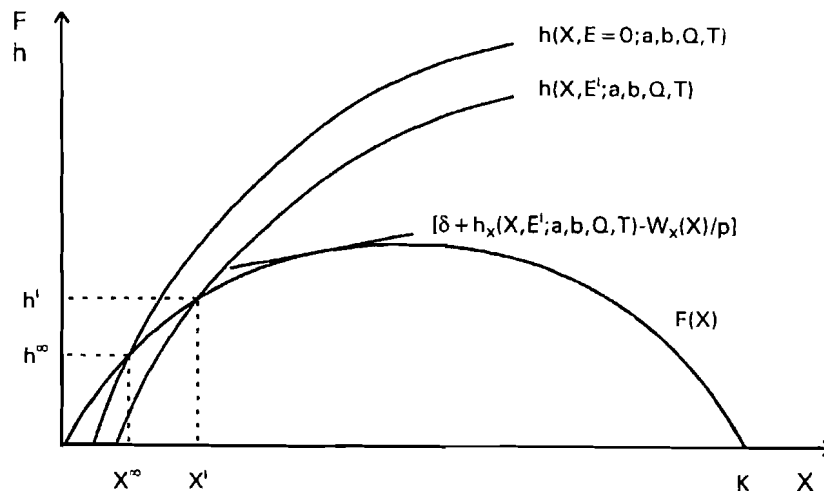


FIGURE 3

THE SOLUTIONS WHEN THERE IS A RELATIVE HARVESTING DOMINANCE OF THE LOCAL PEOPLE. SUPERSCRIT 1 WHEN THERE IS A POSITIVE ANTIPOACHING EFFORT. SUPERSCRIT ∞ WHEN THERE IS NO ANTIPOACHING EFFORT ("OPEN ACCESS").

crucial. Moreover, it will be shown that both the regime of open access and that of exclusive rights and perfect protection (the Clark 1973 model) can be identified under the subsequent scenarios of relative harvesting dominance. That is to say, the functioning of the property rights regime shifts according to varying economic and ecological conditions.

Illegal Dominance and Open Access

We start by considering the case where illegal hunting by the local people dominates completely so there is no legal offtake. When $y = 0$ holds at the steady-state, but there is antipoaching activity so that $E > 0$, equation [10] changes to [10'] as the Clark-Munro necessary condition for maximum, while equation [9] still holds.⁷

$$F_x(X) + W_x(X)/p > \delta + h_x(X, E; a, b, Q, T). \quad [10']$$

The present situation of a dominant poaching pressure is illustrated in Figure 3 with X^1 as the equilibrium stock, E^1 as the antipoaching activity, h^1 as the illegal offtake and $y^1 = 0$ as the legal offtake (superscript 1

denotes the presence of illegal dominance). This scenario will take place if there is a high poaching pressure. A high poaching pressure is prevalent when the opportunity cost of poaching is low, that is, the poaching activity starts to become positive for a small stock size. Moreover, equation [10'] shows that this effect occurs if the marginal non-consumptive/consumptive benefit ratio W_x/p of the resource owner is high. A small magnitude of the stock externality h_x works in the same direction, that is, when the illegal offtake function is quite irresponsive to an increased stock size. While this contrasts with intuitive reasoning, it will occur because, for the resource owner, a small stock externality with respect to the poaching activity makes consumptive use of the wildlife less profitable compared to non-consumptive use.

Therefore, the present notion of harvesting dominance of the local people is a *relative* concept because of the effect of W_x/p . This will also be so for the rate of discount

⁷ The necessary conditions for maximum will now be $\partial H/\partial y = p - \mu < 0$ and $\partial H/\partial E = -q - \mu h_E = 0$, together with $d\mu/dt = \mu(\delta - F_x + h_x) - W_x$. Combining yields [10'] at the steady-state.

δ of the resource owner. Consequently, a higher marginal benefit ratio W_x/p and a lower δ work in the direction of $y^l = 0$ as an optimal solution. Moreover, Figure 3 demonstrates that $(F_x - h_x) < 0$ will hold at the present steady-state. In view of equation [10'], $(W_x/p - \delta) > 0$ must therefore hold when there is no offtake by the resource owner. Consequently, the price of the offtake cannot be "too high" and the marginal non-consumptive benefit cannot be "too low" to obtain the solution depicted in Figure 3.

So when the poaching is dominant and the harvesting activity of the resource owner is no longer economically viable, the stock size is determined only by the poaching activity of the local people together with the resource owner's incentives to use enforcement to protect the non-consumptive exploitation of the resource. In contrast to what was shown in Section IV, a governmental intervention to secure the resource owner's property by granting a subsidy on the antipoaching effort, will now work unambiguously in the direction of safeguarding the wildlife stock. It should also be clear that a marginal shift in the willingness to pay for hunting licenses or in policies attempting to reduce the market price of the legal offtake to safeguard the wildlife will no longer have any stock effects. However, as above, improving the economic conditions in the agriculture sector will shift the poaching function to the right and will therefore tend to increase the long-run stock size.

Under this scenario of relative harvesting dominance of the local people, the economic environment can also be such that the resource owner will get no benefit from using antipoaching efforts. When $E = 0$ in the long term, equation [9] must hold as an inequality at the steady state, $q > -\mu h_E$, while equation [10'] now holds with $E = 0$ as in [10''].

$$F_x(X) + W_x(X)/p > \delta \\ + h_x(X, E = 0; a, b, Q, T). \quad [10'']$$

Therefore, this special case of relative harvesting dominance of the local people can occur if the (market) cost to (shadow) price ratio q/μ is relatively high and the illegal off-

take at the same time responds only slightly to the antipoaching effort so that h_E is small in magnitude. This solution is also depicted in Figure 3 with X^∞ as the "open access" equilibrium stock and h^∞ as the illegal offtake. The solution of the model now coincides with the "open access" case of the Skonhott and Solstad (1996) model.⁸ For the present situation when there is no antipoaching activity, the model implies that the strategic interdependency between the two agents has changed. In a first stage, the equilibrium stock of wildlife is therefore determined by the local people through their unrestricted harvesting. In a subsequent stage, the resource owner passively adapts to that equilibrium stock.

So even though the present management regime meets the condition of the legally defined property rights, the regime functions as if it were absent because of the economic and ecological environment. In this case, the exploitation pressure of the wildlife is therefore totally determined by the myopic view of the local people, and as noted, the local people have a myopic view because they have no legal rights to wildlife resources. Under these conditions, the legally defined property rights therefore work to motivate short-term harvesting behavior by those who are actually steering the degree of resource utilization.

Consequently, if a wildlife population is threatened under such a situation, policies should be directed toward the illegal harvesting incentives of the local people. The most straightforward policy recommendations are to improve the profitability conditions in the agricultural sector and to increase the penalty of poaching, that is, increase the fine. The former approach works as a conflict-reducing policy by redistributing income in favor of the local people, while the latter approach intensifies the conflicts. A more dramatic pol-

⁸ The term "open access" as used here, is not reflecting the traditional use of the term—free entrance of an infinite number of harvesters. Rather, it is meant to reflect the unrestricted access of a *fixed and homogeneous group* of harvesters which base their degree of exploitation completely on short-term considerations. The essence of the term "open access" used here is in line with the definition of Bromley (1991) and is related to the absence or breakdown of a management system.

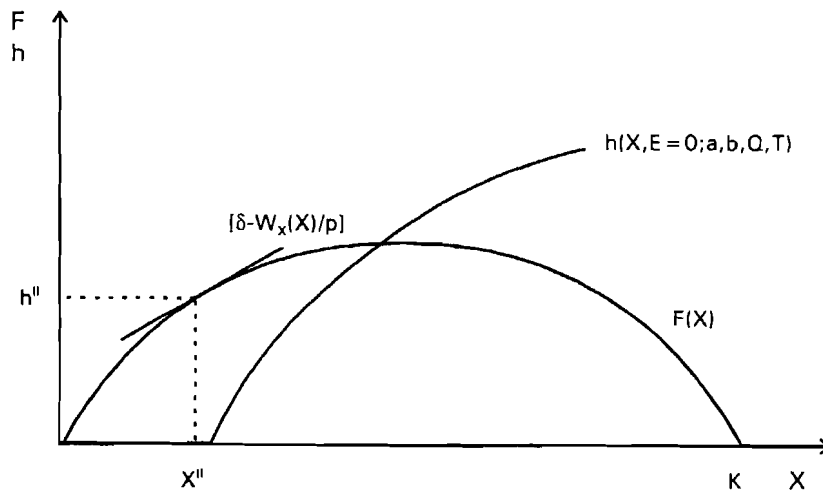


FIGURE 4

THE SOLUTION WHEN THERE IS RELATIVE HARVESTING DOMINANCE OF THE LEGAL RESOURCE OWNER.

icy option would be to give the local people user or property rights to the wildlife, thereby motivating them to consider long-term investment in the resource. This argument is consistent with that of Bromley (1991) and stresses the use of property rights as a policy instrument in resource management. For a more detailed analysis of user and property rights as policy options in wildlife management, see Skonhoft and Solstad (1996).

