An evolutionary approach to wildlife damage of economic activity

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Abstract:

This paper models the effects of wildlife conservation on a community of farmers living in the surroundings of a national park. Community members undertake not only traditional farming activities, but also defensive hunting. In later versions of the manuscript some farmers will complement their earnings with eco-tourism activities. The park authority obtains some revenues from eco-tourism activities and can share part of these earnings with community members. Traditional conflict on carnivores' predation on livestock is still present, but will be modified in those cases where farmers extract additional rents from tourism activities or where the park agency shares part of its income. Traditional farmers hunt carnivores to reduce their loss of livestock. Using and evolutionary economics approach, we explore existence and stability conditions of equilibria in the system, showing that new stable equilibria where wildlife is more highly valued emerge when benefit-sharing policies take place. It is to be seen if this effect is maintained for eco-tourism activities. In addition, benefit-sharing policies entail higher levels of wildlife conservation.

Wildlife; Bioeconomic modeling; Predation; Hunting; Tourism; Europe.

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1. INTRODUCTION

Wildlife Management has been based historically in a strategy of 'Fences and Fines'. That is to say, on the establishment of strongly restricted uses in natural protected areas entailing very often the displacement of rural communities. The result of such strategy is that wildlife becomes a nuisance for locals: herbivores compete for pasture with livestock, predators kill livestock and endanger the life of members of the communities. In short, local communities bear the real cost of wildlife protection but do not get any of the benefits. An observable result has been persistently high levels of poaching which threaten the objectives of preservation of wildlife.

A policy response to this reality has been benefit-sharing policies for local populations to grasp some of the positive effects of wildlife. In many cases this implies that park authorities give cash transfers to local communities. These are supported on the basis of increases of welfare of local communities jointly with improved wildlife stocks.

Previous economic research has addressed the validity of the emergence of these benefits. Skonhoft (1998) develops a simple model where a park authority obtains revenue from hunting licenses and tourism activities and a local population of agropastoralists for whom wildlife is a nuisance. The paper addresses the impact of redirecting some of the benefit stream from the park authority to local residents. The paper shows that the park manager responds by enhancing efforts for wildlife conservation. This effect responds to a decreased return from safari hunting as compared to wildlife for tourism (non-consumptive) uses. Johannesen and Skonhoft (2005) extend this simple setting by considering that both the park manager and the local people can harvest wildlife: The former, once again, through safari hunting and the latter, by illegal poaching. In this context of strategic interdependence between the agents, different compensation flows are considered. The paper supports that wildlife conservation objectives strengthened when the park authority transfers a fixed share of the park profits or a fixed share of profits from safari hunting. However, the effect on stocks of wildlife of income transfers from non-consumptive tourism is ambiguous. Depending on the relative value of game meat for local people and price of safari hunting licenses, the stock of wildlife can increase or decrease. This ambiguous effect is more intense when considering in addition that local people can expand its agricultural land, thus destroying habitat (Bulte and Rondeau, 2007). It is also more intense when taking into account the discrepancy between management geography and biological geography (Skonhoft, 2007). That is, when considering that wildlife can move in and out park boundaries as a response to hunting effort and habitat conditions. When both habitat destruction and discrepancy between management and biological geography are considered together, the effect of benefit-sharing policies on welfare of local communities and conservation objectives are also ambiguous (Skonhoft and Amstron, 2005). Thus, under certain circumstances compensation mechanisms can act as perverse incentives leading to the opposite of its policy goals (Bulke and Rondeau, 2007).

The contribution of this paper is to extend Johannesen and Skonhoft (2005) from a twofold perspective. First, we consider a dynamic analysis which is not only based on the steady state, but takes into account the dynamic path of poaching strategies in local communities. Second, members of these communities are not all considered to follow the same strategies, but each individual can choose her own strategy. Payoffs from each strategy will depend on the strategy chosen by each individual, the strategies chosen by all other members of the community, and the stock of wildlife.

