Compensation for Wildlife Damage: Habitat Conversion, Species Preservation and Local Welfare*

Daniel Rondeau
Department of Economics
University of Victoria
Victoria B.C., Canada, V8W 2Y2
(250) 472-4423
Email: rondeau@uvic.ca
(Corresponding Author)

Erwin Bulte
Department of Economics
Tilburg University
Tilburg, P.O. Box 90153, 5000 LE Tilburg, Netherlands
Email: e.h.bulte@uvt.nl

April 7, 2004

* We are indebted to the many who listened to us during seminars at our respective Departments, at Université Laval, and at the Universities of Wyoming and Montreal. We also thank Yehuda Kotowitz for his insightful comments. This research was supported by a grant of the Social Sciences and Humanities Research Council of Canada.

Compensation for Wildlife Damage: Habitat Conversion, Species Preservation and Local Welfare

Abstract:

The environmental and economic consequences of introducing a program to compensate peasants of a small economy for the damage caused by wildlife are studied. It is shown that the belief that compensation induces wildlife conservation may be erroneous. In a partially open economy, compensation can lower the wildlife stock and result in a net welfare loss for local people. In an open economy, compensation can trigger wildlife extinction and also reduce welfare. The conditions leading to a reduction of the wildlife stock are identified and the implications for current and planned compensation programs in developing countries are discussed.

Keywords: compensation, crop damage, wildlife, endangered species preservation, bushmeat trade

JEL Classification: O13 (Development, Ag., Nat. Resources and Environment); **Q1** (Agriculture); **Q2** (Renewable Resources and Conservation); **D51** (GE, Exchange and production economies); **F18** (Trade and Environment).

Compensation for Wildlife Damage:
Habitat Conversion, Species Preservation and Local Welfare

1. Introduction

Hunting pressure and habitat conversion endanger wildlife species the world over. Yet, current threats to the continued existence of wild species are probably nowhere as severe as in developing countries. Widespread poverty and weak institutions often result in intense hunting pressure and trigger human encroachment into formerly wild land, fragmenting the habitat and often creating conflicts between humans and wildlife.

Human–wildlife conflicts take a variety of forms and can have a significant impact on the wellbeing of affected individuals and communities. Farmers in Tanzania and Zimbabwe rank pests (including wildlife) first among thirty obstacles to the improvement of their quality of life (Naughton et al. 1999). In Malawi, approximately 8% of crop production is lost due to vertebrate pests. In eastern and southern Africa, annual losses attributable to livestock predation range from 1% to 25% percent of potential revenue (Deodatus, 2000; Jackson and Wangchuk, 2000). The annual cost of elephant raids range from \$60 per affected farmer in Uganda to \$510 in Cameroon. Such damage represents up to 70% of family production and income, and can severely affect the ability of households to sustain themselves. Accidental encounters between humans and wildlife can also result in human injuries or death. More than 100 people were killed by elephants in Kenya between 1990 and 1993 (WWF, 2000).

The risk of wildlife-imposed damage provides strong incentives for farmers to hunt in order to keep animal numbers and damages low (Bennett, 2001; Bigalke, 2000). Hunting also yields bushmeat and other traded animal parts, commodities that are often highly valued locally or provide external income (e.g. Bennett, 2000; DFID, 2002). Despite the fact that wildlife can also confer tourism and trophy-hunting benefits to rural communities, Naughton et al. (1999) argue that human-wildlife conflicts are a major obstacle to community support of regional conservation initiatives. In the same vein, Boyd et al. (1999) conclude that in the semi-arid rangelands of eastern Africa, the costs of living with wildlife exceed the income generated from integrated wildlife management programs.

Conservation groups and national governments have sought to neutralize some of the perverse economic incentives leading to the decline in biological diversity. In recent years, the idea of compensating farmers against wildlife-inflicted damage has gained in popularity. The success of these programs has been mixed, however. In developed countries, where property rights are well defined and administrative controls are in place, the Defenders of Wildlife's wolf and grizzly compensation funds have received guarded praise for facilitating the reintroduction and conservation of wolves and grizzlies (Rondeau, 2001). In contrast, the experience in developing countries has not been tremendously successful. The failure of government programs has been attributed to a lack of disbursable funds, bureaucratic inadequacies, and the practical barriers that mainly illiterate farmers from remote areas must overcome simply to produce a claim. In other cases, large numbers of fraudulent claims have led to the demise of poorly funded programs (WWF 2000).

Despite mixed results to date, governmental and non-governmental organizations continue to perceive the establishment of wildlife damage compensation funds as a potentially useful instrument to promote conservation through economic incentives. Echoing many hopeful feelings in the conservation community, the World Wildlife Fund for Nature (WWF) states that: "one of the simplest ways to mitigate conflict without affecting elephant behaviour or population size is to compensate people for the damage they have suffered or would have suffered had they not protected their crops." (WWF, 2000: 5).

Similar beliefs apply to the conservation of many other vertebrate species; from tigers and leopards to monkeys and antilopes. Publicly and privately funded compensation programs have recently been implemented with the aim of reducing the illegal killing by farmers of snow leopards in Tibet and lions in Kenya. Compensation programs exist in India, Nepal, Kenya, Botswana, and Zimbabwe to alleviate the impact of damages caused mainly by elephants but also by rhinos and lions. NGO's are contemplating new programs in China, Nepal and in several regions of Africa.

For well-endowed NGO's funded by residents of developed countries, compensation has several merits. It can be relatively cheap to implement in rural areas of poverty stricken countries. This approach to conservation is readily acceptable to local communities, and local people can be directly involved in the management of compensation funds. The scope for alternative programs is also limited. The institutional context makes it highly unlikely that peasants in developing countries can purchase insurance against wildlife damage on the market (Ray 1998). Setting up a local insurance network is difficult because of the high incidence of crop damage in many areas, and because certain type of wildlife damage may constitute a form of 'catastrophic risk' affecting a large share of the local population simultaneously (e.g. a herd of elephants visiting the village fields).[1] Nevertheless, the lack of market-based alternatives does not imply that compensation of wildlife actually helps governments or NGOs achieve their objectives of encouraging wildlife conservation.

There exists an important literature on compensating property owners for the 'taking' of private land for public purposes (prominently to protect the natural habitat of endangered species – see Blume *et al*. 1984; Innes 1997; Polasky and Doremus 1998; and Smith and Shogren, 2002). However, the economics literature has not considered the issue of wildlife damage compensation in a general equilibrium setting. This is our focus. We analyze programs for wildlife damage compensation and their effects on wildlife and local welfare.

The model we develop brings together the two major threats to wildlife: hunting and habitat conversion for agriculture. In its general equilibrium setting, there is no strategic interaction between the government and landowners and, importantly, land tenure is not secured by property rights. Rather, households have free (open) access to land and wildlife, and respond to economic conditions and policies by myopically adjusting their land use and labor allocation between agriculture and hunting.

Compensation is paid from an external source (e.g. an NGO) to cover wildlife damage. Like any insurance-like program, it should be expected that damage compensation will result in a reduction in the amount of defensive action (e.g. fencing plots, using chemical deterrents, guarding fields). Such defensive measures are ignored. This removes moral hazard from the model and puts the focus more clearly on hunting and land conversion as feedback channels that affect the wildlife stock. Since the

[1] Even when animal damage is highly localized (cataclysmic for affected farmers but insignificant to the regional farming economy), Naughton et al. (1999) conclude that collective coping strategies are typically absent and that crop losses are absorbed by individual households. In any event, the model we develop is deterministic. Reducing risk by purchasing insurance could therefore not play a role.

presence of moral hazard is detrimental to the success of compensation programs, the cumulative effects of compensation are likely to be even worse than the results suggest.[2]

Three central results emerge: 1) compensation schemes aimed at reducing hunting mortality can actually reduce the wildlife stock when the economy is only partially open; 2) compensation can affect the qualitative features of the equilibrium, and may induce a transition to a "small open economy" setting (potentially causing extinction of the wild stock); and 3) compensation programs have ambiguous welfare effects on local people. In both the partially open and open economies, compensation can reduce local welfare. The results show that although compensation programs are well intended, they could lead to the most disastrous outcome of all: compensation that is costly for the sponsoring agency and result in a reduction of the wildlife population and a fall in local welfare.

In the next section, the dynamic model of wildlife damage, compensation and land use conversion in a small rural economy is introduced. In Section 3, the consequences of compensation for land use, wildlife stocks and local welfare are analyzed. Section 4 highlights the consequences of a transition from autarky to trade, which may be facilitated by compensation. Section 5 highlights some policy implications, and section 6 concludes.

2. The Compensation Model

The model developed in this section is of an isolated rural economy in the 'tradition' of Brander and Taylor (1998). In some of its details the model is more closely related to that of Bulte and Horan (2003). The economy is made up of myopic households with open access to both land for agriculture and wildlife for animal products.[3] Labor flows freely between cropping and hunting in response to profit differentials between the two sectors. The assumption that property rights over land and wildlife are not defined (or enforced) implies that the context for the model and the analysis is a less developed country, where conflicts between wildlife and farmers are most profound. The

[2] Important issues associated with moral hazard have been tackled by Rollins and Briggs (1996). See also Dyar and Wagner (2003). Recent evidence regarding compensation for lion predation in Kenya and snow leopard predation in India and Mongolia suggests that conservation agencies are now well aware of potential moral hazard problems (Roach 2003, Mishra et al 2003).