Legal Dominance and Perfect Protection

We now turn to the case where the legal owner of the wildlife resources dominates the harvesting and there is no illegal offtake by the local people. When $y > 0$ and $h = 0$, there will be no antipoaching activity so $E = 0$ will hold as well. Under this case, the Clark-Munro necessary condition reduces to [10'''].

$$F_x(X) + W_x(X)/p = \delta. \quad [10''']$$

The solution is depicted in Figure 4 with X'' as the equilibrium stock and y'' the legal offtake. This special case of harvesting dominance by the legal resource owner occurs if there is a low marginal non-consumptive to

consumptive benefit ratio W_x/p and a high rate of discount. Moreover, it takes place if there is a low poaching pressure due to a high opportunity cost of poaching. The notion of harvesting dominance is therefore still a relative concept. The solution is obviously in line with the traditional Clark (1973) model of exclusive rights and perfect law enforcement. So if the wildlife is threatened, the traditional Clark forces leading toward extinction are operating (see Section I).

In this scenario there is no open confrontation between the two agents and *apparently* no conflict. However, the interest claims of the local people are still present, but no longer transform into illegal activity because of the relatively heavy exploitation pressure of the legal resource owner. Since in the absence of the legal resource owner, the local people would have harvested (see Figure 4), the exploitation of the resource owner constitutes foregone benefits of the local people.

VI. CONCLUDING REMARKS

In this paper we have, from a theoretical point of view, studied the conflicting interests of an agency managing and owning wildlife resources and the local people living

close to the wildlife. The wildlife habitat is assumed to be of fixed size, and the agricultural production of the local people is assumed to take place outside the habitat area. We have analyzed how the conflicting interests translate into illegal hunting. The property-rights regime in our study has been of the type where the ownership of the resources is legally well defined but not well protected by the state. The resource owner obtains legal and economic benefits from the wildlife through harvesting and non-consumptive profit, but must fund his own protection of those legal rights; the local people obtain no legal benefits. The illegal offtake of the local people is based on short-term considerations, while the resource owner has incentive to invest in the stock.

The consequences for the utilization of the wildlife and harvesting are studied in three steps. First, we analyze the general case where the economic and ecological conditions are such that both agents harvest and the resource owner imposes an optimal anti-poaching activity. Under such a scenario, it is shown that the stock will be more heavily exploited than in a situation where there is well-defined legal ownership and perfect state protection. This will hold either the property rights are in the hands of the legal resource owner or the local people. The effects of permanent changes in the economic environment are shown to be much the same as in the traditional Clark (1973) model. However, other factors influencing the degree of illegal harvesting are working. Thus, among others, an increased profitability in the agricultural sector (triggered by a subsidy or as a result of less protection in agricultural trade shifting the producer price of agricultural products up) tends to reduce exploitation pressure and increase the steady-state stock size. A governmental intervention to reduce the cost of the anti-poaching effort will not automatically increase the long-term wildlife population.

We then analyze two special cases of the model where the concept of relative harvesting dominance is introduced. We first study the case where the economic environment is such that the harvesting of the resource

owner is no longer economically viable. Under such a scenario, the stock size is basically determined by the poaching activity of the local people. The wildlife population will therefore be determined *as if* the property rights scheme was of the open-access type. Thus, only factors directly affecting the living conditions of the local people will influence the wildlife stock. So if the wildlife population is threatened under such a situation, policies should be directed towards the illegal harvesting incentives of the local people. The most straightforward policy recommendation is to impose the conflict-reducing policy of improving the profitability conditions in the agricultural sector. A more dramatic policy option would be to give the local people user or property rights to the wildlife, thereby motivating them to consider long-term investment in the resource.

Finally, we study the case where the harvesting activity of the legal owner of the wildlife dominates the solution so there is no illegal offtake. This will take place if the legal resource owner faces a low marginal non-consumptive to consumptive benefit ratio of the wildlife, while at the same time the poaching pressure is low due to a high opportunity cost. This case is shown to fit an institutional arrangement *as if* exclusive rights and perfect law enforcement were present. So, under this scenario, there are apparently no conflicting interest claims because the local people do not interfere with the management of the resource. The solution then coincides with the Clark (1973) model and the traditional Clark forces determine the size of the wildlife stock. So also when there is a relative harvesting dominance of the legal resource owner, the actual property rights relation differs because of the prevailing economic, social, and ecological conditions.

APPENDIX I

In this appendix we formally derive the basic properties of the *reduced-form* illegal hunting function discussed in Section 11 when effort is allocated to the harvesting activity. Maximization of total benefits yields equation [4], leading to an

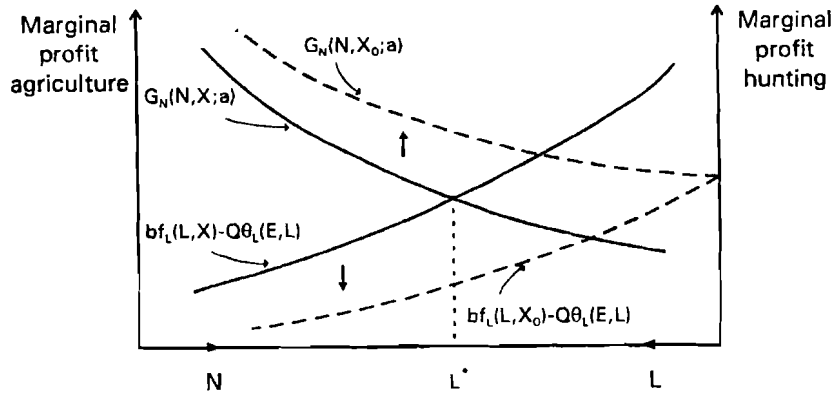


FIGURE 5

THE ALLOCATION OF LABOR BETWEEN THE TWO PRODUCTION ACTIVITIES OF THE LOCAL PEOPLE. THE SCHEDULE G_N SHIFTS UP WHEN X DECREASES WHILE $(bf_L - Q\theta_L)$ SHIFTS DOWN WHEN X DECREASES. AT STOCK SIZES $X \leq X_0$ NO LABOR WILL BE ALLOCATED TO THE HARVESTING ACTIVITY.

optimal effort used on harvesting $L^* = L^*(X, E; a, b, Q, T) > 0$ when an interior solution is present. Figure 5 illustrates the solution.

The properties of L^* can be derived by taking the total differential of [4] which yields (when only considering the effects of X and E)

$$dL^* = [(bf_{LX} - G_{NX})/(-G_{NN} - bf_{LL} + Q\theta_{LL})]dX - [Q\theta_{LE}/(-G_{NN} - bf_{LL} + Q\theta_{LL})]dE, \quad [i]$$

where $(-G_{NN} - bf_{LL} + Q\theta_{LL}) > 0$ because of the second-order condition leading to equation [4]. So if θ_{LL} is negative, there must be a restriction in magnitude. $L_X^* = \partial L^*/\partial X = [(bf_{LX} - G_{NX})/(-G_{NN} - bf_{LL} + Q\theta_{LL})]$ is therefore positive, while $L_E^* = -[Q\theta_{LE}/(-G_{NN} - bf_{LL} + Q\theta_{LL})] < 0$. The differential of the reduced-form harvesting function $h = f(L^*(X, E; a, b, Q, T), X) > 0$ from equation [5] is then

$$h_X = f_L L_X^* + f_X > 0 \quad [ii]$$

and

$$h_E = f_L L_E^* < 0. \quad [iii]$$

Writing [iii] explicitly as a function of its basic arguments, $h_E = f_L(L^*(X, E; a, b, Q, T), X)L_E^*(X, E; a, b, Q, T)$, and differentiating with respect to X , we obtain the cross effect

$$h_{XE} = (f_{LL}L_X^* + f_{LX})L_E^* + f_L L_{XE}^*. \quad [iv]$$

$f_{LL} \leq 0$, $f_{LX} > 0$ and $f_L > 0$ (see the main text), while the sign of L_{XE}^* is unknown (as seen from [i], it will include third-order differentials of the benefit streams). The sign of [iv] is therefore in principle unknown. However, if $L_{XE}^* \approx 0$ and a Schaefer harvesting function is present so that $f_{LL} = 0$, we obtain $h_{XE} < 0$. On the other hand, if $L_{XE}^* \approx 0$, but $f_{LL} < 0$, the sign of h_{XE} is unclear. In the comparative statics discussed in Section IV, we take $h_{XE} \approx 0$ as the starting point. However, we also discuss the case where it is negative, that is, the presence of a Schaefer harvesting function together with the assumption that a term including third-order differentials vanishes.

Moreover, we obtain the second-order anti-poaching effort effect as

$$h_{EE} = f_{LL}(L_E^*)^2 + f_L L_{EE}^*. \quad [v]$$

The sign of h_{EE} is therefore also unclear. When assuming a Schaefer harvesting function, the sign of h_{EE} rests only on L_{EE}^* . From the second-order conditions of the optimization problem of the resource owner in Section III (see Appendix 2), $h_{EE} \geq 0$ must hold; that is, to fulfill this second-order condition, the optimal effort used in the harvesting activity must be convex in the anti-poaching effort.