To do so, we adopt evolutionary game theory to build our model. Since evolutionary game theory studies populations playing games, rather than the behavior of rational individuals, it is particularly useful for studying institutional change (Friedman, 1991, 1998; Mailath, 1998). The origins of such an approach are in evolutionary biology, but the approach is increasingly being used in economic and social sciences (Nowak & Sigmund, 2004). Under evolutionary game theory, payoffs depend on players' actions and the actions of the co-players in the population. Strategies with high payoffs spread through learning, imitation, or other forms of cultural evolution (Friedman, 1991, 1998; Hofbauer & Sigmund, 2003). This shift in strategy has some inertia, which can be attributed to adjustment costs, information imperfections, or bounded rationality (Friedman, 1998). Furthermore, players do not systematically attempt to influence future play of others (Friedman, 1998), nor do they take into consideration the possibility that others adjust their behavior strategically (Mailath, 1998). One justification for this is the existence of a large number of players (Friedman, 1998; Mailath, 1998). This naïve behavior is one crucial difference between evolutionary games and repeated games in orthodox game theory (Friedman, 1998). A second major difference is that the focus of study of evolutionary game theory is the dynamic behavior of the system (Mailath, 1998), extending classical game theory away from the static doctrine of the Nash solution concept (Friedman, 1991; Hofbauer et al., 2003; Nowak et al., 2004)

The main advantage of using evolutionary game theory is that it enables the researcher to discriminate between different equilibria (Mailath, 1998; Nowak et al., 2004; Sethi et al., 1996). It is possible to distinguish stable from unstable equilibria and to identify the regions of initial conditions that eventually lead to a given equilibrium (i.e., basins of attraction) (Friedman, 1991, 1998). In addition, it is preferable in our analysis since it better considers the role of resources dynamics on the long run behavior of players. It is argued that standard game theory frequently fails to consider the dynamic nature of natural resources on equilibrium outcomes (Osés & Viladrich, 2007). This is partly because defining and interpreting subgame perfect equilibrium is easier with a discrete time approach, whereas analyzing a renewable resource model is more amenable to a continuous time approach (Tarui, Mason, Polansky, & Ellis, 2008). Finally, in evolutionary game theory, the equilibrium that players eventually reach is determined by the original distribution of players in the population, the underlying game, and the way strategies spread (Friedman, 1998; Hofbauer et al., 2003), i.e., history matters in achieving a steady state of the system (Mailath, 1998).

This methodology has been previously used in environmental economics more generally (Nyborg and Rege, 2003; Rege, 2004) and also in particular to consider voluntary environmental behavior (Blanco et al., 2009; Nyborg et al., 2006;

Osés and Viladrich, 2007; Sethi and Somanathan, 1996). Sethi and Somanathan (1996) analyze players' environmental behaviors in a population where players can extract low or high levels of a natural resource and where costly informal punishment (for those inflicting and suffering it) is possible among players in response to the observed behavior of others. Using the same methodology, Osés and Viladrich (2007) concentrate on results when environmentally sensitive players enjoy informal social benefits associated with responsible behavior. Nyborg et al. (2006), base their analysis on the existence of internal motivation affecting the decision of whether or not buying green products. Unlike these previous studies, in Blanco et al. (2009) and Lozano et al. (2010), only market forces motivate voluntary environmental contributions. Blanco et al. (2009) consider the development of voluntary environmental action by a population of tourism firms which profits are endogenously affected by the state of natural capital. Lozano et al. (2010) consider two environmentally-friendly strategies as opposed to the non-green strategy in a more general setting where natural capital is exogenous. As far as the authors are aware of, there is no previous application of evolutionary game theory to the conflict between wildlife preservation and the well-being of local populations.

The rest of the manuscript is organized as follows: Section 2 presents the model for wildlife-communities interactions. Section 3 presents the result for the model when there is no benefit-sharing by the park agency. Section 4 extends section 2 by including the possibility that a park authority shares part of its benefits with the local population in form of cash transfers. Section 5 presents some policy implications of the comparison between results in sections 3 and 4. Finally, section 6 presents ideas for further research.