[3] For detailed and interesting discussions of cooperative and non-cooperative management of common property resources, refer to Ostrom (1990) and Baland and Platteau (1996). In what follows we ignore the potential richness of the institutional context and focus on the benchmark case of open access.

assumption that households respond in a myopic fashion to incentives facilitates the analysis but is likely to be not necessary for most of the results presented below.

We assume that land and wildlife are (1) biologically interconnected, so that the capacity of the land to support wildlife is reduced as habitat is converted to agricultural land;[4] and (2) economically interconnected, in that the opportunity cost of time spent growing crops are the foregone returns from harvesting wildlife (and vice versa). This is consistent with observations by Noss (1998: 166), for example, who notes that hunting in an area in the Central African Republic is declining because of the "growing dependence on agriculture and the necessary time investment in clearing, planting, tending and harvesting fields" (see also Hill 2003). At any point in time, the proportion of land devoted to agriculture and the labor choice of households are therefore *endogenous* to the model. The (opportunity) cost of hunting effort is thus also endogenous to the model.

The model extends work by Bulte and Horan along two important dimensions. First, the model explicitly models wildlife damage and is used to analyze the consequences of introducing a compensation scheme. Secondly, we derive the micro-foundations for macro behavior by analyzing a general equilibrium model over time, rather than postulating demand curves for key commodities. Within this framework, we allow the wildlife stock to change over time in response to labor allocation and land use decisions by households.

2.1 Agricultural Production and Revenue

Consider a small economy with a fixed human population endowed with an amount of land L and a time endowment T. A portion $A(t)$ of this homogenous land is used by villagers to grow crops while the remainder is left to be used as wildlife habitat $H(t)$. Without loss of generality, land not used for agriculture is assumed to be immediately suitable as wildlife habitat regardless of previous use. Thus, at any point in time, the following land constraint holds identically (where the time index is suppressed to simplify the notation):

$$A + H \equiv L. \qquad (1)$$

[4] Wirl (1999) also has a model with endogenous habitat. He analyses the management of forests when they can be cleared for agricultural land, and demonstrates that cycles of forest conversion and re-growth may be optimal.

A measure one of households divides its productive time between agricultural labor, $W(t)$, and hunting effort, $E(t)$.[5] The economy is therefore constrained to

$$W + E \equiv T\,. \tag{2}$$

Thus, the model recognizes two sectors of production. An agricultural commodity such as maize or grains is produced with a combination of land and labor, while the inputs to wildlife harvesting are labor and a wildlife stock, the size of which we will denote by $X(t)$. As is characteristic of many rural African situations, we assume that access to land is free and that peasants deciding to increase the scale of their agricultural production can do so by expanding production onto previously unoccupied land. In what follows, we assume that the inputs to agricultural production are perfect complements with a fixed labor requirement per unit of land equal to $W/A = \alpha > 0$. Therefore, the decision to farm an area of size A, necessarily implies the decision to supply agricultural labor in the quantity

$$W = \alpha A\,. \tag{3}$$

We exploit this equality throughout to reduce the dimension of the problem to one of land use selection. By an appropriate choice of unit of measure, we normalize production so that, in the absence of wildlife damage, one unit of land and α units of labor produce one unit of crops. "Potential" agricultural production in the absence of damage can therefore be expressed simply as A. However, the wildlife stock, X, does consume, trample or otherwise destroy a proportion $D(X)$ of the potential harvest, leaving the economy with a net supply of crops equal to $G^S = A[1–D(X)]$. It is assumed that the net amount of crop harvested is a decreasing function of the wildlife stock, with $D(0) = 0$. In what follows, it is postulated that $D(X) = bX$ where $b>0$ is sufficiently small to ensure that even the largest number of animals that can be supported by the land base would not destroy all crops.[6] With this assumed functional form, the amount of crops brought to the market by producers is equal to:

[5] In developed countries ranchers likely have income generating opportunities other than hunting and farming. This may further set the developed and developing world context apart (in addition to the security of property rights issue mentioned in the previous section).

[6] In alternative modeling, we have applied the nonlinear damage function $D(X) = (e^{bx}–1)e^{-bx}$, corresponding to a net production Ae^{-bx} without detecting significant qualitative changes to our results.

$$G^S(t) = A\left(1 - bX\right). \qquad (4)$$

Initially we assume that crops are traded locally by households who take the market price of food crops (*g*) as given (though endogenously determined as the local market clearing price). Peasants in remote areas typically face substantial transaction costs when trading their output on regional or national markets. This implies it might be rational to forego this option and opt for self-sufficiency or local trade on 'shallow' or 'thin' markets instead (in section 4 we explore the case where households do participate in regional markets). Dasgupta (1993: 226) refers to such villages as "self-contained enclaves of production and exchange".

Turning to compensation for the crop damages, the mechanism most often implemented is based on a simple calculation. The physical quantity of crops lost to wildlife is estimated and its value is assessed at the prevailing market price.[7] The most generous programs (those run by NGO's) may cover up to 100% of assessed losses, although, in general, African damage compensation programs run by governments rarely pay more than a fraction of losses. In what follows, we denote the fraction of losses covered by compensation with the parameter *d,* determined by the fund manager and (in this study) held constant over time. Farmers producing a total quantity G^s of crops will now collect in revenue the market price for the quantity supplied, plus a fraction *d* of the market value for the lost quantity $\left(dgAbX\right)$. This translates into total agricultural revenues in the economy equal to

$$gG^S = gA\left(1 + (d-1)bX\right). \qquad (5)$$

2.2 Wildlife Harvesting: Production and Revenue

The alternative economic activity is for households to harvest wildlife. In the absence of enforceable property rights, the stock of animals is an open access resource. Following the standard Gordon-Schaeffer model (Clark 1990), the yield is proportional to the level of effort devoted to

[7] The fund manager thus pays compensation on the basis of the observed market price *g** even though the equilibrium price accounts for the relative scarcity created by wildlife damage. Had the crops reached the market instead of having been destroyed, the equilibrium price would have been lower and the crops worth less than the value at which they are assessed for compensation purposes. The practical arguments in favor of assessing crops at current market price are probably compelling. It is difficult to predict what the hypothetical price of crops would be in the absence of damage. In addition, doing so may appear arbitrary to farmers and erode their trust in the compensation system.

harvesting, and an increasing function of the stock. Specifically, it is assumed that the harvesting technology has the form: [8]

$$M^S = qXE\,, \tag{6}$$

where the amount of product harvested (without loss, we refer to valuable animal commodities as "meat"), M^S, depends positively on the animal stock at time *t*, the hunting effort deployed by villagers, *E* and a constant "catchability" coefficient $q>0$. Everything else equal, a greater value of *q* translates into a greater yield per unit of effort.

It is assumed that harvested meat, a relatively valuable uneasily stored commodity, can be actively traded both within and outside of the local economy (as opposed to the case of locally traded crops). The bushmeat trade may be run by an emerging class of specialized traders (not modeled here) visiting villages in pursuit of meat, and may or may not be legal [see Bennett and Robison (2000:17) on the commercialization of the wildlife harvest].

The important feature is that the price of meat, *p*, is exogenously determined on an open market. This assumption is consistent with the growing trade in bushmeat observed throughout the developing world, across national borders or otherwise.[9] In the absence of compensation for damage (d=0), this is equivalent to assuming that the economy is closed and that *p* is the numeraire against which other prices are evaluated. However, this equivalence no longer holds when external compensation is introduced. External money coming into the local economy will trigger imports. These implications are explored below.

Making use of (2) and (3), the quantity of labor devoted to wildlife hunting can be expressed as $E = T - \alpha A$. With households taking the price of meat as given, total revenues in the hunting sector are then

$$pM^S = pqXE = pqX\left(T - \alpha A\right). \tag{7}$$

[8] When the emphasis is not on hunting for private output but simply on eliminating wildlife (reducing nuisance costs as a public good) it might be feasible to resort to activities that kill wildlife but do not require a lot of labor (such as killing animals with poisoned bait). Such activities are ignored in the model that follows.

[9] The growing importance of bushmeat trade and its increasingly international nature is reflected in the fact that bushmeat received serious attention at the 11th and 12th Conferences of the Parties of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora).

