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Abstract

New policy approaches to facilitate the co-existence of wildlife and livestock are increasingly being sought-after as human sprawl increases and carnivore populations decrease. In this paper, models are developed to assess how alternative policy approaches can provide a livestock herder with incentives to sustain the socially optimal carnivore population. The well-established policy ex-post compensation is analyzed and compared to the innovative conservation performance payment approach. An empirical analysis of the model with data from tiger-livestock conflicts in India is presented.

1 Introduction

Carnivores are widely acknowledged to be an important part of biodiversity conservation. However, today 80, or about a fourth of the world's carnivore species, are listed on the IUCN red list of endangered species as either vulnerable, endangered, critically endangered, or even extinct in the wild. Agriculture, habitat loss and habitat fragmentation cause major threats to nearly all of these carnivores. Sustaining healthy populations of large carnivores often requires vast, undisturbed areas.

Pristine natural areas are persistently shrinking in size as the growing human population is converting more and more land for agricultural purposes. The FAO estimates that the amount of arable land will increase by 120 mio. hectares, or 12%, until 2030 compared to the amount of arable land in 1997/99 (FAO, 2002). Unsurprisingly, carnivore-livestock conflicts arise at the fringe between wild and agricultural land. Loss of livestock to carnivore attacks can be devastating for poor farmers in marginal areas (Thirgood et al., 2005; Woodroffe et al., 2005; Mishra, 1997). Livestock's role as source of food and income is obvious, but livestock has many more functions spanning from forms of saving over means of transportation to tokens of social esteem.

Conflicts between humans and wildlife are estimated to be the most acute in the tropics due to the rapidly increasing human demand for land and scarce resources (Madhusudan, 2003). Case studies from India revealed that close to a tiger reserve households, on average, lost 16% of their annual income due to predation by carnivores (Madhusudan, 2003). In Bhutan households around a national park are reported to have lost more than two-thirds of their average income through carnivore attacks (Wang & Macdonald, 2006). Around the Serengeti National Park in Tanzania, pastoralists' mean average loss of livestock equated to more than two-thirds of the households' average annual cash income (Holmern, Nyahongo & Roskraft, 2006). In Zimbabwe the economic loss per livestock holding household accumulated to an average of 12% of the households' net annual income (Butler, 2000).

Poaching in retaliation or simply to prevent further damage is rather common in many rural societies. During the last decades, various policy approaches have been developed and implemented to alleviate wildlife-livestock conflicts. The range of these policies stretches from fences and fines approaches (Casey et al., 2006) over ex-post compensation to benefit sharing strategies, sometimes referred to as *Community-based Wildlife Management*, CWM (see Songorwa, 1999, for a critical evaluation).

Imposing a punishment on people caught poaching endangered species is a very common policy. Although fines and punishments for poaching may be set at a high level, the probability of getting caught is often very low and, especially in developing countries, law enforcement may be deficient. It is suggested that increasing detection rates and law enforcement is often likely to be a more effective strategy to counteract poaching than merely increasing fines (Leader-Williams & Milner-Gulland, 1993; Hilborn et al., 2006). The imposition of fines on poaching without any supplementary compensation or positive incentive scheme gives rise to equity concerns. In particular, such an approach implies that the local livestock herders have to bear the costs of carnivore conservation without being compensated or remunerated by the rest of society which in turn benefits from carnivore's existence value.

Evidence is scarce that the above mentioned approaches have been successful in creating true pro-conservation incentives among livestock herders. New policy approaches to facilitate the co-existence of wildlife and livestock are increasingly being sought-after as human sprawl increases and carnivore populations decrease.

The recent theoretical literature on wildlife conservation can roughly be grouped into two strains. The first can be termed non-policy models, i.e. models that discuss issues such as wildlife extinction (Swanson, 1994), wildlife reintroduction initiatives (Rondeau, 2001; Skonhoft, 2006), and trade-offs between agriculture and conservation (Bulte & Horan, 2003). These models have policy implications but do not explicitly focus on analyzing policy outcomes.

The second group of models is directly concerned with the analysis of different wildlife management policies. Zivin et al. (2000) discuss alternative management options for species that can be considered as either pest or resource. In particular, they focus on the two population control measures trapping and hunting.

Building on Bulte & Horan (2003), Bulte & Rondeau (2007) criticize the general presumption that paying compensation to offset damage caused by wildlife supports conservation. They develop a model to analyze how compensation payments affect the allocation of labor between agricultural production, protection of crop fields, and wildlife hunting. Compensation payments are found to have ambiguous effects on wildlife stocks and local welfare because they may reduce hunting efforts but simultaneously provide incentives to convert natural habitat into agricultural land which is detrimental for wildlife.

Skonhoft's (1998) model is embedded in a typical scenario where a wildlife conservation park is surrounded by local farmers and their livestock. The model focuses on a cost and benefit sharing policy approach. In particular, the effects of transferring a fixed share of hunting profits to locals are compared to the effects of transferring a fixed share of hunting and tourism profits. Skonhoft concludes that providing locals with benefits from hunting and tourism is a promising approach to reduce incentives for illegal poaching.