2. THE MODEL

We consider the existence of a native population of agropastoralists that uses land next to a national park. Wildlife freely moves in and out of the national park. When wildlife enters the land of the local community it generates agricultural damages or losses of livestock. In either way, it constitutes a nuisance for local people. Members of the local community can hunt for wildlife that moves out of the border of the national park. Hunting is illegal, but drives to main benefits to the local community. On the one hand it reduces wildlife damages to the community and on the other hand it provides benefits from the game.

At this stage we consider that poaching reduces wildlife damage in the same way to all members of the community. Thus, it has public good attributes. In later version of this manuscript we will consider that poaching effort has only local effects in terms of avoided damage and therefore poachers benefit more intensively of avoided damage by wildlife.

All members of the community can choose between two hunting efforts, that for convenience we refer to as high and low. The utility function for each strategy depend on the net benefits from hunting $B(e_i, K)$, which depend on the hunting effort (e^i) with subserscript h for high effort and l for low effort, and the stock of wildlife, K. Utility also depends on the damage cost $D(K)$, which is assumed to depend on the size of the stock.

$$U_h = B_h(e_h, K) - D(K) \tag{1.1}$$

$$U_l = B_l(e_l, K) - D(K) \tag{1.2}$$

where $e_h > e_l$.

The damage functions are assumed to be linear, i.e. $D(K) = \gamma K$; and the net benefit functions of hunting may be expressed as $B_i(e_i, K) = p_i y_i(e_i, K) - c e_i$ where p^j is the price of game for the local population and c_i is the unit cost of organizing the hunting, both assumed to be fixed. The harvest functions, y_i, are re specified as Gordon–Schäfer functions $y_i(e_i, K) = e_i K$. Thus, we can re-write equations 1.1 and 1.2 as:

$$U_h = Pe_h K - c e_h - \gamma K \tag{2.1}$$

$$U_l = Pe_l K - c e_l - \gamma K \tag{2.2}$$

Payoffs for members following each strategy depend on the composition of the population. According to evolutionary game theory, payoff differentials exert evolutionary pressures on the composition of the population, encouraging it to evolve in favor of those groups earning the highest payoff. That is to say, members of the community respond to differences in payoffs by modifying their strategies. This behavioral pattern does not change instantaneously. This is modeled here using the replicator dynamics, which are the simplest evolutionary dynamics one can use to investigate the dynamic properties of stable evolutionary strategies (Mailath, 1998; Sethi and Somanathan, 1996):

$$\dot{s}_i = s_i(U_i - \overline{U}), \text{ i= h, l} \tag{3}$$

where $\dot{s}_i$ is the change in time of the proportion of each population strategy over time, and $\overline{U}$ is the average payoff in the population as a whole. Because shares of the population composition must equal 1, the system can be reduced to its specification for low effort hunters, and the high-effort hunting strategy can be determined residually. Then, the replicator dynamics becomes:

$$\dot{s}_l = s_l(1 - s_l)(U_l - U_h) \tag{4}$$

If we combine equations 2.1, 2.2 and 4, the replicator dynamics becomes the following:

$$\dot{s}_l = s_l(1 - s_l)\left[-PK(e_h - e_l) + c(e_h - e_l)\right] \tag{5}$$

Note that since wildlife damage enters the utility function of both strategies in the same way, i.e. decreased nuisance due to hunting is a public good, it does not affect strategy selection and thus does not enter in the replicator dynamics. This will not be the case in future versions of the manuscript.

The system will be in equilibrium when $\dot{s}_l = 0$, that is, when there is no change in the population's composition. In the following, the concept of local asymptotic stability will be extensively used. Equilibrium is locally asymptotically stable when

every motion starting sufficiently near the equilibrium point converges to it as time tends toward infinity.