2.3 Household Demand

We now turn to villagers as consumers of the commodities available in the economy. Households maximize a Cobb-Douglas utility function over the consumption of crops (*G*) and meat (*M*) subject to their income constraint. Denoting the weight placed on the consumption of *G* by θ, and household income by ω, we find the usual demand functions that solve the consumers' problem:

$$G^D = \frac{\theta\omega}{g}, \text{ and} \tag{8}$$

$$M^D = \frac{(1-\theta)\omega}{p}. \tag{9}$$

where income in the economy is obtained by summing revenues in agriculture and hunting (Eqs 5 and 7):

$$\omega = gA[1+(d-1)bX] + pqX(T-\alpha A). \tag{10}$$

2.4 Market Equilibrium

At every instant, this economy must generate a market-clearing price for grains obtained by equating the quantity demanded in (8) to the quantity supplied in (4) with the appropriate substitution of (10) into (8). This equilibrium price is given by:

$$g^* = \frac{\theta pqX\left(T-\alpha A\right)}{A\left[\left(1-bX\right)\left(1-\theta\right)-\theta dbX\right]}. \tag{11}$$

The equilibrium price of crops increases with a greater preference for grains, θ, the animal stock level, the overall income derived from hunting (p,q), the level of damage to crops b, and the level of compensation, d. The intuition is straightforward. For example, two factors explain why the equilibrium price of grains increases with the wildlife stock. First, a greater wildlife stock increases the returns to hunting. This increases households' income and the aggregate demand for grains. At the same time, the increase in the number of animals increases crop damage, decreasing both the amount of grains supplied on the market and agricultural revenue (for $d<1$). For an equilibrium, closing both gaps requires an increase in the equilibrium price of crops. On the other hand, the equilibrium price decreases with total crop production, with greater preferences for meat, and with an increase in the labor requirement per unit of land, α. This last effect is explained from the fact that, keeping A constant, a greater agricultural labor requirement implies less time available for hunting and depresses hunting revenue. The smaller total household income that follows reduces the demand for grains and decreases the equilibrium price of crops.

2.5 Labor Allocation and its Dynamics

Substituting (11) into (5) and dividing by $W = \alpha A$ yields the average profit per unit of effort in the agrarian sector:

$$\pi_G = \frac{\theta pqX\left(T - \alpha A\right)\left(1 - bX + dbX\right)}{\alpha A\left[\left(1 - bX\right)\left(1 - \theta\right) - \theta dbX\right]}. \tag{12}$$

Inspection reveals that average profits in agriculture are increasing in the compensation level. It is also worth observing that, in the absence of compensation (*d*=0), equilibrium agricultural profits are independent of the level of damage inflicted by wildlife. This is due in part to the fact that, by assumption, the input mix to agricultural production is not modified by the risk of animal damage. Combining this with unit-elastic Cobb-Douglas demands results in a price adjustment that exactly offsets the revenue lost to wildlife damage. Since households are producers and consumers at the same time (and they have to pay more for the crops they consume), it is of course still true that wildlife damage makes them worse off in real terms. Greater damage lowers the economy's production possibility frontier without any offsetting advantage. Introducing compensation removes this independence, however, since the lost crops are compensated at the market price determined by the lower after-damage supply. In the case of full compensation, for instance, farmers end up effectively receiving the after-damage market price on 100% of their potential (no damage) production. This distortion turns out to play an important role in the analysis that follows.

In contrast, the average profit per unit of effort in hunting is :

$$\pi_M = pqX\,. \tag{13}$$

In making their labor allocation at time *t*, individual households observe the wildlife stock and the profits per unit of effort previously realized in both sectors of the economy. As is typically the case in open access models of resource management, it is postulated that households reallocate labor on the basis of the difference they observe between these rates of return.

If they imperfectly adjust to the profit differential, they create disequilibrium dynamics in the labor market that interact with the dynamics of the natural system. Specifically, suppose that the time rate of change in labor devoted to hunting is given by

$$\frac{\partial E}{\partial t} = \dot{E} = \eta\left[\pi_M - \pi_G\right], \tag{14}$$

where $\eta > 0$ represents how rapidly households increase their hunting effort when hunting returns per unit of effort exceed agricultural returns. Furthermore, the rate of labor reallocation increases with the size of the profit differential.

By use of (2) and (3), differentiate the constraint $E = T - \alpha A$ with respect to time (noting that T is a constant), substitute the result as well as (12) and (13) into (14) to eliminate the labor variable. The dynamics of the economy can then be equivalently described in terms of the rate of change in land use, in the (*X,A*) space. Specifically, the rate of change in agricultural land is a function of the current wildlife stock and the current surface of land in agriculture:

$$\dot{A} = \frac{\eta pqX}{\alpha}\left\{\frac{\theta\left(T-\alpha A\right)\left(1-bX+dbX\right)}{\alpha A\left[\left(1-bX\right)\left(1-\theta\right)-\theta dbX\right]}-1\right\}. \tag{15}$$

Before we proceed further, it is worthwhile to discuss some of the implications of the modeling choices reflected in (13), (14) and (15). First, it is important to stress that no assumption is made that peasants specialize in either hunting or cropping. They could very well do both. Therefore, in their ‘role’ as hunters, agents reduce the wildlife stock and contribute to reducing their own future agricultural losses. (Nuisance control also benefits other farmers but clearly it is assumed that no institution is in place to facilitate the internalization of public goods’ benefits). Since they operate in a common access regime, however, their decisions are driven by a myopic comparison of immediate returns and they ignore the future benefits of hunting on agricultural returns.

The assumption of myopic behavior is a strong one but it is a standard of the open access literature. More importantly, it is reasonable to believe that little foresight exists in the type of poor, rural economy we describe. Baland and Platteau (1996, 211) also suggest that peasants may ignore the effect of their harvesting on future stocks because of belief systems that deny the existence of a link between harvesting and future stocks. Some traditional societies share a "magical pre–rationalist" view of the world, where resource flows are given and determined by "supernatural agencies (deities or cosmic forces) in charge of catering to human needs".

Also absent from the model is an explicit inclusion of retaliation killing by frustrated farmers – farmers going out to kill animals in retaliation for damage sustained. While compensation likely alleviates the need for revenge killings, this would free up labor time and allow for agricultural expansion. This mechanism is entirely consistent with the dynamics of the current model. Adding terms or equations to capture revenge killing would make the model more cumbersome without altering the main results of the paper.

Finally, the model is also silent on the killing of animals for immediate protection of livestock. Threatening wildlife is sometimes killed by farmers in the normal course of tending fields or livestock in order to avoid damage. Such defensive action negatively affects the stock and compensation could reduce its frequency. However, there is no evidence that opportunistic defensive killing is affected by compensation payments. If the farmer's choice is to spend a few pennies on a bullet or watch ungulates destroy his crop, it is often simpler to do away with the wild animal than to watch it cause damage and later make a compensation claim (in particular when compensation is incomplete, $d<1$). However, as the possibility remains that compensation may reduce or eliminate the incentives to opportunistically take threatening animals, we soon come back to this issue.

2.6 Wildlife Population Dynamics

To close the model, we consider the evolution of the wildlife stock over time. Many stocks of wildlife, ungulates in particular, grow naturally according to a quadratic growth curve corresponding to a logistic population path bounded from above by the carrying capacity of the habitat. Suppose that at time t, the environment is capable of carrying a maximum of K animals. The biological rate of growth of the stock can then be described by the quadratic function $F(X) = rX(K–X)$ where r is a positive parameter. In our problem, and as in Swanson (1994), the total carrying capacity of the land is a function of the amount of habitat, H, available at time t. Define k as the maximum density that can be supported by a unit of land so that $K = kH$. With an appropriate choice of units of measure for K, we set k=1. Using (1), biological growth of the stock is now given by $F(X) = rX(L–A–X)$. The net rate of growth of the stock is obtained by subtracting hunting mortality from it:

$$\dot{X} = rX\left(L - A - X\right) - qX\left(T - \alpha A\right). \tag{16}$$

Equation (16) is a differential equation that describes the net change in the wildlife stock as a function of the current size of the stock and the amount of land devoted to agriculture. The population increases (decreases) whenever the biological replenishment rate is greater (smaller) than the hunting off-take.