The cross effects of h_X and h_E with respect to the economic parameters underlying the behavior of the local people are also of interest. Differenti-

ating [ii] with respect to the price of the agricultural products a , yields

$$h_{xa} = f_{LL}L_a^*L_x^* + f_{LL}L_{xa}^* + f_{XL}L_a^*. \quad [\text{vi}]$$

The sign of [vi] is also unclear, but when a Schaefer harvesting function is present and $L_{xa}^* \approx 0$, we obtain $h_{xa} = f_{XL}L_a^*$. Differentiation of equation [4] easily reveals that $L_a^* < 0$ when $L^* > 0$, hence $h_{xa} < 0$. In the main text, this is supposed to hold. Arguing along the same lines, we will also have that $h_{xb} > 0$, $h_{xQ} < 0$ and $h_{xT} > 0$.

Finally, differentiating [iii] gives

$$h_{Ea} = f_{LL}L_a^*L_E^* + f_{LE}L_a^*. \quad [\text{vii}]$$

So when again assuming the presence of a Schaefer harvesting function and assuming that the term L_{Ea}^* as an approximation vanishes (as above, this term also includes third-order differentials), we obtain $h_{Ea} = 0$. This is assumed to hold in the main text. Arguing along the same lines, we will also have that $h_{Eb} = h_{EQ} = h_{ET} = 0$.

APPENDIX 2

In this appendix, we formally derive the properties of the optimization problem of the legal resource owner in section IV, that is, the general case when there is an interior solution. The comparative statics are also examined.

The second-order conditions require that the Hamiltonian should be concave in the state variable X and the controls E and y . Concavity in the Hamiltonian means that the Hessematrix should be negative semidefinite in optimum. It can be shown that this implies $p(F_{xx} - h_{xx}) + W_{xx} \leq 0$ and $-ph_{EE}[p(F_{xx} - h_{xx}) + W_{xx}] - (ph_{xE})^2 \geq 0$. $h_{EE} \geq 0$ must therefore hold as well. It is also shown that there must be a restriction on the magnitude of ph_{xE} .

The effect of an increased marginal valuation of the non-consumptive value of the stock, W_x , is introduced by adding a shift-factor $\gamma > 0$ to equation [10] as shown in [i]. The effect of increased marginal stock valuation is thus represented by $\partial X/\partial \gamma$.

$$F_x(X) + W_x(X)/p + \gamma/p = \delta + h_x(X, E; a, b, Q, T). \quad [\text{i}]$$

The comparative statics results can then be found by taking the total differential of equations [i] and [9]. [ii] gives the results.

$$\begin{aligned} & \begin{bmatrix} ph_{EX} & ph_{EE} \\ p(F_{xx} - h_{xx}) + W_{xx} & -ph_{xE} \end{bmatrix} \begin{bmatrix} dX \\ dE \end{bmatrix} \\ &= \begin{bmatrix} -h_E \\ (\delta - F_x + h_x) \end{bmatrix} dp + \begin{bmatrix} -1 \\ 0 \end{bmatrix} d\gamma \\ &+ \begin{bmatrix} -ph_{Ea} \\ ph_{xa} \end{bmatrix} da + \begin{bmatrix} -ph_{Eb} \\ ph_{xb} \end{bmatrix} db \\ &+ \begin{bmatrix} -ph_{EQ} \\ ph_{xQ} \end{bmatrix} dQ + \begin{bmatrix} -ph_{ET} \\ ph_{xT} \end{bmatrix} dT \\ &+ \begin{bmatrix} 0 \\ p \end{bmatrix} d\delta + \begin{bmatrix} 0 \\ -1 \end{bmatrix} d\gamma. \quad [\text{ii}] \end{aligned}$$

The determinant of the matrix on the left-hand side of [ii], $D = \{-ph_{EE}[p(F_{xx} - h_{xx}) + W_{xx}] - (ph_{xE})^2\}$, will be positive in optimum because of the second-order conditions for maximum, $D > 0$. The system [ii] gives all the partial-derivatives effects as shown in Table 1.

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Chapter 6

Investing in Wildlife: Can Wildlife Pay its Way?

Investing in Wildlife: Can Wildlife Pay its Way?

Anders Skonhøft¹ and Jan Tore Solstad
Norwegian University of Science and Technology

The paper analyses economic and ecological mechanisms determining wildlife investments in the context of pastoral exploitation of the semi-arid African rangeland. We consider a group of pastoralists practising two production activities, cattle herding and wildlife harvesting. Livestock and wildlife interact with each other as there is competition for grazing land. A bioeconomic model is formulated to analyse this interaction and the pastoralist's optimal degree of investments in livestock and wildlife. The factors working in the direction of threatening the wildlife are identified. Next, the management problem is analysed in a conservation perspective where CITES-policies are imposed, and where there is international payment for conservation of endangered species.

1. Introduction

African wildlife is today threatened from a variety of sources. This threat is particularly severe in regions with dense and fast growing human populations, where expanding settlements, crops and livestock are displacing wildlife at an ever increasing rate. In the last decades, the observed decline in wildlife abundance has called for action to protect wildlife. Nationalisation and privatisation of local wildlife resources have become common, and traditional hunting practices have been subject to various regulations. To a large extent, wildlife has

¹ Corresponding author (e-mail: anders.skonhøft@sv.ntnu.no). Thanks to the Norwegian Research Council which supported this research through the Biological Diversity Programme. Thanks also to two anonymous referees for helpful comments and suggestions.

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been appropriated by the state through the establishment of national parks and protected areas (Marks, 1984).

The above is a broad description of today's situation in Sub-Saharan Africa, and reflects a land-use and wildlife management policy based on protection rather than on utilisation (for further details see Skonhoft, 1997). For local human populations formerly relying on natural resources for subsistence, this policy has often implied the criminalisation of their traditional rights to harvest as well as loss of land for cultivation and pasture. Prevented from utilising the wildlife as well as eliminating 'problem' animals to protect their crops and livestock, the local people often bears the costs of conservation without obtaining any benefits from it. A rather negative attitude towards wildlife conservation has therefore emerged, and resentment of legal regulations is frequent (Marks, 1984; Swanson and Barbier, 1992; Wells, 1992).² Combined with limited capability of the governments to finance their large protected areas and enforce wildlife laws, the expediency of the present conservation policy is therefore seriously questioned (Marks, 1984; Kiss, 1990; Swanson and Barbier, 1992; Martin, 1993).³

When considering the problem of wildlife conservation in wildlife areas not already under protection, the importance of analysing alternative conservation policies therefore emerges. Land areas not under crops or permanent human settlement and not protected constitute about 85% of the African continent (Martin, 1993). These areas of arid and semi-arid land are habitats for a great variety of wildlife and plant species, but here the humans also constitute an increasing threat to the wildlife. Land tenure is mostly communal. Access to land is therefore generally determined by presence and traditional rights, and the rural people are constantly bringing their production activities, basically domestic livestock, deeper and deeper

² African rural people also lack knowledge of the legal system, and those familiar with it often disregard it (Martin, 1993).

³ Martin (1993, p. 6) writes that 'Africa may have already made the mistake of accepting a conservation legacy bequeathed to it by its former colonial governments: it has too many and too large a system of protected areas to be able to meet their minimum levels of operating costs . . . In the case of African conservation areas, more and bigger is not necessarily better: less and fewer would result in better conservation by the state.'

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into these wildlife habitats (Martin, 1993). The productivity of livestock production here is generally low, but the process of rapid human population growth gives rise to shortages of high-productive land and thereby forces humans to bring their specialised production activities into ever more marginal areas (Eltringham, 1987).⁴ For Sub-Saharan African wildlife, the process of land-use conversion is devastating. First, it directly degrades wildlife in these areas without any status of protection. Secondly, it threatens wildlife even in the protected areas because buffer stocks degrade.

In these vast areas of low-productivity arid and semi-arid communal land, it is argued that wildlife has a significant potential as an alternative, or complementary, land-use option to domesticated species. If this potential is realised, it is believed that wildlife utilisation could be a viable land-use option, thus creating incentives for humans to invest in wildlife and thus reversing the trend of land-use conversion and species decline (Eltringham, 1987; Kiss, 1990; Holdgate, 1992; Swanson and Barbier, 1992; Brown *et al.*, 1993; Martin, 1993; Swanson, 1993, 1994; Barnes, 1996). This will be the perspective in the subsequent analysis of wildlife utilisation and conservation. The focus will be on the rural population's incentives to invest in wildlife compared with domestic livestock, and in particular, we will study factors affecting the choice of wildlife and cattle stocks made by a group of pastoralists having sole access to a fixed area of arid and semi-arid rangeland.⁵ The land is supposed to be communal and there are no formal regulations of the pastoral activities. However, there will be informal structures present, regulating individual grazing and harvesting rights within the group of pastoralists. Hence, we are

⁴ The extent and speed of this process of land-use conversion is well illustrated by the fact that between 1960 and 1980 the proportion of land areas dedicated to specialised species in developing countries altogether increased by 37.5% (Brown *et al.*, 1993).