In addition to the local community, there is an agency managing the national park. This agency obtains some revenues from tourism. The amount of tourism revenues positively depends on the wildlife stock in the following way:

Tourism revenues=wK

Under the benefit-sharing regime the agency distributes a share β of these revenues in equal terms among those members of the population that opt for low hunting. Payoffs for a low hunter are, therefore:

$$U_l = Pe_l K - ce_l - \gamma K + \frac{\beta w K}{s_l}$$

And the dynamics become:

$$\dot{s}_l = s_l(1-s_l)\left[-PK(e_h - e_l) + c(e_h - e_l) + \frac{\beta w K}{N s_l}\right] \qquad (5')$$

We further assume that wildlife in the park is a renewable resource with a logistic natural growth. Thus, the dynamics of wildlife stock will be determined positively by natural growth $F(K)$ and negatively by hunting activities. The severity of hunting over the dynamics of wildlife will depend on the size of the community N, the share of members following each strategy, s_i, and respective hunting efforts, e_i.

$$\dot{K} = F(K) - NK\big(s_l e_l + (1-s_l)e_h\big) \qquad (6)$$

3. THE SOLUTION WITHOUT BENEFIT-SHARING

When the park authority does not share any of its tourism income with the local population, there are two type of equilibria which can take place. First, it is possible that in the long-run different members of the community exercise different hunting efforts, with some community members making low hunting effort and other making high hunting effort. This is presented in section 3.1. Second, it is possible that in the long run the whole community makes the same hunting effort, being it either high or low. This second type of equilibria are presented in section 3.2.

3.1. Equilibrium where community members make different hunting efforts

Proposition 1.a: When there is no benefit-sharing, there is at most one heterogeneous steady state with the following variables values:

$$K^* = \frac{c}{P}\;;\; s_l^* = \frac{e_h}{e_h - e_l} - \frac{F(K^*)}{K^*} \cdot \frac{1}{N(e_h - e_l)}.$$

That is, the equilibrium stock of wildlife positively depends on the hunting costs per unit of effort, c, and inversely depends on the benefit of game meat, P. The size of the proportion of low-effort hunters depends inversely on the proportion of hunting effort reduction to be considered as a low-effort hunter (inverse of the first term of the expression of s_l^*). It also depends negatively on the relation between the

regenerative capacity and the steady-state level of wildlife, and positively on the population size.

Once studied the existence of the heterogeneous equilibrium, proposition 1.b addresses its stability.

Proposition 1.b: The heterogeneous steady state is stable if and only if the marginal regenerative capacity is lower than the aggregate hunting effort in the community $(F'(K^*) < N(s_l e_l + (1-s_l)e_h))$.

Proof: The steady state of a two-dimensional system is locally asymptotically stable when the determinant of the Jacobian evaluated at that point has a positive value while the trace is negative. It is locally asymptotically unstable when both the determinant and the trace are positive, whereas it is a saddle-point when the determinant is negative (Gandolfo, 1996). Taking the following derivatives, we can specify the determinant and the trace of the Jacobian:

$$\partial \dot{s}_l / s_l = 0 \ ;$$

$$\partial \dot{s}_l / K = -s_l(1-s_l)P(e_h - e_l) \ ;$$

$$\partial \dot{K} / s_l = NK(e_h - e_l) \ ;$$

$$\partial \dot{K} / K = F'(K) - N(s_l e_l + (1-s_l)e_h) \ .$$

$$Det = s_l(1-s_l)NPK(e_h - e_l)^2 > 0$$
$$Trace = F'(K) - N(s_l e_l + (1-s_l)e_h)$$

When evaluated at the equilibrium in proposition 1.a., the determinant is always positive. Moreover, for the trace to be negative it is necessary and sufficient that $F'(K) < N(s_l e_l + (1-s_l)e_h)$. ∎

Corollary 1. It is a sufficient (but not necessary) condition for the existence on an stable heterogeneous steady state that the marginal regenerative capacity of the wildlife stock is negative (F'(K)<0). Even if the marginal regenerative capacity of the wildlife stock is positive, the heterogeneous equilibrium can be stable ($F'(K^*)>0$).