2.7 Transitions and Equilibria

Equations (15) and (16) form a system of two autonomous first order nonlinear differential equations in X and A. This system has a trivial steady state at $(X, A)=(0, L)$ and at least one interior steady state for some parameter configurations. In general, profits in both sectors are equal whenever the following holds:

$$A\Big|_{\dot{A}=0} = \frac{\theta T\left(1 - bX + dbX\right)}{\alpha\left(1 - bX\right)}. \tag{17}$$

Along this isocline (defined from Equation 15), the labor market is in equilibrium (profits per unit of effort are equal in both sectors) and there are no incentives to stray away from current labor choices and land use. In the absence of compensation (d=0), this isocline is an horizontal line at $A = \theta T/\alpha$. Figures 1 and 2 present phase diagrams with sample time paths for the system defined by equations (15) and (16), assuming no compensation. In these diagrams, each corresponding to a different set of parameters, the horizontal lines define the A isocline. [10]

For positive levels of compensation, the isocline (17) has a positive slope in the (X,A) space. This is illustrated in Figures 3 and 4. To maintain the equilibrium return to labor in the two sectors, an increase in X must be accompanied by an increase in acreage devoted to agriculture (i.e. a decrease in the amount of wildlife habitat). Furthermore, as d increases, the slope of the isocline becomes

[10] All computations were performed and graphs drawn with Mathematica® by numerically solving the system of differential equations. For Figures 1 and 4, parameter values are p=10, q=0.000025, L=50000, T=10000, r=0.000003, b=0.00001, η=300, θ=0.75, α=0.5. For Figures 2 and 3, p=10, q=0.000003751, L=50000, T=10000, r=0.00001, b=0.00001, η=300, θ=0.5, α=0.18. These parameter values have been selected for illustrative purposes only. The stability properties of the steady states have been computed precisely from the eigenvalues of the corresponding linearized system.

increasingly steep. This is explained by the fact that for a small proportion of losses covered by compensation (d close to zero), an increase in X increases both hunting and agricultural returns in approximately equal amounts, requiring only a small adjustment in agricultural labor. With a more generous compensation scheme (i.e. d closer to one), an increase in the stock increases income through two separate channels, hunting and compensation. The increase in demand for grains that results is then greater than with a smaller d, but the price increase is no longer profit neutral because compensation payments are paid at the (higher) clearing market price based on the after damage supply of the agricultural commodity. Returns to agriculture now exceed the returns to hunting and a greater supply of grains to the market is required to lower the price and re-establish the equilibrium. This occurs by increasing the amount of labor and acreage devoted to agriculture and establishes the positive slope of the A isocline when $d>0$.

Equilibrium in the natural system requires that the off take of animals corresponds exactly to the natural rate of regeneration for a given stock and available habitat. The X isocline is the locus of points that satisfy this equilibrium. Setting (16) equal to zero and solving for A yields:

$$A\Big|_{\dot{X}=0} = \frac{qT - r(L-X)}{q\alpha - r}. \tag{18}$$

The slope of this isocline is determined exclusively by the sign of the denominator. For $q\alpha > r$ (Figure 1), the X isocline is positively sloped. This means that in order to maintain an equilibrium in the natural system, an increase in the stock must be matched by an increase in the amount of land devoted to agriculture. To understand this relationship, set (16) equal to zero. For the non-trivial case where $X>0$, increasing X modifies the rate of change in stock density by a quantity directly related to r (a greater r implies a larger change in the growth rate as X increases). A greater stock also increases the productivity of labor devoted to hunting. $q\alpha > r$ indicates that the gain in hunting productivity is large relative to the change in stock growth. Offsetting this gain in productivity thus requires reducing the amount of natural habitat and is accomplished by transferring labor from hunting to agriculture. This generates an upward sloping X isocline, a situation that we characterize as one where the “hunting effect” dominates.

On the other hand, when $q\alpha < r$ as in Figure 2, the increase in harvesting productivity associated with an increase in X is small relative to the change in the stock's growth rate, and is insufficient to maintain an equilibrium in the natural system. A greater stock thus requires an increase in hunting effort (and consequently a decrease in land used for cropping), resulting in a downward sloping X isocline. We refer to these topologies as situations where the "habitat effect" dominates.

In what follows, we are particularly (but not exclusively) interested in cases where the habitat effect dominates. For a given, α, this scenario is more likely to occur for fast-growing or hard-to-catch nuisance species. Primates or even duiker may have either or both of those characteristics, but it would be misleading to label any species as a "habitat effect" or "hunting effect" type. This is because the dominant effect is not a characteristic of the species, but rather of the biological-economic system as a whole. It is determined by the relative magnitude of the three parameters involved. Though estimates of the parameter r may readily be available from population biologists (and perhaps even transferable between populations), the catchability coefficient (q) and agricultural labor input requirement (α) certainly need to be assessed specifically for local conditions. Ultimately, one of the important messages of this paper is that a careful examination of local circumstances is required before the implementation of a compensation program.

3. Compensation and the Conservation of Wild Stocks

The first derivative of (17) with respect to d yields the expression $[\theta TbX]/[\alpha(1-bX)]$ which is equal to zero if X=0 but positive otherwise under the maintained assumption that damage can never exceed 100% of potential production. Compensation has therefore the effect of rotating the A isocline in a north-west direction about its origin. It follows directly that if an interior steady state existed in the no compensation case with a downward sloping X isocline, a steady state still exists in which more land is devoted to agriculture and where the stock of wildlife has been reduced.

Figure 3 illustrates the situation in which the habitat effect dominates and where damage is fully compensated for (d=1). Presenting the full compensation case is without loss of generality since for with partial compensation the A isocline lies between those illustrated in Figures 2 and 3. The solid lines appearing on the phase diagrams are actual numerical solutions to the system of differential equations. They trace the evolution of the system over time for given sets of parameter values and initial conditions. Each trajectory begins at the point furthest away from the steady state and follows the direction fields indicated by the arrows. They asymptotically reach stable steady states.

In assessing the impact of compensation when the habitat effect dominates, two observations are worth making. First, the steady state stock of wildlife is *smaller* with compensation than without. This will be the case anytime the habitat effect dominates -- a truly perverse result from the perspective of the funding agency. Second, in addition to reducing the stock level, compensation could induce economic cycles. For the parameters employed, the steady state of the economy without and with compensation are respectively a stable node and a stable spiral. Therefore, while the economy converges toward a locally stable steady state in both instances, the economy with compensation is subject to greater economic fluctuations in the form of damped cyclical variations in labor allocation, land use and wildlife stock.[11]

The effect of compensation when the hunting effect dominates is more complex, since it gives rise to the possibility of multiple steady states. Figure 4 replicates the economy of Figure 1 but with a 50% compensation level. Several properties are worth noting. First, even though there can be multiple steady states, the myopic agent equilibrium is always unique and fully determined by initial conditions.[12] Second, the stable steady state with a low stock and low agricultural use lies above the steady state without compensation. Furthermore, the equilibrium remains stable. This is therefore an example where compensation can, as intended, provide incentives to preserve wildlife.

Note, however, that further *increasing* the compensation parameter d in the context of multiple equilibria shifts the A isocline up and makes the 'high' wildlife equilibrium stock fall. It could also be that for relatively low initial acreage and high stock, the amount of wildlife decreases under hunting pressure, causing households to shift their labour away from agriculture at an

[11] While the model does not contain any objective criterion to evaluate whether economic and biological cycles are "bad", economists generally think negatively of cyclical economic patterns. Here, these cycles result squarely from the introduction of compensation into the economy.

[12] A model with forward-looking agents might potentially generate multiple equilibria (more than one equilibrium originating from a given initial condition). Such models may be driven by expectations about the behavior of others, and could feature self-fulfilling prophecies (e.g., Krugman 1991, Kremer and Morcom 2000). However, addressing this is much more complex as it requires a three dimensional model resulting in a two point boundary value problem.

increasingly rapid rate. This further reduces the amount of land devoted to agriculture and reinforces the decay of both the stock and agricultural land. This process is self-reinforcing and leads to a degenerate solution in which agriculture is abandoned. No producer wishes to supply crops since time spent hunting provides greater income. As a result, local welfare goes to zero as the supply of grains shrinks. [13]

We now return to the issue of defensive hunting and a discussion of how incorporating it into the model may affect the results. There are many ways in which defensive hunting could be incorporated into the model, but the following principles are at play. If defensive hunting is done at very little or no cost (in particular at no opportunity cost of labour) and it removes incentives for defensive killing, it clearly reduces defensive hunting mortality. However, the compensation program can be viewed as a subsidy to agriculture and, *as long as there exists a regular hunting sector*, it will provide incentives to reallocate some labour away from hunting in order to expand the agricultural land base. Thus, while compensation reduces defensive hunting mortality and bushmeat hunting mortality, it also reduces the available habitat. It follows that the net stock effect following compensation remains fundamentally ambiguous. In a model with defensive hunting, the technical relationship between $q\alpha$ and r that currently define the domains where the habitat or hunting effects dominate would be altered. It would be "easier" for compensation to have a positive effect on the wildlife stock, but the effect of compensation would remain ambiguous.[14]

Another possibility is that defensive hunting is a third alternative labour allocation. It would have its own reward (avoided crop loss) and opportunity costs (revenue from regular hunting or cropping). In this context, if compensation is effective at decreasing the amount of defensive hunting,

---

[13] We also observe the appearance of a singularity within a relevant portion of the domain. The singularity arises at $X=(1-\theta)/b(1-\theta+\theta d)$. At this value of X, the denominator of (15') is exactly zero and the law of motion for $A(t)$ is undefined. This is indicated on the graph by the vertical line at X=40,000. The behavior of the system around this stock level is poorly understood in mathematical theory. Nevertheless, we do know that in our system, the singularity creates basins of attraction. To its left, the system behaves as before, with a stable node or spiral steady state. It is not possible, however, to cross the singularity. In personal communications, Dr. John Guckenheimer, a Cornell mathematician specializing in systems of differential equations, indicated that little is known about such regions where the vector field is unbounded in a compact region of the phase space.