⁵ Pastoralism is widespread, and the pastoral economy is still dominant in large parts of Sub-Saharan Africa (Prins, 1992). About 25% of the region's human population relies on domestic livestock for their primary dietary and exchange needs (Smith, 1992). Moreover, pastoralism has its greatest economic significance for those living in the least developed areas of the region. In these areas livestock holding is the main production activity, and because the land is basically of the arid and semi-arid type, pastoralism is the principal mode of livestock production (Koncsacki, 1978).

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looking away from any problems of the 'tragedy of the common' type so the pastoralists are treated as a homogeneous group managing pasture and animals in a controlled way.⁶

As is well known, pastoralism takes several forms of economic and social organisation. In what follows, we will think of pastoral nomadism in its pure form; that is, pastoral nomads not involved in agricultural production at all⁷ (Konczacki, 1978). Cattle herders are therefore the group of pastoralists considered. In addition, they are involved in wildlife utilisation in the form of hunting.⁸ The livestock provides consumptive benefits in the form of meat and skins. But it also provides products such as milk when not slaughtered. The livestock, also the stock of wildlife, will be considered as assets for the pastoralists, where harvesting determines investment activity. However, investing in livestock will influence the wildlife stock and vice versa, because both species compete for the scarce factor grazing land. It is therefore an ecological interdependency between the stocks which also translates into an economic interdependency.

We start in Section 2 to present this ecological system of livestock and wildlife. The benefit function of the pastoralists is also formulated here. In Section 3, we solve the model and find the pastoralist's optimal investment in livestock and wildlife. Factors working in the direction of threatening a viable wildlife population are also analysed. In Section 4, we discuss some policy implications and study the model in a conservation perspective by attaching a positive stock value to the wildlife as representing a public good value in the form of existence value, biodiversity and so forth. Some policy implications are

⁶ This means that we have a setting in which individual conformity to group norms prevails among them. In line with traditional reasoning, it is supposed that the elders are in charge of their activities (Marks, 1984).

⁷ Relaxing this assumption will not change the basic results of the present model. If, say, the pastoralists were engaged in agricultural production as well, the extension of the model would be to add an additional nuisance effect of wildlife because roaming wild animals are destroying crops. The obvious result would have been a reduction of the optimal size of the wildlife stock (see below). For an explicit analysis of the conflicts between wildlife and agricultural production, see Schulz and Skonhoft (1996).

⁸ Various forms of hunting can be considered, but we will basically think of traditional subsistence hunting and commercialised hunting for meat and trophies. In addition, it can be sports and safari hunting in which the pastoralists are selling hunting licences to outsiders (Eltringham, 1994; Roth and Merz, 1997).

discussed, and the effects of the policy recommendations of the Convention on International Trade in Endangered Species (CITES; Swanson and Barbier, 1992) are also analysed.

2. Population Dynamics and the Benefit Function of the Pastoralists

As already noted, there are two production activities practised by the group of pastoralists, namely cattle herding and harvesting of wildlife. Both activities are constrained by the population dynamics of the livestock and wildlife, where one stock is assumed to represent the whole wildlife population. The dynamics are given by equations (1) and (2), where (1) is for wildlife and (2) is for cattle. X (wildlife) and Y (cattle) are the biomasses at a given point of time (the time index is omitted), $F(X, Y)$ and $G(Y, X)$ are their accompanying natural growth functions, and f and g are the rates of harvesting.⁹ Natural growth are assumed to be density dependent following humped curves increasing to peak values for intermediate values of the own stock size; $\partial F/\partial X = F_X > 0$ for $X < X_{msy}$, $F_X \leq 0$ for $X \geq X_{msy}$, $F_{XX} < 0$ and $G_Y > 0$ for $Y < Y_{msy}$, $G_Y \leq 0$ for $Y \geq Y_{msy}$ and $G_{YY} < 0$. In addition, the stock growth, as well as the marginal stock growth, decreases with the size of the other stock, $F_Y < 0$, $G_X < 0$, $F_{XY} < 0$ and $G_{YX} < 0$. These assumptions obey the properties of logistic growth. To obtain more clear-cut results, the specific functional forms as given by equations (1') and (2') will also be used in part of the analysis. Here K and L are the carrying capacities in absence of the other stock, r and s are the maximum specific growth rates, and α and β are the interaction coefficients. Thus, αXY represents the biomass of wildlife lost per unit of time because of the competition from the livestock while βYX gives the biomass of livestock lost because of the competition from the wildlife. When using the specific natural growth functions (1') and (2'), we will therefore also have that $F_{YY} = G_{XX} = 0$, $F(0, Y) = F(K, 0) = 0$ and $G(0, X) = G(L, 0) = 0$ hold.

$$(1) \quad dX/dt = F(X, Y) - f$$

$$(1') \quad F(X, Y) = rX(1 - X/K) - \alpha XY$$

⁹ It is therefore assumed that the pastoralists do not influence the natural growth of their cattle, say, through selective harvesting.

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$$(2) \quad dY/dt = G(Y,X) - g$$

$$(2') \quad G(Y,X) = sY(1 - Y/L) - \beta YX.$$

The ecological system with the specific functional forms (1') and (2') represents therefore the Gause model of interspecific competition (see e.g., Maynard Smith, 1974). It can be confirmed that the model without harvesting ($f = g = 0$) does not cause oscillations. The equilibrium is either of the unstable saddle-point type or it is a stable one. That is to say, if the system is perturbed away from equilibrium, an equilibrium with both species present or an equilibrium with just one of the species surviving will be the outcome. The actual outcome depends on the degree of competition between the two populations, and it can be shown that the interaction coefficients α and β have to be constrained in magnitude to obtain a stable equilibrium with both stocks present. The degree of ecological competition will also be crucial for obtaining a meaningful economic solution of the model (see below).

The current benefits of the pastoralists are given by equation (3). The first term represents the harvesting benefits related to the wildlife with p as the fixed price net of harvesting costs. Generally, it will be assumed that $p > 0$, but we will also briefly analyse the special case where $p < 0$ so that the wildlife is merely a nuisance to the pastoralists. The second term gives the harvesting benefits of the livestock where $q > 0$ is also the net of harvesting costs off-take price.¹⁰ In addition, there will be stock benefits from the cattle as given by $W(Y)$. As already noted, it can represent various animal products (e.g., milk). In addition, it can represent a measure of status as well as an insurance motive (Konczacki, 1978; Collett, 1987; Livingstone, 1991; Smith, 1992; Perrings, 1993; Walker, 1993; Dasgupta and Mäler, 1995). It will therefore be assumed that more cattle means more benefits, so $W_Y > 0$ holds. Furthermore we assume that $W(0) \geq 0$ and $W_{YY} \leq 0$, so the stock effect has strong similarities to the so-called 'wealth effects' in models of optimal growth (Kurz, 1968). To shed some further light on the

¹⁰ p (and q) can also represent the marginal valuation of the off-take when not sold for a market (see footnote 8). When interpreted as prices, it is therefore supposed that the stock sizes do not affect the harvesting costs, that the costs are linear in the off-take, and that the prices are not influenced by the off-take.

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results, the linear functional form $W(Y) = wY$ will be applied in parts of the analysis.

$$(3) \quad U = pf + qg + W(Y).$$

Equations (1)–(3) are the basic equations of the model which we are now ready to analyse. We start by analysing what will be termed the market solution of the model. In Section 4 we add a public good effect to the benefits of the wildlife and analyse overall optimality.

3. Optimal Production and Stock Sizes of the Pastoralists

Due to the biological competition between the two populations, the pastoralists face a trade-off between keeping livestock and wildlife as assets. In what follows, we assume that the behaviour of the pastoralists is steered by long-term considerations and that they seek to maximise the present-value benefit stream.¹¹ The optimal stock investments are then found by maximising equation (4) where δ is the rate of discount, subject to the ecological constraints (1) and (2).

$$(4) \quad PV^* = \int_0^{\infty} (pf + qg + W(Y))e^{-\delta t} dt.$$

The current-value Hamiltonian of this problem is $H = pf + qg + W(Y) + \mu (F(X, Y) - f) + \lambda (G(Y, X) - g)$, with f and g as control variables, X and Y as state variables, and μ and λ as the shadow prices (costate variables) of wildlife and livestock, respectively. Equations (5) and (6) yield the reduced form necessary conditions for maximum when an interior solution is supposed to be present (positive stock sizes, and positive harvesting rates at the steady state, see also Appendix 1). These equations represent a 'double singular' jointly determining the long-

¹¹ Instead of long-term utility maximisation, Walker (1993, p. 80), among others, argues that the behaviour of pastoralists in semi-arid regions is directed to 'maintain the maximum number of animals which satisfies a number of subsidiary aims, such as drought and status in the community'. This is a rule-of-thumb-type of behaviour where the size of the livestock plays a crucial role. Because a stock effect also is included in the present benefit function, parts of Walker's argument are captured in our model.