Thus, a sufficient condition for different hunting efforts by community members to take place in the long run is that the wildlife stock is such that an increase of it reduces its regenerative capacity. In a standard logistic equation this holds for high levels of the stock. This condition is necessary but not sufficient, since it can be the case that the community displays different hunting efforts for stocks of wildlife such that an increase in the stock implies an increase in its regenerative capacity. This is a striking result as *F'(K)>0* implies that the natural dynamics of the resource push the resource out of the equilibrium level after having been affected by external shocks. However, in our model the dependence of the hunting behaviour on the resource level exerts a counterbalancing effect that may give stability to an equilibrium where

$F'(K)>0$: When $F'(K)>0$ a reduction in the resource level causes reductions in the replenishment capacity that feeds new future reductions in the resource. However, for a given aggregate hunting effort in the community, lower wildlife stocks imply lower hunting success, which reduces human pressures on wildlife and helps to its recovery. If this second effect is stronger, the equilibrium is stable.

3.2. Equilibria where all community members make the same hunting effort

Proposition 2.a: Given the mathematical expression of the replicator dynamics, homogeneous equilibria, where all community members make the same hunting effort, always exist.

This includes both equilibria where all members of the community make high-hunting effort or where all of them make low-hunting efforts. Propositions 2.b and 2.c study the stability of each of them respectively.

Proposition 2.b: An equilibrium where all community members make high hunting effort is stable when, at the equilibrium, payoffs for high hunting members are higher than payoffs for low hunting members and the marginal regenerative capacity of wildlife is lower than the aggregate hunting effort of high-effort members of the community ($F'(K)<Ne_h$).

Proof: The partial derivative, the determinant of the Jacobian and the trace in this case are:

$$\partial \dot{s}_l \big/ s_l = -PK(e_h - e_l) + c(e_h - e_l) = U_l - U_h$$

$$\partial \dot{s}_l \big/ K = 0$$

$$\partial \dot{K} \big/ s_l = NK(e_h - e_l)$$

$$\partial \dot{K} \big/ K = F'(K) - Ne_h$$

$$Det = \left[F'(K) - Ne_h \right]\left(U_l - U_h \right)$$
$$Trace = U_l - U_h + F'(K) - Ne_h$$

If $F'(K)-Ne_h<0$, then it is necessary for the determinant to be positive that $U^L<U^H$ when $s_l=0$, which also implies a negative trace. If $F'(0) -Ne_h >0$, $U_l>U_h$ is necessary for the determinant to be positive, but this implies that the trace is also positive, which implies instability.∎

Proposition 2.c: An equilibrium where all community members make low hunting effort is stable when, at the equilibrium, payoffs for low hunting members are higher than payoffs for high hunting members and the marginal regenerative capacity of wildlife is lower than the aggregate hunting effort in the community, which is low for all its members ($F'(K)<Ne_l$).

Proof: The partial derivatives, the determinant of the Jacobian and the trace in this case are:

$$\frac{\partial \dot{s}_l}{\partial s_l} = PK(e_h - e_l) - c(e_h - e_l) = -(U_l - U_h)$$

$$\frac{\partial \dot{s}_l}{\partial K} = 0$$

$$\frac{\partial \dot{K}}{\partial s_l} = NK(e_h - e_l)$$

$$\frac{\partial \dot{K}}{\partial K} = F'(K) - Ne_l$$

$$Det = -\big[F'(K) - Ne_l\big]\big(U_l - U_h\big)$$
$$Trace = -(U_l - U_h) + \big(F'(K) - Ne_l\big)$$

If $F'(K) - Ne_l < 0$, then it is necessary for the determinant to be positive that $U_l > U_h$ when $s_l = 1$, which also implies a negative trace. If $F'(0) - Ne_h > 0$, $U_l < U_h$ is necessary for the determinant to be positive, but this implies that the trace is also positive, which implies instability.■

Corollary 2. Corollary 1 also holds for equilibria where all community members make the same hunting effort.

Corollary 3: If a heterogeneous equilibrium exists, homogeneous equilibria cannot be stable (neither where all community members make high nor low hunting effort). Further, the two homogeneous equilibria cannot coexist stably.