[14] Note that compensation is always good for conservation when there is only defensive hunting and no bushmeat hunting in the wilds (so that no effort can be freed up to push the extensive frontier outwards). However, throughout large parts of the developing world there is ample evidence of significant amounts of efforts devoted to hunting in wild habitats.

the gains in wildlife stock through decreased mortality will be at least partly offset by both an increase in regular hunting and agricultural expansion. Once again, the net impact on the stock of wildlife would be ambiguous.

3.1 Compensation and Local Welfare

When the habitat effect dominates, the net impact of compensation on the welfare of local peasants is ambiguous. The argument proceeds from the change in instantaneous utility level around the steady state that follows a change in the compensation level, *d*. The Cobb-Douglas utility of the household is defined over $G = A[1-bX(1-d)]$ (it is more convenient to use the expression for the supply quantity which is equal to demand in partial autarky) and the consumption of $M = (1-\theta)\omega/p$ where ω is given by (10) and (11). The change in the instantaneous rate of utility (at the steady state) associated with a change in compensation level is therefore given by:

$$\frac{\partial U(G^*,M^*)}{\partial d}=\theta\frac{M^{*1-\theta}}{G^{*1-\theta}}\left[\frac{\partial A^*}{\partial d}[1-bX^*(1-d)]-A^*b\left((1-d)\frac{\partial X^*}{\partial d}-X^*\right)\right]+(1-\theta)\frac{G^{*\theta}}{M^{*\theta}}\left[\frac{\partial\omega^*}{\partial d}\frac{(1-\theta)}{p}\right]$$

It has already been established that when the habitat effect dominates, $\partial A^*/\partial d > 0$ and $\partial X^*/\partial d < 0$. It follows that the expression in the first square brackets ($\partial G^*/\partial d$) is positive. The second square bracket ($\partial M^*/\partial d$) has an ambiguous sign since the effect of increasing compensation on income is itself ambiguous. The expression for $\partial\omega^*/\partial d$ is not reproduced here (it is four lines long), but the direction of this margin is ambiguous because the decrease in stock reduces hunting yields and depresses hunting revenues. Steady state income with compensation can therefore be above or below the no-compensation income level.

Figure 5 plots the computed steady state utility level for the habitat effect case illustrated in Figures 2 and 3. In this example, it is possible to improve the steady state welfare level with low levels of cash compensation. However, it is worth noting that the rate of welfare with full compensation (*d*=1) is actually lower than when no compensation payments are made (*d*=0). In general, a weaker habitat effect ($q\alpha$ not much smaller than *r*) can produce a monotonically increasing relationship between *d* and steady state welfare, while a strong habitat effect can produce a decreasing relationship (even at d=0). For intermediate cases the inverted U shape of Figure 5 materializes.

When the steady state welfare level is lowered by compensation, it is still possible for compensation to temporarily improve local welfare. However, if the labor allocation response to profit differentials between farming and hunting is sufficiently rapid (i.e. η is large), the economy will quickly converge to the new steady state. From a normative perspective, if one wishes to assess the welfare effect of compensation using a sum of welfare over time, the lasting welfare losses of the new steady state with compensation may outweigh any temporary gains that could be made along the adjustment path.

This, we believe, is quite a damning result. Together with our previous analysis, it turns out that it is possible for well intended compensation programs to lead to the worst possible outcome of all: the compensation program is costly to its sponsors, it promotes habitat conversion, it reduces the stock of wildlife, and it lowers the welfare of local people.

4. Compensation and Regional Trade

In this section we examine another potential effect of compensation. Transfers to the village from an external source may induce a transition from partial autarky to regional trade. Sadoulet and de Janvry (1995:149) explain how this works. Assume that trading commodities at regional markets entails transaction costs. The existence of such costs implies village households face different selling and buying prices for commodities. The width of the price margin (or band) is determined by the magnitude of the transaction costs. These may be considerable for perishables.[15] In partial autarky (as in Section 2) local markets for crops clear at a price located within this price band and trading outside of the village is unprofitable. This may change after implementation of a compensation program.

Compensation affects both the demand for and supply of crops and a new price emerges. While this new price may still be within the price band defined by transaction costs (as implicitly assumed thus far), this need not be the case. The endogenous price may also leave the price band. In

[15] As argued above we have assumed above that trade in meat is possible. Bushmeat is a relatively valuable commodity. In certain regions a specialized class of bushmeat traders has emerged that is willing to incur these costs. Transaction costs as a percentage of the value of the commodity (say, per kilogram) are relatively modest.

these circumstances, trading at the fixed regional prices become feasible and the village can be represented as a small open economy.

In the open economy case, both prices are established on an open market and taken as given by the local community. Define φ as the exogenous selling price of crops, and assume that the village stays 'open' after implementation of the compensation program. For local workers, the average return per unit of labour in farming is henceforth:

$$\pi_G = \frac{\varphi[1+(d-1)bX]}{\alpha} \qquad (12')$$

and the law of motion for the allocation of land becomes:

$$\dot{A} = \frac{\eta}{\alpha}[\pi_G - \pi_M] = \frac{\eta}{\alpha}[\frac{\varphi(1+(d-1)bX)}{\alpha} - pqX]. \qquad (15')$$

The new expression for the new A isocline is then reduced to:

$$X^{**} = \frac{\varphi}{\alpha pq + \varphi(1-d)b}. \qquad (17')$$

This isocline is vertical in the X-A space, implying a unique equilibrium, regardless of whether the X isocline slopes up or down. Figure 6 presents the combination of two phase planes for the case where the habitat effect dominates. On this phase diagram are drawn a single X isocline denoting the biological equilibrium (which is independent of d), and two A isoclines: the horizontal one where d=0 (as in Figure 2) and the vertical isocline corresponding to the new economy after full compensation has been introduced (d=1).

The key feature illustrated by Figure 6 is that the *qualitative nature* of the equilibrium has changed after the introduction of compensation. Whereas the steady state of the partial autarky case is stable, the steady state of the small open economy is a saddle point. This is readily verified from observing the vector fields. It is also important to observe that there is no planner to guide the small open economy to the saddle point equilibrium. With the exception of the slim possibility that the system follows the separatrix to the steady state, the open economy will completely specialize over time into one of the two sectors of activity. For initial conditions above the separatrix, the economy eventually specializes into agriculture, driving the stock to extinction in the process. From initial conditions below the separatrix, households abandon agriculture, eventually devoting all labor resources to hunting.[16]

Outside intervention" by NGOs (but also general movements towards the creation of broader market systems and globalization), can have important impacts on resource management. They may trigger specialization of activities with far-reaching consequences on conservation (for better or for worse). When the pre-intervention (pre-compensation) is in equilibrium, and the wildlife stock X^* is smaller than the open economy stock X^{**} as defined by (17''), specialization in cropping and local extinction of wildlife will result. This is the case drawn in Figure 6. Conversely, for $X^* > X^{**}$ specialization in hunting will result in a thicker wildlife stock. Which case emerges depends on the magnitude of φ. In the absence of full information about the system's parameters and variables, the implications of outside intervention, however, are ambiguous and unpredictable.

The ranking of income levels from specialization in hunting and cropping is ambiguous and again depends on the terms of trade and the magnitude of φ. Consistent with the autarky case of Section 3, we therefore conclude that compensation can result in higher or lower wildlife stocks, and either higher or lower local welfare.

5. Discussion

Assuming international NGOs are mainly interested in the conservation of wildlife in developing countries, how should they go about their business? Rather that attempting a full-fledged analysis of optimal policy, we make a few additional observations on outside compensation and sketch their implications.

First and foremost, the type of instrument should depend on local circumstances. Compensation can be effective if the hunting effect dominates. It is therefore important to assess the sensitivity of labor reallocation to changes in agricultural revenue, and to understand the impacts of the reallocation on wildlife hunting mortality and habitat conversion.

Factor availability also matters. The model assumes that, prior to the introduction of compensation, there exists a certain amount of land and labor that could be re-allocated to agriculture.

---

[16] Note that such forces towards specialization do not arise when the hunting effect dominates. It can be verified that the interior steady state is stable when the X isocline slopes upwards.

This, obviously, may not be the case – all land or labor may be 'tied up' in agriculture already. A binding labor constraint, however, can be relaxed by regional migration flows. This may be an important issue affecting the potential success of compensation schemes. The fact that compensation increases the returns to agriculture may provide incentives for households to relocate from nearby regions where no compensation scheme was implemented. A net inflow of people would have an unambiguously negative impact on local wildlife (but presumably a positive effect on some other wildlife from the region of origin). Compensation could negatively affect the local stock of wildlife if it triggers significant immigration, even when the hunting effect dominates.[17]

The observation that wildlife damage compensation schemes act as subsidies to agriculture is central to the analysis. Note that similar effects should be expected when NGOs sponsor or subsidize expenditures on preventive measures (e.g. electric fences). While this approach mitigates moral hazard issues, it, just like compensation, increases the profitability of agriculture relative to hunting (or any other occupation) and ultimately promotes land conversion.