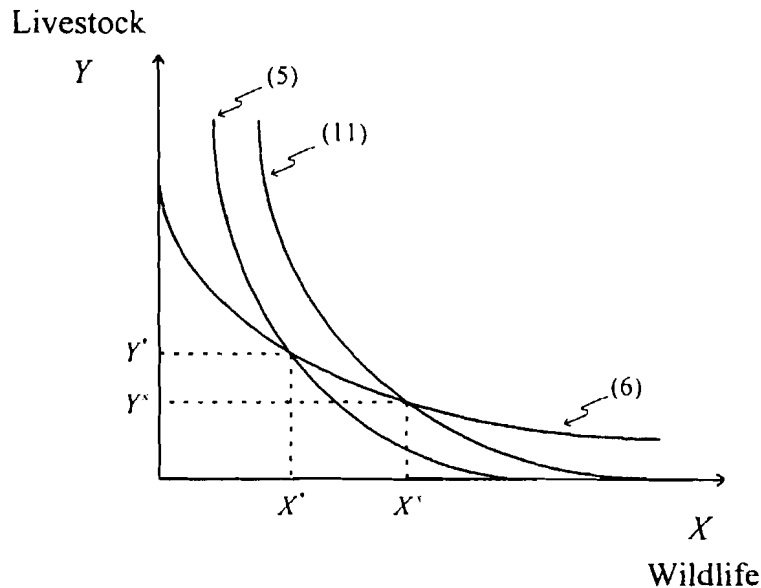


Figure 1: Long-term Stock Equilibrium under the Market Solution (X^*, Y^*) and Overall Optimality (X^S, Y^S)

term equilibrium stocks as X^* and Y^* . In addition, the steady-state off-take rates follow from equations (1) and (2) as $f^* = F(X^*, Y^*)$ and $g^* = G(Y^*, X^*)$ when $dX/dt = 0$ and $dY/dt = 0$, respectively.¹² The stock equilibrium is depicted in Figure 1. As indicated, equation (5) will intersect with equation (6) from above when X is measured along the horizontal axis. This will be so because of the second order conditions for maximum (again, see Appendix 1).

$$(5) \quad F_X(X, Y) = \delta - (q/p)G_X(Y, X)$$

$$(6) \quad G_Y(Y, X) + W_Y(Y)/q = \delta - (p/q)F_Y(X, Y).$$

¹² Contrary to a one species model, it seems difficult to find the optimal trajectories of the stocks when originally being outside equilibrium. The so-called Most Rapid Approach Path (the MRAP-strategy) does not generally apply to a 'double singular'. But as Clark (1990, Ch. 10.3) notes, the MRAP-strategy will be the 'practically acceptable approach' in a two species model. Basically, the MRAP-strategy says that one should harvest as much as possible when the initial stock sizes are above that of the long-term optimum, whereas one should stop harvesting when initially below.

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Equations (5) and (6) are the present versions of the Clark-Munro rule. The equilibrium condition of an optimal harvesting strategy of the livestock in equation (6) is extended with the marginal non-consumptive benefit component $W_Y/q > 0$, which partially works in the direction of driving up the size of the livestock. In addition, there is the competition effect $(p/q)F_Y < 0$ imposed on the wildlife working in the opposite direction. A competition term is present in the long-term equilibrium condition for the wildlife (5) as well, $(q/p)G_X < 0$, and works partially in the direction of driving down the wildlife stock size. Because of the absence of a non-consumptive benefit component here, the wildlife stock size will always be at a point where $(\delta - F_X) < 0$ holds. On the other hand, we will have that $(\delta - G_Y) > 0$ holds if W_Y/q dominates $(p/q)F_Y$, while the opposite will be true if the marginal non-consumptive benefit effect is small and the marginal value of the biomass loss imposed on the wildlife at the same time is large.

By taking the total differential of equations (5) and (6), we can demonstrate the effects of permanent changes in the economic environment and see what factors are working in the direction of threatening the wildlife (Appendix 1). An increased price of the wildlife off-take has unambiguous effects, and contrary to the standard one-species harvesting model (Clark, 1990), we will have that the wildlife stock will increase when the off-take price increases, $\partial X^*/\partial p > 0$. This discrepancy can be related to two distinct features of our model compared with the Clark model. The *first* has to do with the mechanisms of a one-species model and concerns the different assumptions about the stock effects of the wildlife. The only stock effect in the Clark model is positive since it originates from the assumption of a negative relationship between harvesting costs and the stock size. The presence of a positive stock effect obviously means a higher optimal stock size than when there is no stock effect. However, an increased off-take price will reduce this impact since the relative importance of the stock effect will be lower when the profitability of harvesting increases. Hence, a higher off-take price reduces the stock. On the contrary, the only stock effect present in our model originates from the assumption of wildlife representing a nuisance for cattle herding and is thus negative. The presence of a negative stock effect means a lower optimal stock size compared with a situation without it, and, as above, this impact is reduced by an increased off-take price. Hence, a higher off-take price increases the

stock in this case. The *second* discrepancy compared with the Clark model is related to the two-species nature of our model. A more valuable wildlife implies additional costs of keeping cattle because the value of the lost wildlife biomass due to the competing cattle increases. Obviously, this works partially in the direction of a smaller optimal cattle stock size and, because of reduced competition, it reinforces the first effect so the result will be a larger stock of wildlife.¹³ Because of the increased competition for grazing land due to more wildlife, and the increased costs of keeping cattle, the effect on the cattle stock size of a permanent shift in the off-take price of the wildlife is unambiguously negative, $\partial Y^*/\partial p < 0$.

The above result holds when $p > 0$. As already mentioned, however, we will also consider the case when the wild species are only a nuisance so that the harvesting price falls short of harvesting costs. When p is negative, the pastoralists have to weigh the benefits of a smaller wildlife stock against the net cost of harvesting. In such a case, it can be demonstrated that the most likely result of an increase in the price, i.e., a reduction of net harvesting costs, will be a smaller wildlife stock. Hence, the result will be in accordance with the standard one-species harvesting model (see Appendix 2). This is also in accordance with intuitive reasoning; a price increase lowers the costs of getting rid of 'problem' animals relative to the negative stock effect of the wildlife. It will therefore be optimal for the pastoralists to reduce the wildlife stock through an increased harvesting activity.¹⁴

The long-term effects of a permanent shift in the off-take price of cattle are generally unclear. Compared with the wildlife case above, the difference lies in the fact that it has attached a positive stock effect on cattle, the non-consumptive benefit term $W(Y)$, in addition to the negative competition effect. This term represents a stock effect similar to the one of the Clark model (see above). Hence, if the marginal non-consumptive benefit effect dominates the marginal effects

¹³ If we relax the assumption of stock-independent harvesting costs of wildlife, allowing costs to decrease with the stock size as in the Clark model, this result will still hold as long as the marginal effect of the imposed cost does not dominate the marginal effects originating from the nuisance term and the partial reduction of the stock of cattle. However, if it does, we will arrive at the Clark result.

¹⁴ The point of including a negative harvesting value so that wildlife is merely a nuisance was suggested by an anonymous referee.

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originating from the competition, we will arrive at the Clark result $\partial Y^*/\partial q < 0$. In such a case the effect on the wildlife stock will be ambiguous. This will be so because two partial effects are working in opposite directions; the reduced competition due to less cattle increases the wildlife stock while a more valuable cattle stock motivates for shrinking the wildlife. On the other hand, if the marginal competition effects dominate the non-consumptive benefit effect, we obtain $\partial Y^*/\partial q > 0$. Because more cattle means more competition for the wildlife, in addition to the fact that a more valuable cattle stock motivates for less wildlife, we arrive at $\partial X^*/\partial q < 0$. The general conclusion is therefore that at least one of the stocks must decrease when q increases. For a related discussion, in a somewhat other context, see Flaaten (1991).

A permanent increase of the rate of discount δ also has unclear stock effects. The reason is first of all that it motivates for stock disinvestments due to an increased opportunity cost of the biological capital. Second, the grazing land competition for both stocks will be reduced as a result of this first round effect. It can, however, be demonstrated that at least one of the stocks will decrease when the rate of discount increases. This result can be proved by showing that the assumption of larger populations of both species when δ shifts up will contradict the second order condition for maximum. Hence, the first round effect motivating for stock disinvestments when the opportunity costs of the biological capital increases must therefore dominate at least for one of the stocks. The valuation of the non-consumptive livestock benefits can change as well. This can be analysed by adding a shift parameter $\gamma > 0$ on the left-hand side of equation (6) (see Appendix 1). The effect on the livestock is obviously $\partial Y^*/\partial \gamma > 0$, while $\partial X^*/\partial \gamma < 0$ will hold because of more competition for grazing land. To the extent that modernisation reduces the non-consumptive livestock valuation, this will therefore tend to motivate for an increased size of the wildlife stock.