The effects of benefit sharing programs on communities' incentives to conserve wildlife are also addressed in a model by Fischer, Muchapondwa & Sterner (2005). They find that wildlife conservation programs, such as CAMPFIRE, that focus on sharing resource profits do not necessarily result in net benefits for the communities. Whether profit sharing succeeds in providing conservation incentives to communities is found to depend on (i) the type of resource profits that are shared, (ii) to what extent the shared profits offset the agricultural losses, and (iii) the feedback of community-external actors in terms of changes in their resource management practices. Very similar to Skonhoft (1998) they point out that to strengthen locals' incentives for conservation, there must be a straightforward and comprehensible link between locals' actions, changes in the park's wildlife stock and profits shared with the community. If locals receive payments that are disjuncted from their actions and changes in the park's wildlife stock, this monetary transfer will not affect their conservation incentives.

Conservation performance payments, which are a type of payments for environmental services, are a relatively new policy approach and have not been analyzed in previous models of wildlife conservation. Performance payments are monetary or in-kind payments made by a paying agency to individuals or groups and are conditional on specific conservation outcomes (Albers & Ferraro, 2006; Engel et al., 2008). In our context, the conservation outcome is the size of the wildlife stock (or a function of stock such as offspring). Performance payments are suggested to be more direct and more cost-effective than alternative approaches (Ferraro & Simpson, 2002; Wätzold & Drechsler, 2005; Casey & Boody, 2007). To our knowledge, in the carnivore conservation context the only existing large-scale performance payment scheme is currently implemented in Sweden (Zabel & Holm-Müller, 2008).[1]

The purpose of this paper is to add to the above-mentioned literature on wildlife conservation policies by analyzing the effects of conservation performance payments in comparison to the more conventional ex-post compensation approach. Due to the deficiencies discussed above, the fines and fences approach will not be included into the analysis.

The paper is structured as follows: Section 2 introduces the theoretical model developed to compare the alternative policy schemes. The focus is on the two policy approaches (i) ex-post compensation and (ii) performance payments. In section 3, an empirical simulation of the model with data from tiger-livestock conflicts in India is presented. Section 4 discusses and summarizes the results.

[1] See Wunder et al. (2008) for a recent review of payment for environmental services schemes in other contexts.

2 The model

Our model incorporates the dynamics of livestock and carnivore populations. We compare the long-run equilibria, i.e. steady state solutions, for two different scenarios. The analysis starts by taking the view of a social planner whose goal is to maximize the present value of society's welfare. The social planner takes into account the costs and benefits that accrue to a livestock herder as well as society's existence value for the carnivore population. In a next step, we determine the decentralized market outcome for a homo-economicus livestock herder who optimizes the present value of his individual lifetime utility in the absence of policy measures.

The theoretical model presented here draws on the models developed in Damania et al. (2003), Bostedt (2001) and Bostedt (2005), the latter in turn have connections to other models of agricultural households (e.g. Singh, Squire & Strauss, 1986), as well as models of self-employed forest owners (e.g. Johansson & Löfgren, 1985, chapter 7). The most important difference compared with these previous models is that this model focuses on the effects of large carnivores on pastoralist livestock herders, and on the incentives for poaching caused by different compensation systems.

We assume that the livestock herder does not internalize society's existence value for carnivores and it is further assumed that the herder personally assigns no existence value to carnivores. Thus by intuition, the carnivore population in the livestock herder's steady state equilibrium must be smaller than the carnivore population in the social planner's steady state equilibrium. The goal of the analysis is to determine how alternative policy mechanisms can influence the livestock herder's decision making process and eventually alter the steady state carnivore population in the herder scenario. The steady state equilibrium derived from the social planner scenario is used as a benchmark to compare and evaluate the two alternative policy mechanisms (i) ex-post compensation and (ii) performance payments.

2.1 Social planner and market equilibria

The social planner maximizes the present value of lifetime income of the representative livestock herder plus the existence value of the carnivore population.

$$\max PV = \int_{t_0}^{\infty} \left[p_t\left(H_t\right)h_t + ro_t + E\left(W_t\right)\right] \cdot e^{-\delta t} dt, \ \delta \geq 0 \quad (1)$$

where δ is the discount rate and t is an index of time. The social planner takes into account the income that the livestock herder generates by harvesting and selling livestock, h, at the price p, $p_H \leq 0$ (subscripts indicate the argument of a derivative). In general, p is a function of the total amount of livestock sold on the world market and i is the country index, $H_t = \sum_i h_{it}$. For simplicity we take the amount of livestock supplied by the rest of the world, $\bar{H}_t$, to be constant over time. Also for simplification reasons we denote $p(\bar{H}_t + h_t)$ by $p(h_t)$ in the following.

The term ro_t captures the herder's off-farm income. It is the product of the exogenously given off-farm wage rate, r, and the time spent working off-farm, o_t. For simplicity, harvesting livestock is assumed not to consume time. The time consuming activities that the livestock herder can choose between are either carnivore hunting, l, or off-farm work, o. With leisure time assumed constant, L is total labor time and thus his time constraint is defined as:

$$L = l_t + o_t \quad (2)$$

Finally, the social planner also takes society's existence value of the carnivore population, $E(W_t)$, into account. It is assumed that the existence value depends positively on the population size ($E_w > 0$).

In his optimization, the social planner considers the population dynamics of carnivores and livestock:

$$\dot{W}_t = G(W_t) - f(l_t)W_t \quad (3)$$
$$\dot{X}_t = F(X_t) - k(W_t) - h_t \quad (4)$$

In the following the time index t is dropped for notational simplicity.