When the habitat effect dominates it follows logically that any conservation program should aim to penalize rather than subsidize agricultural production. A tax on agricultural output, for instance, would have effects nearly opposite to those of compensation. With dominance of the habitat effect, a marginal tax on output would trigger larger wildlife stocks. Similarly, it may be worthwhile to 'subsidize' hunting (or other activities that are unrelated to the wildlife stock), for example through higher prices for meat or through facilitating the trade in this commodity. The principle being that policies that act differentially on labour allocation decisions should favour the sector that has a positive net effect on the stock, after careful consideration of all of the feedback channels that ultimately impact the target species.

---

[17] Compensation could adversely affect wildlife through other mechanisms, even if the land base is fixed. As an example, ranchers near Amboseli National Park (Kenya) live at the boundary of the reserve where parkland use for agriculture is prohibited and enforced. While there is no extensive margin, the intensity of livestock grazing outside the park is endogenously chosen by ranchers. There, the introduction of compensation for livestock predation (in an effort to conserve lions and other predators) provides incentives for ranchers to increase their stocking rate. With wildlife from the park seasonally spilling onto adjacent lands (as is the case in many African settings), more livestock implies increased competition for forage, at the detriment of both the wild ungulate population and the predators.

But there are other intervention options other than subsidizing or taxing agriculture and hunting. For example, in the context of our model it makes sense for NGOs to offer alternative employment (*N*) unrelated to land or wildlife, and create a new outlet for labor other than hunting and farming. In effect, this amounts to adding a new argument to the time constraint (2): $T = W + E + N$, relaxing pressure on both habitat and wildlife. Such "indirect intervention" approaches are currently a dominant strategy chosen by NGOs, and they aim to re-direct labor and capital away from uses that are detrimental to habitat and wildlife. Alternatively, other commercial activities that supply ecological services as a by-product can be encouraged (e.g. ecotourism, anti-poaching enforcement). Ferraro (2001) and Ferraro and Simpson (2000) criticize this approach and argue that "direct payments" for the creation and conservation of nature are more efficient and effective. Indirect mechanisms are probably more likely to suffer from negative feedback channels and unforeseen consequences.[18] More direct approaches such as transfer payments based on estimates of wildlife abundance or production of forage (conservation of habitat) may have a better chance. They will be more likely to be successful, however, if they are implemented together with effective mechanisms or institutions for local communities to increase their positive involvement in resource management. Further experimenting with such programs seems worthwhile.

Finally, if compensation transfers are to be provided, it might be advisable to make them conditional on cooperation at the village level. This would imply a transition from a non-cooperative model to a cooperative one that internalizes the external effects of open access to land and wildlife. One related caveat is worth noting. We have assumed throughout that access to land and wildlife resources is open to all households, and that it remains open even after the compensation scheme is implemented. It is well known that the definition and enforcement of property rights is endogenous and dependent on relative prices (e.g., De Meza and Gould, 1992; Hotte et al, 2000). It is therefore conceivable that compensation programs that drive up crop prices could change the social fabric that supports the types of equilibria discussed above. Compensation could favor the transition from open

[18] For example, Liu et al (2001) describe how promotion of (eco)tourism in the Wolong reserve for giant pandas has had adverse effects on panda habitat. "… the booming tourism has helped to transform the reserve from a closed economy to an open economy." The tourism sector supported a much larger local population of people, and has increased extraction of key resources and resulted in fragmentation of habitat.

access to land towards the establishment of private property rights and perhaps foster better resource husbandry.

6. Concluding Remarks

Poverty and natural resource dependence in rural areas throughout the world have resulted in many conflicts between humans and wildlife, with many casualties on both sides. One important response by conservationists worried about the long-term fate of wild animals has been the promotion of so-called Integrated Community Development Programs, where people are encouraged to utilize local natural resources in a sustainable fashion (see also Barrett and Arcese, 1995). An important complementary measure, employed worldwide, is compensating farmers for wildlife damages.

This paper provided a descriptive analysis of a ‘typical’ compensation scheme. In the most recent literature, one can find critical assessments of such compensation schemes in developing countries (e.g. AFESG, 2002), but the reasons for criticizing these schemes emphasizes ineffective bureaucracies, corruption, cheating, lack of funds, and moral hazard. We abstracted from these issues to find that the situation may in fact be much worse. Compensation may not only be ineffective, it could have negative consequences for wildlife, possibly threatening a local stock with extinction. In addition, compensation could also have negative consequences on local welfare.

The unintended consequences come about through feedback channels that standard partial equilibrium modelling most often fail to incorporate in the analysis. Here, compensating for agricultural damage does not only reduce the immediate incentives to hunt animals, it is an agricultural subsidy that encourages the conversion of natural habitat into agricultural fields. Whenever the removal of habitat has a greater effect on the stock than the reduction in hunting effort that accompanies a shift toward agriculture, the stock will be negatively affected. Compensation may also have the moral hazard implication of removing the farmers’ incentives to defend their field with fences, fires or other non-lethal methods. As a result, the cash value of compensation payments, their real value to farmers, and the extent of the farmer’s response to the modified incentives may be greater than described.

Wildlife damage problems are part of a greater family of natural damage for which afflicted parties seek compensation (a family that includes, for example, coastal property damages because of hurricanes). One may interpret such damage as externalities from a natural production process, and to the extent that other individuals care about the natural product, invoke Coasian principles to resolve the conflict. Environmental groups compensating farmers for the wildlife damage they suffer in order to increase the abundance of wildlife can certainly be considered in that context. But more generally, Baumol and Oates have pointed out that in the presence of a large number of individuals, "…compensation of victims leads to other economic inefficiencies… it tends to produce excessive entry into the "victim activity…" (Baumol and Oates 1988: 24).

As in the classic externality model, excess entry is the major culprit driving our perverse results. However, the circumstances leading to our results are different. If we were to recast our study in a public economics model *à la* Baumol and Oates, the objective criterion to assess the desirability of compensation would be how successful it is at increasing the number of polluters (i.e. the number of animals causing damage) rather than social optimality. Furthermore, we have victims who are involved in two economic activities (farming and hunting) both of which *directly* impact the number of polluters. There is no such mechanism in the standard public economics model. However, the fact that the analogies between the two approaches can be drawn suggests that, as a referee pointed out, there may be significant gains in knowledge to be made by pursuing the development of a more general, more flexible "public economics" model to study incentives mechanisms for conservation. This could lead to a more unified framework with which to assess and compare the merits of alternative policies, and also prove to have appeal beyond environmental and resource economics.

References

AFESG (2002). "Review of Compensation Schemes for Agricultural and Other Damage Caused by Elephants," Technical Brief, Human-Elephant Conflict Working Group, African Elephant Specialist Group (afesg), IUCN, Gland, Switzerland

Baland, J.M. and J.P. Platteau (1996). "Halting Degradation of Natural Resources". Oxford: Clarendon Press

Barrett, C.B. and P. Arcese (1995). "Are Integrated Conservation-Development Programs (ICDPs) Sustainable? On the Conservation of Large mammals in Sub-Saharan Africa", World Development, 23, 1073-1084

Bennett, R. (2000). "Food for Thought: The Utilization of Wild Meat in Eastern and Southern Africa", Nairobi: Traffic East/Southern Africa, IUCN and WWF

Berck, P. and J.M. Perloff, (1984). An Open Access Fishery with Rational Expectations, Econometrica 52: 489-506

Bigalke, R. (2000). "Functional Relationships Between Protected and Agricultural Areas in South Africa and Namibia", Chap 9 In: H. Prins, J. Grootenhuis and T. Dolan (eds.). Wildlife Conservation by Sustainable Use, Dordrecht: Kluwer Academic Publishers

Blume, L., D. Rubinfeld and P. Shapiro (1984). "The Taking of Land: When Compensation Should be Paid?", Quarterly Journal of Economics, 100, 71-92

Baumol, W.J. and W. Oates. 1988. The Theory of Environmental Policy. Second Edition. Cambridge: Cambridge University Press.

Boyd, C., R. Blench, D. Bourn, L. Drake and P. Stevenson (1999). "Reconciling Interests Among Wildlife and People in Eastern Africa: A sustainable Livelihoods Approach", Natural Resource Perspectives, 45, ODI, London, UK.

Brander, J. A. and M.S. Taylor (1998**).** The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use, American Economic Review 88,119-38.

Bulte, E.H. and R.D. Horan (2003). "Habitat Conservation, Wildlife Extraction and Agricultural Expansion", Journal of Environmental Economics and Management 45, 109-127

Clark C.W. (1990). "Mathematical Bioeconomics", New York: Wiley

Dasgupta, P. (1993). "An Inquiry into Well-Being and Destitution", Oxford: Clarendon Press

De Janvry, A., M. Fafchamps and E. Sadoulet (1991). "Peasant Household Behavior with Missing Markets: Some Paradoxes Explained", Economic Journal, 101, 1400-1417

De Meza, D. and J.R. Gould (1992). "The Social Efficiency of Private Decisions to Enforce Property Rights," Journal of Political Economy, 100, 561-580

Deodatus, F. (2000). "Wildlife Damage in Rural Areas with Emphasis on Malawi", Chap 7 In: H. Prins, J. Grootenhuis and T. Dolan (eds.), Wildlife Conservation by Sustainable Use, Dordrecht: Kluwer Academic Publishers

DFID (2002). "Wildlife and Poverty Study", London: Dept. for International Development

Dyar, J. and J. Wagner (2003). "Uncertainty and Species Recovery Program Design," Journal of Environmental Economics and Management, 45, 505-522

Ferraro, P.J., 2001. Global Habitat Protection: Limitations of Development Interventions and a Role for Conservation Performance Payments, Conservation Biology 15: 990-1000

Ferraro, P.J. and R.D. Simpson, 2000. The Cost-Effectiveness of Conservation Payments, Resources for the Future, Discussion Paper 00-31.