Proof: The first part of this corollary stems from the stability conditions of the homogeneous equilibria. Thus, if a heterogeneous equilibrium exists (that is, there is a $0 < s_l < 1$ that implies a K for wich $U_l = U_h$), then for a lower s_l (specifically, for $s_l = 0$) then it must be true that $U_l > U_h$ which implies instability of the $s_l = 0$ homogeneous equilibrium. By the same token, existence of the heterogeneous equilibrium implies that for a higher s_l (specifically, for $s_l = 1$) it turns out that $U_l < U_h$ which implies instability of the $s_l = 1$ homogeneous equilibrium.

The second part of the corollary results also from the stability conditions for the homogeneous equilibria. For instance, stability of the $s_l = 0$ equilibrium implies that for $s_l = 0$ $U_l < U_h$. Therefore, since higher s_l implies higher K, which in turns favours payoffs for high hunting compared to payoffs for low hunting, it therefore turns out that for $s_l = 1$ also $U_l < U_h$, which makes the homogeneous low hunting equilibrium unstable.

4. THE SOLUTION WITH BENEFIT-SHARING

In this section we assume that the park agency transfers a fixed share of its profits to members in the community who make low-hunting effort. This implies that the park agency can discriminate between low- and high-effort hunters in a community.

4.1. Equilibrium where community members make different hunting efforts

Proposition 3.a: When there is benefit-sharing, there is at most one heterogeneous steady state with the following variables values:

$$K^* = \frac{c}{P - \left(\dfrac{\beta w}{N s_l^* (e_h - e_l)} \right)} \quad ; \quad s_l^* = \frac{e_h}{e_h - e_l} - \frac{F'(K^*)}{K^*} \cdot \frac{1}{N(e_h - e_l)}. \text{ For its existence it is}$$

necessary that $P(e_h - e_l) > \dfrac{\beta w}{N s_l^*}$.

When comparing proposition 1.a to 3.a, corollary 3 can be introduced:

Corollary 4: The introduction of benefit-sharing strategies increases the stock of wildlife in equilibria where different members of the community make different hunting efforts. This result holds even though the effect on the proportion of low-effort members of the community is ambiguous.

Proof: A quick comparison reveals that K is larger in the benefit-sharing solution. Now, the comparison of s_l, depends on the sign of $F'(K)$ in the equilibrium without benefit-sharing. If $F'(K^*)<0$, then it is clear that s_l is larger with benefit sharing, since $F'(K)/K$ depends negatively on K. However, if $F'(K^*)>0$, it may be possible that a larger K implies larger $F'(K)/K$ and, therefore, smaller s_l. Given that K* is higher, $F'(K^*)/K^*$ is smaller. If $F'(K^*)>0$, then s_l^* is bigger. However, it needs to be said that with standard logistic equation: $F(K) = rK(1 - \dfrac{K}{\overline{K}})$, it cannot, because

$$s_l^* = \frac{N e_h - r + r\dfrac{K}{\overline{K}}}{N(e_h - e_l)}, \text{ which imply positive monotonous relationship between } s_l \text{ and } K. \blacksquare$$

Proposition 3.b: *F'(K)<0* is sufficient but not necessary for the heterogeneous steady state to be stable.

Proof: The partial derivatives, the determinant of the Jacobian and the trace in this case are:

$$\partial \dot{s}_l / s_l = -(1 - s_l)\frac{\beta w K}{N s_l} \quad ;$$

$$\partial \dot{s}_l / K = s_l(1 - s_l)\left[\frac{\beta w}{N s_l} - P(e_h - e_l) \right] ;$$

$$\partial \dot{K} / s_l = NK(e_h - e_l) ;$$

$$\partial \dot{K} / K = F'(K) - N(s_l e_l + (1 - s_l)e_h)$$

$$Det = (1-s_l)\frac{\beta wK}{Ns_l}\left(N\left(s_l e_l + (1-s_l)e_h\right) - F'(K)\right) + s_l(1-s_l)NK\left[P(e_h - e_l) - \frac{\beta w}{Ns_l}\right];$$

$$Trace = F'(K) - N(s_l e_l + (1-s_l)e_h) - (1-s_l)\frac{\beta wK}{Ns_l}.$$

F'(K)<0 is sufficient but not necessary for the determinant to be positive and the trace negative, and therefore, for the heterogeneous steady state to be stable.■