The carnivore population (W) changes over time (Eq. 3) as a function of natural growth, $G(W)$, minus the number of carnivores that are hunted, $f(l)W$. The latter is a function of the time spent hunting carnivores and carnivore abundance itself. It is assumed that $f(l)$ exhibits decreasing returns to scale in l ($f_l > 0$, $f_{ll} < 0$) (see Damania et al., 2003). The natural growth function $G(W)$, is assumed to be of the logistic humped-shaped type with

$$G(W) = g\left(1 - \frac{W}{W_{max}}\right)W$$

where g is the intrinsic growth rate and W_{max} is the carrying capacity.

Furthermore,

$$G_W = \begin{cases} > 0 & for \quad W < 0.5W_{max} \\ = 0 & for \quad W = 0.5W_{max} \\ < 0 & for \quad W > 0.5W_{max} \end{cases}$$

and $G_{ww} < 0$.

The livestock population, X, changes over time (Eq. 4) as a function of natural growth, $F(X)$, minus the number of livestock killed by the carnivores, $k(W)$ with $k_w > 0$ [2,3], and the number of livestock harvested by the herder, h. The natural growth function for livestock, $F(X)$, is also assumed to be logistic with

$$F(X) = j\left(1 - \frac{X}{X_{max}}\right)X$$

where j is the intrinsic growth rate and X_{max} is the carrying capacity.

Moreover,

$$F_X = \begin{cases} > 0 & for \quad X < 0.5X_{max} \\ = 0 & for \quad X = 0.5X_{max} \\ < 0 & for \quad X > 0.5X_{max} \end{cases}$$

and $F_{XX} < 0$.

The dynamic optimization problem of maximizing (1) subject to (2), (3) and (4) with $W(0) = W_0$ and $X(0) = X_0$ given, results in the following current value Hamiltonian where off-farm work, o, has been substituted from (2):

$$\psi^{sp} = p(h)h + r(L - l) + E(W) + \lambda^{sp}\left(G(W) - f(l)W\right)$$
$$+\gamma^{sp}\left(F(X) - k(W) - h\right) \quad (5)$$

where the superscript SP indicates the social planner scenario. The state variables are the carnivore population, W, and the livestock population, X. The co-state variables are λ^{sp} and γ^{sp}. The control variables are the amount of livestock harvested, h, and the amount of time spent hunting carnivores, l.

The first order conditions for this social planner model are as follows.

$$\lambda^{sp} = -\frac{r}{Wf_l} \quad (6)$$
$$\gamma^{sp} = p_h h + p(h) \quad (7)$$
$$\dot{\lambda}^{sp} - \delta\lambda^{sp} = -\psi_W^{sp} = -\lambda^{sp}G_W + \lambda^{sp} f(l) + \gamma^{sp}k_W X - E_W \quad (8)$$
$$\dot{\gamma}^{sp} - \delta\gamma^{sp} = -\psi_X^{sp} = -\gamma^{sp}F_X \quad (9)$$

[2] Considerable ecological research exists about this relationship, known as the predator functional response, see e.g. Abrams & Ginzburg (2000).

[3] In an alternative version of the model, the predation function was also made dependent on the abundance of livestock. The results of the model were in principle the same as those presented here but the expressions obtained were considerably more complicated. The calculations are available upon request.

Equation (6) states that the shadow price of carnivores is equal to the off-farm wage rate divided by the number of carnivores killed per marginal time unit spent hunting carnivores. Equation (7) simply says that the shadow price of livestock is equal to its market price. Assuming for simplicity a small open economy in which a marginal change of livestock harvested, h, has no influence on the world market price, the first term on the right hand side of (7) is zero. For simplicity, this term will be dropped in the remainder of the analysis.

As in Zivin (2000) we assume that in the steady state, the carnivore and livestock populations as well as their shadow prices are constant over time, $\dot{W} = \dot{X} = \dot{\lambda}^{sp} = \dot{\gamma}^{sp} = 0$.

This allows us to determine the following steady state conditions:

$$G(W) = f(l)W \qquad (3')$$

$$h = F(X) - k(W) \qquad (4')$$

$$G_W - \frac{G(W)}{W} = -\frac{W}{r} p(h) f_l(l) k_W(W) + \frac{W}{r} f_l(l) E_W + \delta \qquad (8')$$

$$F_X = \delta \qquad (9')$$

Equation (3') requires that to maintain a stable population, the amount of carnivores hunted must exactly equal carnivore population growth. Similarly, equation (4') states that livestock population growth must equal the sum of livestock harvested by the herder and livestock killed by carnivores. Equation (8') describes the marginal carnivore population regeneration at the steady state. The left-hand side stands for the marginal regeneration minus the number of carnivores hunted in the steady state. The first term on the right-hand side is the ratio of the two stock variables' shadow prices times the number of livestock killed by a marginal carnivore. The second term on the right hand side is the existence value of a marginal carnivore divided by the shadow price of carnivores. The last term on the right hand side is the discount rate. Equation (8') will be used for further analysis. Equation (9') states that the net marginal livestock population growth must be equal to the discount rate.

The steady state livestock population is determined by (9'). Equations (3'), (4') and (8') together determine the steady state carnivore population number, the corresponding level of carnivore hunting, and the equilibrium livestock harvest level.

As discussed earlier, by intuition, the livestock herder who does not internalize carnivores' existence value will favor a smaller carnivore population than the social planner.