While the general functional forms of the population growth and the benefit functions have given some insight on the economic forces determining the long-term stock sizes, more clear-cut results can be obtained, at the cost of generality, by using the specific functional forms. When introducing $F(X,Y)$ and $G(Y,X)$ from equations (1') and (2') together with the benefit function $W(Y) = wY$ (see also Section 2), the long-term stock equilibrium conditions (5) and (6) change to (7) and (8) after a few rearrangements.

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$$(7) \quad (2r/K)X + (\alpha + (q/p)\beta)Y = r - \delta$$

$$(8) \quad (\beta + (p/q)\alpha)X + (2s/L)Y = s - \delta + w/q.$$

These equations represent straight lines in the XY -plane and both lines have negative slopes. The second order condition requiring that $D = (4rs/KL) - ((q/p)\beta^2 + 2\alpha\beta + (p/q)\alpha^2) > 0$ (see Appendix 3) also means that the determinant of the left-hand side of equations (7) and (8) must be positive since it is equal to D . Hence, equation (7) should be more negatively sloped than equation (8) (see also the slope of the above equations (5) and (6) in Figure 1). The interpretation of this condition for obtaining a meaningful economic solution to the maximisation problem is that there must be a restriction on the degree of competition between the two stocks. This is just as in the general model (see Appendix 1), but now the condition has a very simple parametric representation. As can be seen, the interaction coefficients α and β must be constrained in magnitude. Moreover, there must be restrictions on the relative price of the off-takes if the degree of competition is biased. If, say, the interspecific competition is largely biased in favour of the wildlife so that $\beta \gg \alpha$ holds, the off-take price ratio q/p must be constrained in magnitude.¹⁵ See also Figure 2.

In what follows, it is assumed that both $r - \delta$ and $s - \delta + w/q$ are positive. So if the maximum specific growth rates are above that of the rate of discount, which is quite reasonable for large African mammals (see e.g., Caughley and Sinclair, 1995), it is seen from Figure 2 that the condition for obtaining an interior solution, $X^* > 0$ and $Y^* > 0$, will be fulfilled if the interaction between the stocks is not too heavy, i.e., just as in the ecological model without harvesting. It will therefore be no wildlife in the long term if the stock equilibrium condition for cattle (8) intersects with the Y -axis outside that of the stock equilibrium condition for wildlife (7). $(s - \delta + w/q)/(2s/L) > (r - \delta)/(\alpha + (q/p)\beta)$ must then hold. The condition for having a positive stock of wildlife is therefore also captured by a very simple parametric representation under the given specific functional forms. Hence, if the competition between the species is fierce (α and β large), the off-take price of wildlife compared with cattle is low (q/p large), the marginal

¹⁵ In the linear model $p > 0$ must always hold to fulfil the second order conditions (see also Appendix 2).

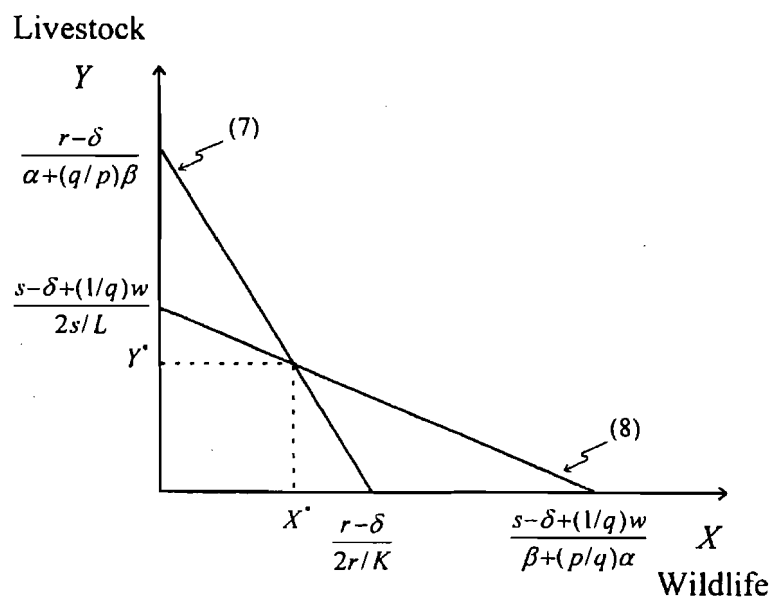


Figure 2: *The Linearised Model: Long-term Stock Equilibrium under the Market Solution*

non-consumptive benefit ratio of cattle is large (w/q large) and the wildlife is slow-growing (r low), the pastoralists will keep only livestock in the long term. The presence of fast-growing cattle (s high), however, does not necessarily work in the same direction. The symmetric representation of the competition coefficient should also be noticed; it is a general high degree of competition that can make extermination of the wildlife an optimal policy, not only a high degree of nuisance from wildlife to cattle. When equation (7) intersects at the X-axis outside that of equation (8) so that $(r - \delta)/(2r/K) > (s - \delta + w/q)/(\beta + (p/q)\alpha)$ holds, there will be no cattle in the long run. Hence, if the competition between the species is fierce, q/p and w/q are small and cattle is slow-growing (s low), keeping only wildlife can be an optimal policy.

4. The Conservation Perspective

Summing up the above results when only the cost and the benefits of the pastoralists influence the stock sizes, i.e., the market solution, we can conclude that a low positive price of the wildlife off-take will always be a threat to wildlife in the present setting. In the linearised

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model this threat is also identified as a high off-take price ratio q/p . When the value of the non-consumptive benefit of the livestock is high there will be strong incentives to shrink the wildlife stock in the long-term as well. In the linearised model this threat is also identified as a high marginal benefit ratio w/q . Ecological factors also play a role. Consequently, the wildlife will be threatened if there is a high degree of grazing competition among the two stocks and the wildlife is slow-growing. On the other hand, the pastoralists will favour wildlife at the expense of cattle if the off-take price ratio q/p is low and the marginal benefit ratio w/q is low. The possibility of a complete abandoning of cattle herding increases if the interspecific competition is fierce and the cattle is slow-growing.

The stock sizes and off-take rates in the market solution will, however, differ compared with what is socially optimal because there generally will be present a stock value of the wildlife as existence value, biodiversity and so forth, not taken care of by the pastoralists. In particular, this will be so if the wildlife belongs to a relatively rare and threatened species (Krutilla, 1967). We therefore now introduce a public good value of the wildlife as given by equation (9). $B(X)$ is also assumed to be non-negative and concave, $B(0) \geq 0$, $B_X > 0$ and $B_{XX} \leq 0$. The public good value can be recognised through national and international conservation groups etc., or it can be recognised by the government.

$$(9) \quad B = B(X).$$

Current overall benefits are therefore given by $pf + qg + W(Y) + B(X)$. Overall optimal stock investments are then found by maximisation of equation (10), again subject to the ecological constraints (1) and (2).¹⁶

$$(10) \quad PV^s = \int_0^{\infty} (pf + qg + W(Y) + B(X))e^{-\delta t} dt.$$

¹⁶ It is usually argued (see e.g., Markandya and Pearce, 1988) that the rate of discount of people living in semi-arid regions in Africa will be high and well above that of the social rate. In what follows, however, this discrepancy is disregarded.

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It can be checked that equations (6) and (11) give the reduced form long-term necessary conditions for maximum. These two equations therefore determine the long-term overall optimal stock sizes as X^s and Y^s (superscript 's' denotes social or overall optimality). It can be confirmed that we will now have $X^s > X^*$. Moreover, because of increased competition for the livestock as a result of more wildlife, it also follows that $Y^s < Y^*$ will hold in the long term. See also Figure 1. The general conclusion when introducing a non-consumptive good of the wildlife is therefore that the market solution, i.e., the situation when the public good nature of the wildlife is disregarded, will give too little wildlife and too much livestock.

$$(11) \quad F_X(X, Y) + B_X(X)/p = \delta - (q/p)G_X(Y, X).$$

There is therefore room for economic policy and interventions to move the outcome of the market solution in direction of the social optimal stock sizes. Generally, there will be two types of policy options: direct regulation of the off-take and indirect regulations through economic incentives, i.e., internalising the public good value of the wildlife through the market mechanism. In what follows, it will be assumed that the pastoralists feel no obligation to behave according to regulations through the legal system, and that there is no law enforcement to ensure that they do (see Section 1). The only way considered to direct the investment decisions of the pastoralists will therefore be through economic incentives. The economic incentives may come from foreign policy interventions like CITES or other trade interventions, or by international conservation efforts taking place through direct payment for conservation. As already mentioned, the government may also pursue policy interventions. However, it is beyond the scope of this paper to discuss how taxes and payment transfers actually should be collected and distributed.