In sum, with *F'(K)>0* the equilibrium can be stable; and in principle, it seems that even though the introduction of benefit-sharing always implies and increase in the steady state stock of wildlife in the heterogeneous equilibrium, it does not necessarily imply an increase of the share of members of the community making low hunting efforts. It is possible that this share of low-effort hunters increases after benefit-sharing policies when *F'(K)>0* in the steady state (in this case, higher harvesting implies higher stock of wildlife in the steady-state).

4.2. Equilibria where all community members make the same hunting effort

Proposition 2.a. also applies after benefit-sharing policies have been introduced. Therefore, homogeneous equilibria always exist. Propositions 4.a and 4.b address the stability of equilibria where all members in the community follow the same strategies when benefit-sharing policies are in place.

Proposition 4.a: An equilibrium where all members of the community make high hunting efforts cannot be stable.

Proof: The partial derivatives, the determinant of the Jacobian and the trace in this case are:

$$\partial \dot{s}_l \Big/ s_l = \infty$$

$$\partial \dot{s}_l \Big/ K = \beta w$$

$$\partial \dot{K} \Big/ s_l = NK(e_h - e_l)$$

$$\partial \dot{K} \Big/ K = F'(K) - Ne_h$$

This makes the trace to be infinite, and thus bigger than zero. As a result, this equilibrium cannot be stable.■

The intuition is that as the proportion of low-effort hunters tends to zero, "per capita" profits resulting from benefit-sharing policies tend to infinite. This is an "anomaly" due to the continuity of s_l that allows for only a fraction of individual to be low hunter.

Proposition 4.b: The introduction of benefit-sharing policies does not change the stability conditions for the equilibrium where all community members make low hunting effort.

It is the same as stated in proposition 3.c.

Proof: The partial derivatives, the determinant of the Jacobian and the trace in this case are:

$$\partial \dot{s}_l \Big/ s_l = PK(e_h - e_l) - c(e_h - e_l) - \frac{\beta w}{s_l} = -(U_l - U_h)$$

$$\partial \dot{s}_l \Big/ K = 0$$

$$\partial \dot{K} \Big/ s_l = NK(e_h - e_l)$$

$$\partial \dot{K} \Big/ K = F'(K) - Ne_l$$

$$Det = -\big[F'(K) - Ne_l\big]\big(U_l - U_h\big)$$

$$Trace = -(U_l - U_h) + \big(F'(K) - Ne_l\big)$$

If $F'(K) - Ne_l < 0$, then it is necessary for the determinant to be positive that $U_l > U_h$ when $s_l = 1$, which also implies a negative trace. If $F'(0) - Ne_h > 0$, $U_l < U_h$ is necessary for the det to be positive, but this implies that the trace is also positive, which implies instability.

However, if the heterogeneous equilibrium exists (that is, there is a $0 < s_l < 1$ that implies a K for wich $U_l = U_h$), then for a larger s_l (specifically, for $s_l = 1$) then it must be true that $U_l < U_h$ (that is, with lower s_l there is more K, which reduces differential profits for low hunters). Thus it cannot coexist a heterogeneous equilibrium with a homogeneous stable equilibria where $s_l = 1$.∎

Corollary 5: The introduction of benefit-sharing policies does not enable the coexistence of a heterogeneous equilibrium with the stability of any homogeneous equilibrium (neither where all community members make high nor low hunting effort).

The reasoning parallels the one for the case without benefit sharing. Thus, if the heterogeneous equilibrium exists (that is, there is a $0 < s_l < 1$ that implies a K for wich $U_l = U_h$), then for a larger s_l (specifically, for $s_l = 1$) it must be true that $U_l < U_h$ (that is, with higher s_l there is a larger stock of wildlife (K), which reduces differential profits for low hunters).

Corollary 6: After the introduction of benefit-sharing policies it is not possible for the two homogeneous equilibria to coexist in the long-run, since the all-high-effort equilibrium is never stable.