To formalize this intuition, the livestock herder's optimization problem is set up. The only difference to the social planner scenario developed above is that it does not include the term for the existence value, $E(W)$.

The livestock herder maximizes the present value of his lifetime income subject to the population dynamics and his time constraint:

$$\max PV = \int_{t_0}^{\infty} [p(H)h + r(L-l)] \cdot e^{-\delta t} dt, \quad \delta \geq 0$$

s.t.

$$\dot{W} = G(W) - f(l)W$$

$$\dot{X} = F(X) - k(W) - h$$

$$L = l + o$$

$W(0) = W_0$ given, $X(0) = X_0$ given.

The current value Hamiltonian for the livestock herder is:

$$\psi^{LH} = p(h)h + r(L-l) + \lambda^{LH}\left(G(W) - f(l)W\right) + \gamma^{LH}\left(F(X) - k(W) - h\right) \qquad (10)$$

where the superscript LH refers to the livestock herder scenario. Since the analysis of the first order conditions is basically equivalent to that for the social planner model we will not write them down in detail here. The steady state conditions for the livestock herder model are:

$$G(W) = f(l)W$$

$$h = F(X) - k(W)$$

$$G_W - \frac{G(W)}{W} = -\frac{W}{r} p(h) f_l(l) k_W(W) + \delta \quad (11)$$

$$F_X = \delta$$

To compare the carnivore population in the steady state of the social planner and livestock herder models we examine how equations (8') and (11) relate to each other. The difference is in the additional term $\frac{W}{r} f_l E_W$ on the right hand side (RHS^{SP}) of equation (8'). The term is positive and stands for the existence value of a marginal carnivore divided by its shadow price. In other words it signifies the marginal benefit to marginal cost ratio of an additional carnivore.

$$RHS^{SP} = -\frac{W}{r} p(h) f_l(l) k_W(W) + \frac{W}{r} f_l(l) E_W + \delta$$

$$RHS^{LH} = -\frac{W}{r} p(h) f_l(l) k_W(W) + \delta$$

$$LHS^{SP} = LHS^{LH} = G_W - \frac{G(W)}{W}$$

To find out whether the carnivore population must increase or decrease when moving from the livestock herder's to the social planner's steady state we can insert W^{LH*} into the social planner model. (The asterisk in the superscript indicates the steady state). This would result in an inequality with $LHS^{SP}(W^{LH*}) < RHS^{SP}(W^{LH*})$ due to the additional term on the RHS^{SP} of (8'). To retain the equality $LHS^{SP} = RHS^{SP}$, the carnivore population must adjust. The essential question is then how the LHS^{LH} and RHS^{LH} change subject to a marginal change of W.[4]

$$LHS_W^{LH} = -\frac{g}{W_{max}} < 0 \quad (12)$$

$$RHS_W^{LH} = -\frac{k_w f_l p W}{r}\left(-\frac{p_h k_w}{p} + \frac{1}{W} + \frac{f_{l,l}}{f_l^2}\frac{dl^*}{dW^*} + \frac{k_{W,W}}{k_W}\right) < 0 \quad (13)$$

The term in front of the bracket in equation (13), $-\frac{k_w f_l p W}{r}$, is equal to the $LHS^{LH} - \delta$. A helpful relationship is:

$$\frac{dLHS^{LH}}{dW} = \frac{LHS^{LH}}{W} \quad (14)$$

Making use of (14), equation (13) can be rephrased as

$$RHS_W^{LH} = LHS_W^{LH}\left[1 + WA + \delta\frac{W_{max}}{g}\left(\frac{1}{W} + A\right)\right],$$

where $A = \left(-\frac{p_h k_w}{p} + \frac{f_{l,l}}{f_l^2}\frac{dl^*}{dW^*} + \frac{k_{W,W}}{k_W}\right)$. The sign of A depends on the functional form of the carnivore predation function, $k(W)$. Provided $k(W)$ is either linear or convex, the term A is positive. A linear form of $k(W)$ implies that each carnivore preys upon a constant number of livestock. A convex shape of $k(W)$ accounts for positive scale effects in the carnivores' hunting techniques. This may be especially relevant for carnivore species that are more efficient predators when they hunt in packs, e.g. wolves. For linear and convex functional forms of $k(W)$, we can conclude that $\left|LHS_W^{LH}\right| < \left|RHS_W^{LH}\right|$. The same may hold for a concave form of $k(W)$ unless k_{WW} is so negative that it dominates the other summands in A. Concavity of $k(W)$ may occur for carnivore species which, with increasing population densities, face intraspecies crowding-out effects. For example, carnivores spend substantial amounts of time and energy on defending their territories and thus prey on relatively less livestock.

Provided $\left|LHS_W^{LH}\right| < \left|RHS_W^{LH}\right|$ holds, this relationship allows us to confirm the intuition that the steady state carnivore population is larger in the social planner model than in the livestock herder model. A very simplified depiction of the problem in Figure 1 may help illuminate this finding. The intersection of LHS^{LH} and RHS^{LH} indicates the steady state equilibrium carnivore population W^{LH*}. The difference between the RHS^{LH} and RHS^{SP}, which for simplicity is drawn as a parallel shift, signifies the addi-

[4] Please note that dl^*/dW^* in (13) is negative. In the steady state $f(l) = G(W)/W$ holds. An increase in W lowers $G(W)/W$ and therefore also l as we assumed strict monotonicity with respect to $f(l)$.

tional term that the social planner takes into account, $\frac{W}{r} f_l E_W$, the marginal existence value of a carnivore divided by its shadow price.