Hill, C.M., 2000. A Conflict of Interest Between People and Baboons: Crop Raiding in Uganda, International Journal of Primatology 21: 299-315

Hill, C.M., 2003. People, Crops and Primates: A Conflict of Interest. Working Paper, Department of Anthropology, Oxford Brookes University

Hotte, L. N. van Long and H. Tian, 2000. International Trade with Endogenous Enforcement of Property Rights, Journal of Development Economics 62: 25-54

Inness, R., S. Polasky and J. Tschirhart (1998). "Takings, Compensation and Endangered Species Protection on Private Lands," Journal of Economic Perspectives, 12, 35-52

Innes, R. (1997). "Takings, Compensation and Equal Treatment for Owners of Developed and Undeveloped Property," Journal of Law and Economics, 40, 403-432

Jackson, R. and R. Wangchuk (2000). "People-Wildlife Conflicts in the trans-Himalaya". Paper presented at the Management Planning Workshop for the trans-Himalayan Protected Areas, Ladakh,

Kremer, M. and C. Morcom (2000). "Elephants", American Economic Review, 90, 212-34

Krugman, P. (1991). "History versus Expectations", Quarterly Journal of Economics, 651-667

Liu, J., M. Linderman, Z. Ouyang, L. An, J. Yang and H. Zang (2001). "Ecological Degradation in Protected Areas: The Case of Wolong Nature Reserve for Giant Pandas", Science 292: 98-101

Mishra, C., P. Allen, T. McCarthy, M. Mudhusudan, A. Bayarjargal and H. Prins, 2003. "The role of incentive programs in conserving the snow leopard", Conservation Biology 17: 1512-1520

Naughton, L., R. Rose and A. Treves (1999). "The Social Dimensions of Human-Elephant Conflict in Africa: A Literature Review and Case Studies from Uganda and Cameroon", A Report to the African Elephant Specialist Group, Human-Elephant Conflict Task Force, IUCN, Glands, Switzerland

Noss, A.J. (1998). "The Impacts of BaAka net hunting on Rainforest Wildlife", Biological Conservation, 86, 161-167

Ostrom, E. (1990). "Governing the Commons", Cambridge: Cambridge University Press

Polasky, S. and H. Doremus (1998). "When the Truth Hurts: Endangered Species Policy on Private Land with Imperfect Information", Journal of Environmental Economics and Management, 35, 22-47

Ray, D. (1998). "Development Economics", Princeton: Princeton University Press

Roach, J. (2003). "Lions vs Farmers: Peace Possible?" National Geographic News (hhtp://news.nationalgeographic.com/news/2003/07/0716_030716_lions.html)

Rollins, K. and H.C. Briggs (1996). "Moral Hazard, Externalities and Compensation for Crop Damages from Wildlife", Journal of Environmental Economics and Management, 31, 368-386

Rondeau, D. (2001). "Along the Way Back from the Brink", Journal of Environmental Economics and Management, 42, 156-182

Sadoulet, E. and A. De Janvry (1995). Quantitative Development Policy Analysis", Baltimore: The Johns Hopkins University Press

Smith, R and J. Shogren (2002). "Voluntary Incentive Design for Endangered Species Conservation", Journal of Environmental Economics and Management, 43, 169-187

Swanson T.M. (1994). "The Economics of Extinction Revisited and Revised: A Generalized Framework for the Analysis of the Problems of Endangered Species and Biodiversity Losses", Oxford Economics Papers, 46, 800-821.

Wirl, F., 1999. De- and Reforestation: Stability and Limit Cycles, Environmental and Resource Economics 14: 463-479
WWF (2000). "Elephants in the Balance: Conserving Africa's Elephants." www.panda.org/resources/publications/species/elephants/index.html

Figure 1
Dynamics of the Economy – No Compensation
Cobb-Douglass Utility, Linear Damage, Dominant Hunting effect

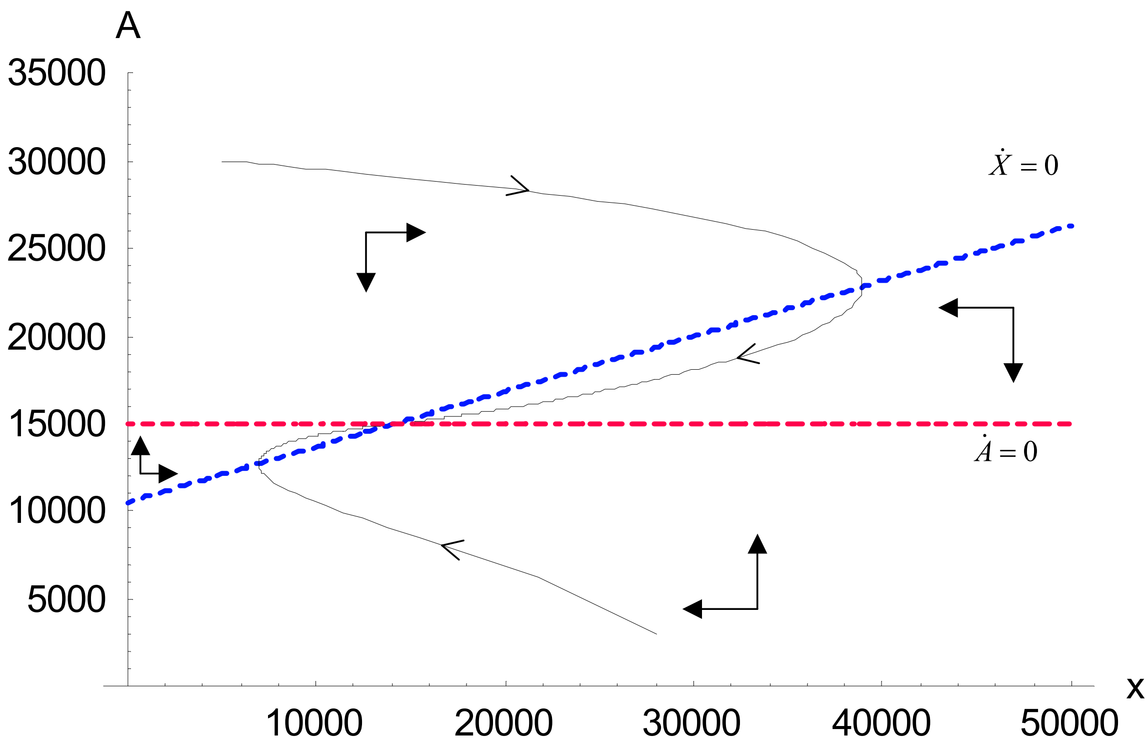

Figure 2
Dynamics of the Economy - No Compensation
Cobb-Douglass Utility, Linear Damage, Dominant Habitat effect