The first policy option to be considered is a tax-cum-subsidy to wildlife products, giving a permanent shift in the producer price of the off-take of wildlife. This may be implemented nationally or by international regulation of wildlife trade, both aiming to adjust the misallocation of the market solution. Because an increased off-take price shifts the wildlife stock up, a subsidy which increases the producer price on harvesting will therefore work in the right

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direction.¹⁷ It is also clear that the recommendation of the CITES convention to impose restrictions on trade with wildlife products in order to reduce the profitability of wildlife harvesting and reduce the off-take price will work counterproductively in the present setting. The outcome will namely be less wildlife and more livestock compared with the market solution, and therefore stock sizes that are even further away from what is socially optimal.

To some extent, this conclusion rests on our assumption of no stock-independent harvesting costs of the wildlife. If stock-dependent costs are included, however, the opposite conclusion can be reached only if this component is sufficiently large to dominate the marginal effects originating from the nuisance term and the partial reduction of the cattle stock (see footnote 13). But in such a case, the size of the wildlife stock would have been larger than without stock-dependent costs. The presence of a negative price effect would therefore have been associated with a more viable and less endangered wildlife population compared with our scenario of no stock-dependent harvesting costs. When addressing the problem of endangered wild species, the stock-dependent harvesting costs, if present, are therefore likely to be small. Consequently, for endangered species managed in a controlled way, i.e., when disregarding any 'open-access' problems as in the present context, it is most likely that the price effect is positive and working in the opposite direction of the assumed CITES-policy.¹⁸ As demonstrated, we can also reach the conclusion of a negative price effect if the wildlife essentially is a nuisance. However, for such low-valued species the relevance of CITES-policy is limited because CITES is basically dealing with species of a high commercial harvesting value.

Another policy option is to change the price of the off-take of the livestock. As the analysis in Section 3 demonstrates, such a policy has unclear stock effects. However, if the marginal non-consumptive benefit effect is small, a tax which shifts the producer price on the livestock off-take down will work in the right direction as the size of

¹⁷ However, it should be noted that if the right wildlife stock level is reached, it is not generally possible to reach the social optimal size of the livestock. There are namely two targets and only one policy variable.

¹⁸ However, this does not mean that the CITES-policy cannot work under other circumstances. For example, it may work if there are 'open-access' problems.

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the livestock will shrink and the wildlife population will increase. If the marginal non-consumptive stock effect is sufficiently large, however, the effect will be ambiguous. Irrespective of the consequences for the stock sizes, such a policy will, however, have quite different welfare effects for the local people compared with the above case of subsidy of the price of the wildlife. Namely, a subsidy giving a marginal positive shift in the off-take price of the wildlife will change the present-value benefit stream positively according to

$$\partial PV^* / \partial p = \int_0^{\infty} f e^{-\delta t} dt$$

where f is evaluated along the optimal path (see e.g., Kamien and Schwartz, 1991, Ch. II8). On the other hand, a tax shifting the harvesting price of the cattle marginally down reduces the present-value benefit according to

$$\partial PV^* / \partial q = \int_0^{\infty} g e^{-\delta t} dt.$$

Here, again, the harvesting rate is evaluated along the optimal path.

A third policy option to achieve overall optimality is to impose a subsidy related to the stock of wildlife, and we will basically think of this as an international transfer reflecting a direct payment for conservation.¹⁹ When the public good value of the wildlife is reflected through a stock transfer related to the stock size as $T = T(X)$, the objective function of the pastoralists then changes from (4) to (12). The long-run stock equilibrium conditions will now therefore be equations (6) and (13).

$$(12) \quad PV^T = \int_0^{\infty} (pf + qg + W(Y) + T(X)) e^{-\delta t} dt$$

¹⁹ See Simpson and Sedjo (1996) for a general discussion. They make a distinction between direct and indirect payment for conservation. Indirect payment is efforts intended to commercialise natural products.

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$$(13) \quad F_X(X, Y) + T_X(X)/p = \delta - (q/p)G_X(Y, X).$$

By comparing the conditions (6) and (11) with overall optimality, it is seen that the international transfer rate $T_X = B_X(X^s)$ (\$ per wildlife animal per unit of time), and hence a total transfer of $T = B_X(X^s) X^s$ (\$ per unit of time), will bring the market solution in accordance with overall optimality.²⁰ So, using a stock related transfer, it is therefore possible to safeguard the wildlife and reach overall optimality.²¹

5. Concluding Remarks

In this paper we have, from a theoretical point of view, analysed economic and ecological mechanisms determining wildlife investments in the context of pastoral exploitation of the semi-arid African rangeland. The pastoralists, treated as a homogeneous group having sole access to a fixed area of pasture, are practising two production activities: cattle herding and wildlife harvesting. The livestock provides consumptive benefits when being slaughtered (meat, skins etc.) and non-consumptive benefits (milk, status, insurance etc.). Wildlife represents only consumptive benefits for the pastoralists. Livestock and wildlife interact with each other as there is competition for grazing land. It is assumed that the pastoralist's livestock and wildlife investments are steered by long-term considerations and that they seek to maximise present-value benefit. Because of the ecological interdependency, there will also be an economic interdependency.

In this setting, factors working in the direction of threatening the wildlife are identified. It is demonstrated that, unlike the result of the standard harvesting model (Clark, 1990), a low positive price of

²⁰ This reasoning can also be interpreted in light of the Coase theorem (Coase, 1960) given that the property rights to the wildlife and its habitat are recognised as belonging to the pastoralists. In the present context, this implies that the most efficient way to reach overall optimality is that the conservationists should compensate the pastoralists not to deplete the wildlife stock below X^* .

²¹ Consequently, when introducing only one stock related transfer it is possible to reach two targets. This result hinges on the structure of the equations characterising the market solution and the social solution. It is namely only one discrepancy which is linked to the size of the wildlife stock. In Figure 1 this is identified as the same long-term stock equilibrium condition for the livestock (6), while the stock equilibrium condition for the wildlife (5) shifts according to the size of the non-consumptive stock effect.

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wildlife products will be a threat to the wildlife. When the value of the non-consumptive benefit of the livestock is high there will also be problems for the wildlife to pay its way so there will be strong incentives for the pastoralists to shrink the wildlife stock. This result clearly fits intuitive reasoning, and to the extent that cultural changes and modernisation reduce the non-consumptive livestock valuation, the threat is therefore reduced. The consumptive value of the livestock has an ambiguous effect, but under certain conditions a high consumptive value will motivate for reducing the wildlife population. This will be so if the non-consumptive benefit of the livestock is small and of minor importance, i.e., we have a modernised type of pastoralism where the livestock benefit is primarily attached to the value of slaughtered animals (see e.g., Konczacki, 1978). Under such a scenario, our model contrasts the recommendation of Brown *et al.* (1993) of increasing the profitability in agropastoral and pastoral activities to safeguard wildlife populations. The result is therefore in line with the model of Schulz and Skonhott (1996), which finds that improved profitability in agropastoral activities is always a threat to wildlife as it triggers land conversion. However, when the non-consumptive benefit of livestock is large, i.e., with the more traditional mode of pastoralism, the effects of a more valuable cattle off-take is ambiguous.

In a next step, we consider the social optimal stock investments when adding a public good value to the wildlife, as representing existence value, biodiversity and so forth, not taken care of by the pastoralists. The public good value can be recognised through international conservation groups or by the government. The result will be more wildlife and less livestock compared with the situation when only the benefits of the pastoralists influence the stock sizes, i.e., the market solution. Policies to change the market solution in the direction of overall optimality are then analysed. It is shown that giving values to wildlife products will work in the direction of safeguarding the wildlife. Hence, policy interventions like CITES will in our setting of a controlled management regime work counter-productively as reduced profitability in wildlife harvesting will give less wildlife in the long-term. A policy option to increase the off-take price through subsidies of the livestock can also work counter-productively, while an international payment for conservation linked to the stock size of the wildlife will give the pastoralists incentives to

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increase the wildlife stock and therefore bring the market solution more in accordance to what is socially optimal.

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Appendix 1

Necessary conditions for maximum of the problem in Section 3 are $\partial H/\partial f = 0$, $\partial H/\partial g = 0$, $d\mu/dt = \delta\mu - \partial H/\partial X$ and $d\lambda/dt = \delta\lambda - \partial H/\partial Y$. When eliminating the shadow prices, we arrive at equations (5) and (6), which represent a singular system.