The comparison of the social planner and livestock herder models has revealed that in the absence of policy measures, the livestock herder will reduce the carnivore population to a lower level than is socially desirable.

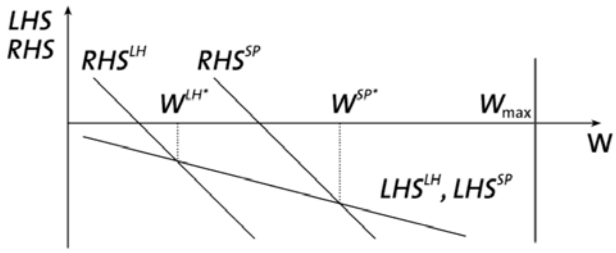

***Figure 1:** Steady state equilibria in the livestock herder and social planner models*

2.2 Policy analysis

The steady state equilibrium in the social planner model can now be defined as the benchmark that is supposed to be attained by means of alternative policy mechanisms. Two policy mechanisms, (i) ex-post compensation and (ii) performance payments, will be analyzed for their potential to shift the livestock herder's steady state carnivore population closer to the steady state defined in the social planner model.

Ex-post compensation

Ex-post compensation means that livestock herders receive a certain amount of money for livestock lost in carnivore attacks. This is a rather common policy in Europe and the US but also in developing countries such as India or Kenya (Saberval et al., 1994; Mishra, 1997; Fourli, 1999; Madhusudan, 2003; Western & Waithaka, 2005). Several problems inherent to ex-post compensation schemes have been identified. In particular these are (i) moral hazard, (ii) long time lags between the predation incident and the actual payment, (iii) high transaction costs, and (iv) problems of trust and transparency (Nyhus et al., 2005; Zabel & Holm-Müller, 2008). Although well-intended, due to these accompanying problems, ex-post compensation may often fail to provide true pro-conservation incentives.

In the model, we only focus on the general functioning of ex-post compensation and do not consider any of the afore-mentioned problems. Ex-post compensation is included into the livestock herder model as the product of the compensation payment, q, and the number of livestock that are killed by carnivores, $k(W)$. The new current value Hamiltonian for the livestock herder is:

$$\psi^{LHex-post} = p(h)h + r(L-l) + qk(W)$$
$$+\lambda^{LH}\left(G(W) - f(l)W\right) + \gamma^{LH}\left(F(X) - k(W) - h\right)$$

The steady state carnivore population for the livestock herder in the model with ex-post compensation can now be compared to the model without any policy. The $RHS^{LHex-post}$ is found to be larger than RHS^{LH} by the positive term $\frac{qWf_l}{r}k_W$. In other words, this term equals the compensation payment times the number of livestock killed per marginal carnivore divided by the shadow price of a carnivore. This result tells us that, ceteris paribus, the steady state carnivore population will increase along with an increase in the compensation payment. It will also increase as the number of livestock killed by an additional carnivore increases. Equivalently, it will increase along with a decrease in the shadow price of a carnivore.

The term $\frac{qWf_l}{r}k_W$ can be compared with $\frac{W}{r} f_l E_W$, which was the difference between the private and socially optimal solution in absence of policy measures. This means that if $qk_W = E_W$ the ex-post compensation system will achieve the social planner's solution. This requires two crucial pieces of information; knowledge on the marginal existence value for the carnivore, E_W, and knowledge on the marginal effect of an increase in the carnivore population on the number of livestock killed by carnivores, k_W. Note that not only point estimates are sufficient, but the whole functions are necessary. The ratio between the values of these two functions, when evaluated at W^{SP*}, the social planner's optimal carnivore population, will give the correct level of the ex-post compensation payment.

Another policy implication that can be derived from the model is that, provided the number of livestock killed by a marginal carnivore is relatively small, introducing an ex-post compensation scheme will not significantly aid in increasing the steady state carnivore population unless the compensation payment, *q*, is sufficiently large.

Performance payments

In the performance payment approach, the payments are directly linked to the size of the wildlife stock (or a function of stock, such as offspring). In the Swedish conservation performance payment scheme, the government has defined explicit goals for the size of the wolverine and lynx populations that it would like to host in the country (Swedish Government Bill, 2000). Wolverines (*Gulo gulo*), which are listed as vulnerable on the IUCN red list of endangered species (Mustelid Specialist Group, 1996) and lynx (*Lynx lynx*) are two predators that feed on reindeer and cause great economic damage to the indigenous reindeer herding Sami people (Persson, 2005; Swenson & Andrén, 2005; Danell et al., 2006). The semi-domesticated reindeer are kept in a nomadic system and are moved between lowlands and mountains depending on season. Neither wolverines nor lynx hibernate and especially during the winter months both depend on the abundance of reindeer as prey species (Pedersen et al, 1999). Prey availability is also considered an important factor for wolverine reproduction success (Persson, 2005). Until 1996, an ex-post compensation scheme was installed under which the herders could claim compensation for reindeer that were verified to have been killed by carnivores. In 1996, the ex-post compensation scheme was abolished and replaced by a performance payment scheme. Today, the reindeer herders are remunerated based on the number of carnivore offspring that are certified on their reindeers' grazing grounds. The great advantage of these conservation performance payments is that they provide very straightforward pro-conservation incentives (Zabel & Holm-Müller, 2008). The main activities that the reindeer herders can engage in to promote carnivore conservation are to refrain from (illegal) poaching and to let reindeer roam free as potential food for carnivores. Illegal poaching of carnivores is a serious issue in Sweden (Swedish National Council for Crime Prevention, 2007). In a long-term study 60% of adult mortality among wolverines was ascribed to sure and likely cases of illegal poaching (Persson, 2007); for lynx the corresponding rate was estimated at 46% (Andrén et al., 2006). However, data from the annual carnivore inventories suggests that especially the endangered wolverine population is facing an upward trend in recent years. This population increase must be interpreted and appreciated with care since next to anthropogenic influences natural environmental factors and improved data collection methods may also play a role.