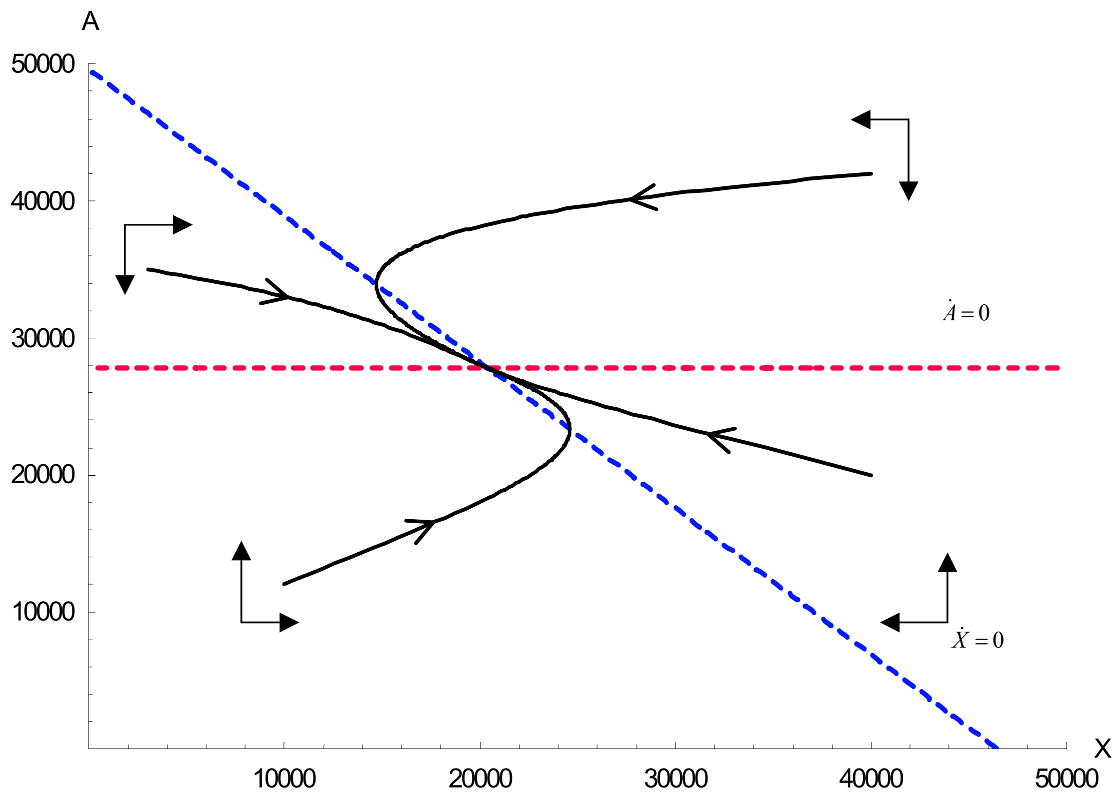

Figure 3
Dynamics of the Economy with Full Compensation (d=1)
Cobb-Douglass Utility, Linear Damage, Dominant Habitat effect

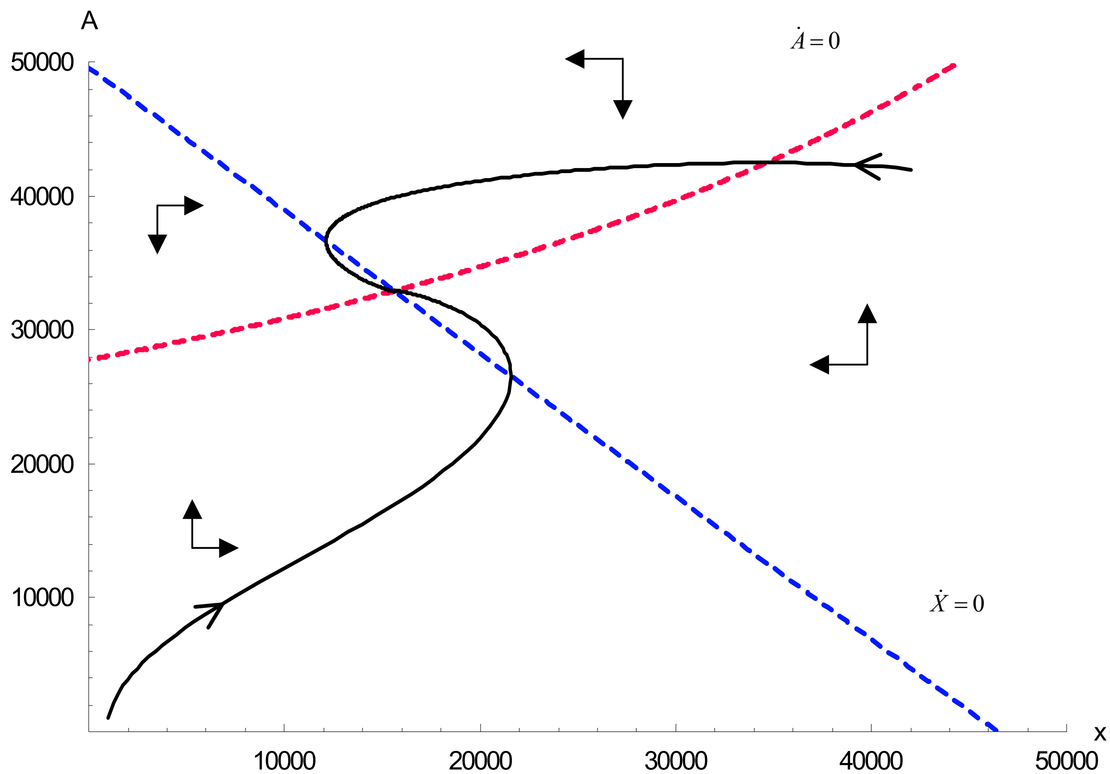

Figure 4
Dynamics of the Economy with 50% Compensation (d=0.5)
Cobb-Douglass Utility, Linear Damage, Hunting effect

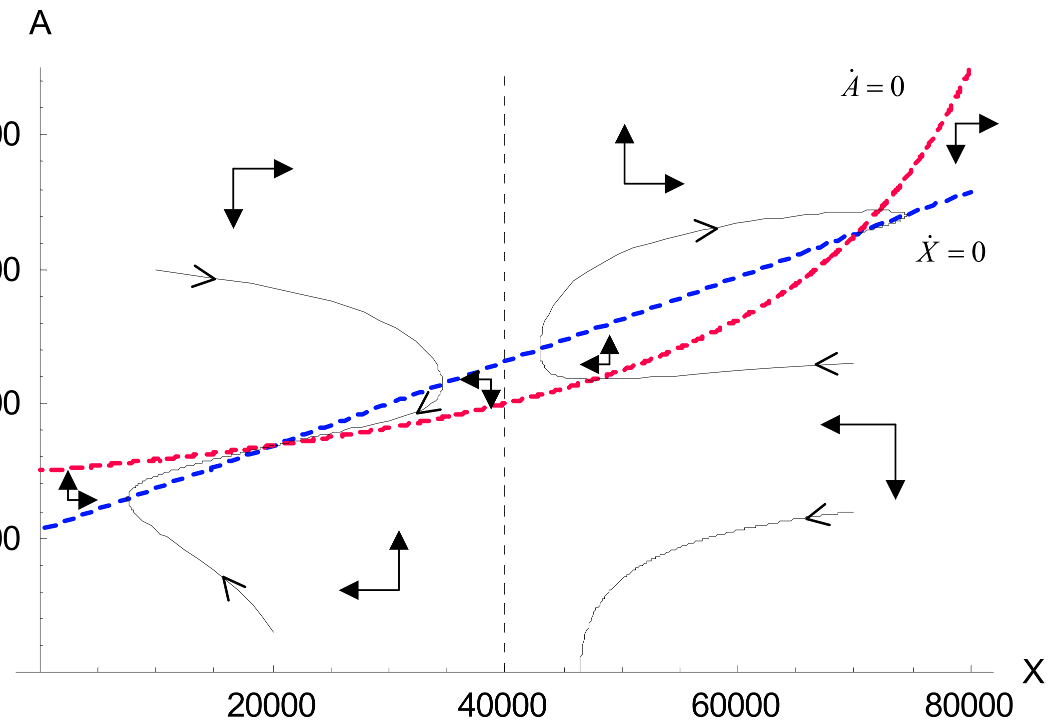

Figure 5
Possible Relationship between Compensation Level and the Rate of Welfare Accumulation in Steady State
Dominant Habitat Effect

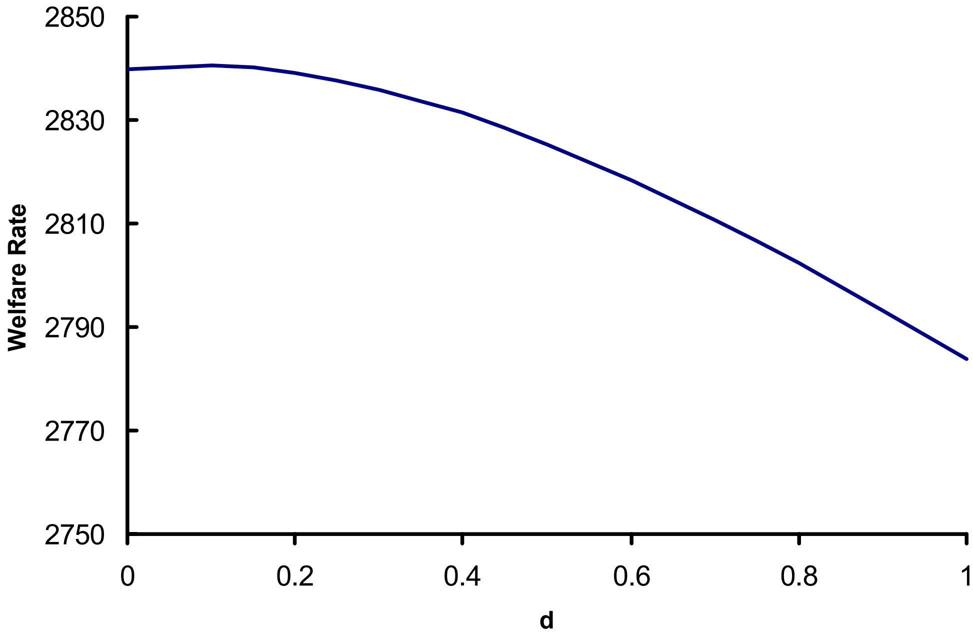

Figure 6
Compensation and the Transition to an Open Economy (Habitat Effect).