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 $F_{XX} + (q/p) G_{XX} \leq 0$, $(F_{XX} + (q/p)G_{XX})(G_{YY} + (p/q)F_{YY} + (1/q)W_{YY}) - (F_{XY} + (q/p)G_{XY})(G_{YX} + (p/q)F_{YX}) \geq 0$ and $G_{YY} + (p/q)F_{YY} + (1/q)W_{YY} \leq 0$. The second of these conditions implies that equation (5) will be steeper than (6). Hence, at the optimum (5) will intersect with (6) from above (see Figure 1). Increased marginal valuation of the non-consumptive benefits of the livestock is introduced by adding a shift-factor $\gamma > 0$ to (6) as in (A1). The effect of increased marginal stock-valuation is then demonstrated as $\partial X^*/\partial \gamma$.

$$(A1) \quad G_Y(Y, X) + W_Y(Y)/q + \gamma/q = \delta - (p/q)F_Y(X, Y).$$

The comparative static results are found by taking the total differential of (5) and (A1). (A2) shows the result.

$$(A2) \quad \begin{bmatrix} F_{XX} + (q/p)G_{XX} & F_{XY} + (q/p)G_{XY} \\ G_{YX} + (p/q)F_{YX} & G_{YY} + (p/q)F_{YY} + (1/q)W_{YY} \end{bmatrix} \begin{bmatrix} dX \\ dY \end{bmatrix} = \begin{bmatrix} dp \\ dq \\ d\delta \\ d\gamma \end{bmatrix}$$

$$\begin{bmatrix} (q/p^2)G_X & -(1/p)G_X & 1 & 0 \\ -(1/q)F_Y & (1/q^2)(pF_Y + W_Y + \gamma) & 1 & -1/q \end{bmatrix}$$

The determinant of the left-hand side of (A2),

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$$N = (F_{XX} + (q/p)G_{XX})(G_{YY} + (p/q)F_{YY} + (1/q)W_{YY}) - (F_{XY} + (q/p)G_{XY})(G_{YX} + (p/q)F_{YX}),$$

will be strictly positive in optimum due to the second order conditions for maximum, $N > 0$. We then obtain

$$\frac{\partial X^*}{\partial p} = \frac{\frac{q}{p^2}G_X(G_{YY} + (p/q)F_{YY} + W_{YY}/q) + \frac{1}{q}F_Y(F_{XY} + (q/p)G_{XY})}{N} > 0,$$

$$\frac{\partial Y^*}{\partial p} = \frac{-\frac{1}{q}F_Y(F_{XX} + (q/p)G_{XX}) - \frac{q}{p^2}G_X(G_{YX} + (p/q)F_{YX})}{N} < 0,$$

$$\frac{\partial X^*}{\partial q} = \frac{\frac{1}{q^2}(pF_Y + W_Y + \gamma)(F_{XX} + (q/p)G_{XX}) + \frac{1}{p}G_X(G_{YX} + (p/q)F_{YX})}{N} = ?,$$

$$\frac{\partial X^*}{\partial q} = \frac{-\frac{1}{p}G_X(G_{YY} + (p/q)F_{YY} + W_{YY}/q) - \frac{1}{q^2}(pF_Y + W_Y + \gamma)(F_{XY} + (q/p)G_{XY})}{N} = ?,$$

$$\frac{\partial X^*}{\partial \delta} = \frac{(G_{YY} + (p/q)F_{YY} + W_{YY}/q) - (F_{XY} + (q/p)G_{XY})}{N} = ?,$$

$$\frac{\partial Y^*}{\partial \delta} = \frac{(F_{XX} + (q/p)G_{XX}) - (G_{YX} + (p/q)F_{YX})}{N} = ?,$$

$$\frac{\partial X^*}{\partial \gamma} = \frac{\frac{1}{q}(F_{XY} + (q/p)G_{XY})}{N} < 0,$$

$$\frac{\partial Y^*}{\partial \gamma} = \frac{-\frac{1}{q}(F_{XX} + (q/p)G_{XX})}{N} > 0.$$

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Appendix 2

When there is attached a net negative harvesting value to the wildlife, i.e., the wildlife is essentially representing a nuisance, we can replace p by $-c$, where $c > 0$ is the net harvesting cost. The reduced form necessary conditions for maximum when an interior solution is supposed to be present are then given by (A3) and (A4):

$$(A3) \quad F_X(X, Y) = \delta + (q/c)G_X(Y, X),$$

$$(A4) \quad G_Y(Y, X) + W_Y(Y)/q = \delta + (c/q)F_Y(X, Y).$$

The second order conditions for maximum, requiring joint concavity of the Hamiltonian in the state and control variables, are now $F_{XX} - (q/c)G_{XX} \geq 0$, $(F_{XX} - (q/c)G_{XX})(G_{YY} - (c/q)F_{YY} + (1/q)W_{YY}) - (F_{XY} - (q/c)G_{XY})(G_{YX} - (c/q)F_{YX}) \leq 0$ and $G_{YY} - (c/q)F_{YY} + (1/q)W_{YY} \leq 0$. Hence, to obtain an interior optimal solution, G_{XX} has to be negative and less than $(c/q)F_{XX}$, while F_{YY} cannot, if negative, be less than $(q/c)G_{YY} + W_{YY}/c$.

The effect of an increase in the price, i.e., a decrease in c , is found by taking the total differential of (A3) and (A4) with respect to X , Y and c . (A5) shows the result.

$$(A5) \quad \begin{bmatrix} F_{XX} - (q/c)G_{XX} & F_{XY} - (q/c)G_{XY} \\ G_{YX} - (c/q)F_{YX} & G_{YY} - (c/q)F_{YY} + (1/q)W_{YY} \end{bmatrix} \begin{bmatrix} dX \\ dY \end{bmatrix} = \begin{bmatrix} -(q/c^2)G_X \\ (1/q)F_Y \end{bmatrix} dc.$$

The determinant of the left-hand side of (A5), $M = (F_{XX} - (q/c)G_{XX})(G_{YY} - (c/q)F_{YY} + (1/q)W_{YY}) - (F_{XY} - (q/c)G_{XY})(G_{YX} - (c/q)F_{YX})$, will be strictly negative in optimum due to the second order conditions for maximum, $M < 0$. We then obtain

$$\frac{\partial X^*}{\partial c} = \frac{-\frac{q}{c^2}G_X(G_{YY} - (c/q)F_{YY} + W_{YY}/q) - \frac{1}{q}F_Y(F_{XY} - (q/c)G_{XY})}{M}.$$

The sign of $\partial X^*/\partial c$ is generally ambiguous. But $\partial X^*/\partial c$ will be positive if $(F_{XY} - (q/c)G_{XY})$ is negative. If not, $\partial X^*/\partial c$ will still be positive if the positive value of $(F_{XY} - (q/c)G_{XY})$ is not too large. Recalling that $(F_{XY} - (q/c)G_{XY})$ is constrained in magnitude (due to the second order conditions), we will most likely have that $\partial X^*/\partial c$ is positive. Hence, an increase in the price (reduced c) will most likely lead to a reduction of the wildlife stock in the case when there are net costs attached to harvesting.

Appendix 3

For the specific functional forms of equations (1') and (2') and $W(Y) = wY$, it can be verified that the second order conditions now will be $-2r/K \leq 0$, $(4rs/KL) - ((q/p)\beta^2 + 2\alpha\beta + (p/q)\alpha^2) \geq 0$ and $-2s/L \leq 0$.

The comparative static results of the linearised model are found by taking the total differential of equations (7) and (8). (A6) gives the result.

$$(A6) \quad \begin{bmatrix} -2r/K & -(\alpha + (q/p)\beta) \\ -(\beta + (p/q)\alpha) & -2s/L \end{bmatrix} \begin{bmatrix} dX \\ dY \end{bmatrix} = \begin{bmatrix} dp \\ dq \\ d\delta \\ dw \end{bmatrix} \begin{bmatrix} -(q/p^2)\beta Y & (1/p)\beta Y & 1 & 0 \\ (1/q)\alpha X & -(1/q^2)(p\alpha X - w) & 1 & -1/q \end{bmatrix}$$

The determinant of the left-hand side of (A6), $D = (4rs/KL) - ((q/p)\beta^2 + 2\alpha\beta + (p/q)\alpha^2)$, will be strictly positive in optimum due to the second order conditions for maximum, $D > 0$. We then obtain

$$\frac{\partial X^*}{\partial p} = \frac{\frac{2sq\beta}{Lp^2}Y + \frac{\alpha}{q}X(\alpha + q/p)\beta}{D} > 0,$$

$$\frac{\partial Y^*}{\partial p} = \frac{-\frac{2r\alpha}{Kq}X - \frac{q\beta}{p^2}Y(\beta + (p/q)\alpha)}{D} < 0,$$

$$\frac{\partial X^*}{\partial q} = \frac{-\frac{2s\beta}{Lp}Y - \frac{(p\alpha X - w)}{q^2}(\alpha + (q/p)\beta)}{D} = ?,$$

$$\frac{\partial Y^*}{\partial q} = \frac{\frac{2r}{Kq^2}(p\alpha X - w) + \frac{\beta}{p}Y(\beta + (p/q)\alpha)}{D} = ?,$$

$$\frac{\partial X^*}{\partial \delta} = \frac{-\frac{2s}{L} + (\alpha + (q/p)\beta)}{D} = ?,$$

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$$\frac{\partial Y^*}{\partial \delta} = \frac{-\frac{2r}{K} + (\beta + (p/q)\alpha)}{D} = ?,$$

$$> \frac{\partial X^*}{\partial w} = \frac{-\frac{1}{q}(\alpha + (q/p)\beta)}{D} < 0,$$

$$\frac{\partial Y^*}{\partial w} = \frac{\frac{2r}{Kq}}{D} > 0.$$