The performance payments can be incorporated into the model as a function of the carnivore population, $V(W)$. In the Swedish example the payment is based on carnivore offspring but for generality we will model the payment as a general function of the carnivore stock. The resulting Hamiltonian for the livestock herder is:

$$\psi^{LHperformance} = p(h)h + r(L-l) + V(W) \\ +\lambda^{LH}\left(G(W) - f(l)W\right) + \gamma^{LH}\left(F(X) - k(W) - h\right)$$

As in the analysis above, we compare the steady state conditions for this model with the steady state conditions for a livestock herder in a scenario without any policy. The comparison reveals that the performance payment shifts the $RHS^{LHperformance}$ by the positive term $\frac{V_w W f_l}{r}$. This term stands for the performance payment per marginal carnivore times the carnivore population and the number of carnivores hunted per marginal unit of time, divided by the external off-farm wage rate. This term can be compared with $\frac{W}{r} f_l E_W$, which was the difference between the private and socially optimal solution in absence of policy measures. Thus, if $V_W = E_W$ the performance payment system will achieve the social planner's solution. This requires only one crucial piece of information; knowledge on the marginal existence value for the carnivore, E_W. The marginal existence value for the carnivore when evaluated at W^{SP*}, the social planner's optimal carnivore population, will give the correct level of the performance payment.

Corner solutions

So far, we have assumed that the model will reach an interior solution. However, if the social planner's optimal steady state carnivore population is beyond the limits given by the ecosystem's carrying capacity, the policy analyses must operate with a corner solution. Figure 2 depicts such a scenario. The livestock herder's optimal steady state carnivore population is smaller than the carrying capacity but the social planner's optimal carnivore population is larger. In this case, the social planner's willingness to pay is larger than the payment that is necessary to shift the livestock herder to the carrying capacity. Such scenarios are likely to occur when the social planner takes the global existence value of a charismatic carnivore into account and compares it to costs that only arise at a local scale in a developing country.

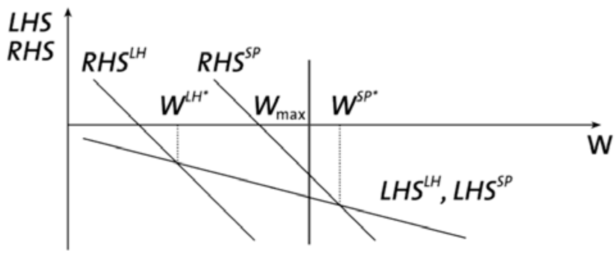

Figure 2: *Social planner model limited by carrying capacity,* $W_{\max}$

Comparison of total program cost

Given that ex-post compensation and performance payments can both be used to achieve the social planner's optimum (or the corner solution), an interesting question is which program will cause higher costs. This is of interest because program budgets are frequently limited, and raising program funds is likely to cause transaction costs (Engel et al., 2008). For an interior solution of the model, total program costs (denoted as TC) under the ex-post compensation scheme are given by

$TC^{ex-post} = q^* k(W)$, where $q^* = \left.\frac{E_W}{k_W}\right|_{W=W^{SP*}}$.

Assuming for simplicity that performance payments are linear in the level of carnivore stock[5], total program costs of performance payments can be written as

$TC^{performance} = V_W W$, where, to achieve the social planner's optimum, $V_W = E_W|_{W=W^{SP*}}$.

Thus, we have:

$TC^{ex-post} \underset{<}{\overset{>}{-}} TC^{performance}$ *if and only if* $\frac{k(W)}{W} \underset{<}{\overset{>}{-}} k_W$.

Thus, the relative size of the two programs' total costs depends on the shape of the function $k(W)$, i.e. the functional response in the predator prey relationship, at the optimal level of carnivore stock. This implies that the total cost of the ex-post compensation is

(i) equal to that of the performance payment if $k(W)$ is linear in W (at least at W^{SP*});

(ii) higher than the cost of the performance payment if $k(W)$ is concave in W (at least at W^{SP*}); and

(iii) lower than the cost of the performance payment if $k(W)$ is convex in W (at least at W^{SP*}).

In case of a corner solution the ex-post payment, q^{corner}, respectively marginal performance payment, V_W^{corner} that is necessary to shift the livestock herder to the carrying capacity can be computed as follows[6]:

$$q^{corner} = (G_W - \delta)\frac{r}{W f_l k_W} + p\Big|_{W=W_{\max}}$$

$$V_W^{corner} = (G_W - \delta)\frac{r}{W f_l} + p k_W\Big|_{W=W_{\max}}.$$

The comparison of the total costs for a corner solution reveals the same results as for the interior solution. Which of the policy schemes is less expensive depends on the functional response in the predator prey relationship evaluated at the carrying capacity.