Corollary 7: The introduction of benefit-sharing strategies does not change the stock of wildlife in the equilibrium where all members of the community make the same hunting efforts.

The steady-state conditions for the all-low-effort equilibrium do not change with the introduction of benefit-sharing policies and at the same time the all-high-effort equilibrium can no longer be stable.

5. POLICY IMPLICATIONS

In sections 3 and 4 we explore the steady-state stocks of wildlife with and without benefit-sharing policies respectively. Corollary 4 presents one first result which is that the introduction of benefit-sharing strategies unambiguously increases the stock of wildlife in equilibria where different members of the community make different hunting efforts. Corollary 6 presents a second result, showing that the stock of wildlife cannot worsen in equilibria where all community members follow the same hunting strategy. Thus, as opposed to Skonhoft (1998), Johannesen and Skonhoft (2005), our results reject the possibility that benefit-sharing strategies reduce the stock of wildlife.

6. IDEAS FOR FURTHER RESEARCH

Future versions of the manuscript will incorporate three main topics of further research:

First, the paper will address the welfare implications for local communities of benefit-sharing by park agencies. Findings in Skonhoft (2007) support that after the introduction of such policies, welfare and conservation may go hand in hand, or in the opposite direction. Thus, it is a question for future research to check whether our model reproduces this result. Methodologically it presents its own challenges. It implies solving questions such as whether the important comparison is between the original situation and the steady state only (in line of welfare analyses based on the notion of Nash equilibrium) or the welfare changes along the dynamic path are also relevant. If the latter is to be considered it can become analytically very complex and only manageable with simulation analyses.

Secondly, it is our intention to incorporate the discrepancy between management geography and biological geography. This implies to consider the implications that wildlife moves in and out of protected areas depending on the hunting effort inside and outside the park as well as habitat conditions. In this direction we may enable agropastoralists to expand their agricultural land, modifying the habitat conditions outside the park, or consider that tourism uses also have an impact on habitat conditions.

Thirdly, we would like to incorporate in future versions of the manuscript a comparison between benefit-sharing policies and community-based management in terms of welfare and conservation objectives. The community-based management will be inspired in the case of Namibia, where the NGO World Widelife Fund[3] created a program in the 90s to alleviate the severe poaching pressures that wildlife in the country was suffering, almost leading to local extinction several of the big African mammals. The Namibian government has given its communities the opportunity and rights to manage their wildlife through communal conservancies. According to WWF, the conservancy movement has engaged more than 220,000 community members with the creation of 52 communal conservancies covering 30 million acres of prime wildlife habitat. Conservancies have shifted the engaged communities from a

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[3] http://www.worldwildlife.org/what/wherewework/namibia/

situation where poaching by community members was extensive to a new situation where poaching no longer socially acceptable and only undertaken by members of other communities who do not belong to conservancies. Poachers are early identified and prosecuted by conservancy members. For many of the conservancies that WWF in Namibia works with, tourism is the most important source of income. As a result, wildlife is no longer only a nuisance harming productive activities and endangering humans' life, but communities benefit from it. In 2008 conservancies in Namibia generated 5.7 million dollars, constituting a new relevant economic activity in the country, improving the living conditions of local communities. Tourism development requires tight collaboration with the tourism industry and strong private sector partnerships while guaranteeing sound business principles. Conservancies have entailed enormous improvement in wildlife stocks. Just to mention two examples, in 1995, there were only 20 lions in the entire Northwest of the country, but today, there are more than 130 lions. The black rhino was almost extinct in 1982, but today this region has the largest concentration free-roaming black rhinos in the world. There are now also restored populations of cheetahs, zebras and other native species[4]. The short-term future objective is to make the program financially viable from this point on. Thus, after 15 years of intervention by WWF facilitating the empowerment of local communities and the establishment of partnerships with the private tourism industry, communities involved in conservancies may have moved to a new stable equilibrium characterized by low hunting efforts, high stocks of wildlife and increased wellbeing of local communities.

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