5 Most current schemes of payments for environmental services have constant per-unit payment (Engel et al., 2008).

6 Please note that at the carrying capacity population growth is zero, $G(W) = 0$.

3 Empirical analysis

Tigers (*Panthera tigris*) are one of the carnivore species that are currently facing dramatic declines in population size. India's tiger population is estimated at only approximately 1400 individuals (Jhala et al., 2008). Currently there are two different conservation policy approaches implemented in India. Convicted poachers face fines and prison sentences. Next to punishments for poaching, compensation payment schemes are installed in the buffer zones of many tiger reserves. Recently, however, park managers, conservationists, and policy makers expressed general interest in the conservation performance payments approach (Damania et al., 2008).

As discussed above, the functional forms of carnivore population and livestock population growth functions $G(W)$, and $F(X)$ are assumed to be logistic. The data we use for the analysis is collected from various case studies and conservation reports. They are very rough estimates and although they are drawn from the available literature, we do not claim they necessarily are good representations of the actual ecological and economic relationships. Most prominently, there still is a research gap concerning the function for tigers' existence value. For the computation below we estimated an existence value function based on data for national annual investments into 27 tiger reserves and their respective tiger populations. It is important to notice that since this function was derived only with data on national investments, we are simulating a national social planner, who does not take the global society's existence value for tigers into account. A global social planner who acknowledges tigers' existence value as a true universal public good is likely to incorporate higher marginal existence values into his calculations. An analysis of six data points provided in Damodaran (2008) on international investments into Indian tiger reserves provides evidence in support of this hypothesis.

In this empirical analysis, tigers' livestock predation technology is described by a linear function which implies that each tiger kills a constant number of livestock. A concave functional form would mean that tigers, e.g. due to intraspecies crowding-out effects, are less efficient hunters as their population density increases. A convex functional form, by contrast, would imply that tigers become more efficient as their population density increases.

The goal of the empirical analysis below is to provide an indication of how the model could be used for policy implications if reliable data were available. The functional forms and data sources used here are enlisted in Table 1.

For the given data, the model arrives at an interior solution. The national social planner's optimal carnivore population for the 1350sqkm reserve is 163.5 tigers. This corresponds to roughly 75% of the carrying capacity. Prior to the implementation of any policies, the steady state population of carnivores in the livestock herder model is 0.023 animals.

The question now is how the alternative policy mechanisms could be implemented to provide the livestock herder with incentives to increase the carnivore population up to the social planner's optimum. As discussed in the theoretical section above, ex-post compensation can provide pro-conservation incentives. For the given data, a compensation payment of INR999.94 (or approx. USD19.65) per goat, i.e. nearly a goat's market price is necessary to provide sufficient incentives for the herder to let the carnivore population grow to the social planner's goal.

Table 1: Values and functional forms used in empirical analysis

Variable		Value or functional form	Data source
δ	Discount rate	0,08	Grameen Bank (2008)
j	Intrinsic goat population growth rate	1,6	Dey et al. (2007)
g	Intrinsic tiger population growth rate	0,06	Smirnov & Dale (1999)
r	Off-farm wage rate	INR 12000 (Proxy for a year's salary with INR 40 per day.)	Damania et al. (2003)
$f(l)$	Poaching technology	$f(l)=l^{0,5}$	Damania et al. (2003) (for computational ease $l^{0.46}$ was rounded to $l^{0.5}$)
p	Price of goat (per animal)	INR 1000	Madhusudan (2003)
$k(W)$	Tigers' livestock predation technology	5*W	Tigers are estimated to prey on appr. the equivalent of 50 wild ungulates per year. Scat analyses revealed that 10% of tigers' diet is livestock (Bagchi et al., 2002).
E_w	Tigers' marginal existence value	INR 154273 -INR 912.92*W	Estimation based on national investments into 27 Indian tiger reserves in 2001-2002 and the reserves' tiger populations. (R^2 = 0.4622) Data source: Project Tiger (2008)
$W_{\max}$	Carrying capacity	216	Damodaran (2007) (for an average sized 1350sqkm reserve)

INR 100 ≈ USD 1.96 (December 2008).

The calculation above refers to a national social planner but it is also possible to run the model for regional or global social planners who, due to different existence values, may strive for differing optimal carnivore population sizes. Figure 3 shows the optimal compensation payments for alternative policy goals. The horizontal axis indicates the hypothetical policy goals and the vertical axis shows the corresponding optimal compensation payment. If there is no deviation between the social planner's and the livestock herder's initial steady state, obviously no compensation payment is necessary. For our given data, any policy objective that aims at achieving a carnivore population somewhere in the interval between 0.023 and the carrying capacity of 216 tigers results in an optimal compensation payment that is lower than the market price of livestock. The development of the optimal compensation payments in this interval is due to two counteracting effects. As the carnivore population increases, hunting becomes less time consuming and thus the opportunity costs of hunting decrease. In the calculation of the optimal compensation payment this benefit is subtracted from the market price of livestock. However, the higher the social planner's intended carnivore population, the lower is the corresponding hunting level. The goal of attaining 100% of the carrying capacity rules out all hunting activities. Thus, at this level, the reduced opportunity costs of hunting do not play a role and a full compensation of the livestock's market price becomes necessary.

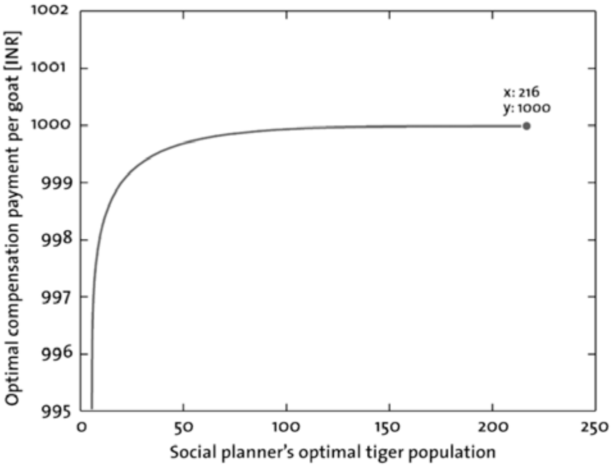

Figure 3: *Development of optimal compensation payment for data given in Table 1.*

As alternative to ex-post compensation we have proposed the performance payment approach. For the empirical assessment the national social planner's goal is again to increase the carnivore population to 163.5 tigers. For the given functional forms and data in Table 1, a performance payment of INR4999.72 (or approx. USD 98.25) per tiger would be necessary to provide the livestock herder with the adequate incentives to achieve the goal. Due to the assumption that the functional response in the predator-prey relationship has a linear form the total program costs will be equal for this empirical example.

4 Discussion

In the previous sections we developed a model for a social planner and a livestock herder and compared the steady state carnivore populations that resulted from the models. As intuition suggested, the steady state carnivore population in the social planner model was higher than in the livestock herder model. We then analyzed the potential of the ex-post compensation policy to provide incentives for the livestock herder to reach the socially optimal carnivore population. Additionally, we analyzed a rather new policy approach, conservation performance payments, which in the carnivore conservation context is currently only implemented at a large scale in Sweden.

A result derived from the theoretical models is that both performance payments and ex-post compensation provide pro-conservation incentives. Although not modeled here, relatively high ex-post compensation payments that are issued without any conditions on livestock protection measures may distort incentives to optimally protect livestock. Moral hazard created by these distorted incentives results in welfare losses. This problem arose in some industrial countries (Swenson & Andrén, 2005), but is of less concern in developing countries where compensation payments tend to be far below the actual value of the livestock, the process of filing for compensation is often cumbersome, and dependence of individual households on single animals is often high. Performance payments do not distort incentives to optimally protect livestock since the payments are directly linked to the conservation goal (e.g. the carnivore stock or carnivore offspring).

In section three, the model was analyzed with empirical data drawn from other models and case studies on tiger-livestock conflicts in India. Due to the existing knowledge gaps on tiger ecology and tigers' existence value, many functions in the empirical model are rather rough estimates. The given data resulted in a model with an interior solution. The optimal ex-post compensation payment was found to be only slightly less than the market price of livestock. Most Indian states have compensation schemes for livestock depredation but full compensation of the animal's market price is an exception. In Maharashtra for example, compensation payments do not exceed 75% of the livestock's market price (Union Ministry of Environment and Forests, 2005). A study conducted at Bhadra tiger reserve revealed that the compensation issued by the forest department only corresponds to 5% of the total losses claimed. If compensation is paid to a herder, on average, it offsets 27% of the livestock's value that the herder declared in the application (Madhusudan, 2003). Referring to the results of our model, it is unlikely that such low compensation payments can provide optimal conservation incentives.

Which single scheme or mix of policies is optimal for a certain carnivore-livestock conflict will also always greatly depend on the specific context. An important factor that may influence the decision is the size of the budget available to set up, run, and monitor a scheme. Our results indicate that the relative cost of an ex-post compensation scheme vs. a performance payment scheme depends on the functional response in the predator prey relationship; both for models with interior and corner solutions. The discussion of the alternative policies focused on assessing the amount of payments that are necessary to achieve certain policy goals. However, the models could also be utilized to compute which level of carnivore conservation is theoretically realizable with a given budget.

Apart from budget issues, the degree of effective law enforcement in a country is also of importance. Livestock herders will want to have securities of being able to claim the payments they are entitled to. Corruption can be a great obstacle for all types of schemes. Corruption together with a lack of public confidence in wildlife management authorities provide dim prospects for the success of any scheme, no matter how well designed it is (Ferraro, 2005). Another obstacle in developing countries is that any type of payment scheme might act as a welfare magnet, attracting people to move to the carnivore dense areas.
Next to the more general framework conditions, understanding how livestock herders make decisions is crucial when designing incentive-based schemes. Profound knowledge of socio-economic household factors may prove to be essential. For example, people in some rural regions of India are strictly vegetarian whereas in others they are not. Incentives that, e.g. aim at reducing competition between livestock and carnivores' natural prey species by increasing livestock harvest rates may simply not work in regions where there is no market for meat. Similarly, infrastructure availability may determine whether off-farm work is a real alternative to agriculture. Many more such examples could be mentioned, but which socio-economic factors are most relevant will always vary from case to case.

There are several lines of possible extension to the model presented here. An obvious one is the consideration of multiple livestock holders. Another one would be to include livestock protection effort as an additional activity, thereby permitting an examination of potential moral hazard effects of ex-post compensation.

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