Wildlife Damage and Agriculture: A Dynamic Analysis of Compensation Schemes

Daniel Rondeau and Erwin Bulte

We study the environmental and economic consequences of introducing a program to compensate peasants for damages caused by wildlife. We show that the widely held 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. We identify the conditions leading to a reduction of the wildlife stock and discuss the implications for current and planned compensation programs in Africa and Asia.

Key words: compensation for wildlife damages, crop damage, endangered species preservation.

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The two principal threats to African wildlife are agricultural expansion and hunting. Increasing human populations are associated with greater conversion and fragmentation of wild habitats, and more intense hunting pressure on remaining wildlife stocks. Increased human encroachment in formerly wild habitat also sets the stage for conflicts between humans and wildlife, with casualties on both sides. Perhaps the most common cost imposed on humans by wildlife is damage to agricultural output, where a significant share of agricultural production near the extensive margin of human-nature interface can be destroyed by wildlife (e.g., Deodatus 2000). Predator species routinely take local livestock, and various other species have made a habit out of invading fields. In many areas of the developing world the conflict between humans and wildlife is tense, and indeed growing tenser over time.

The economic (and emotional) costs of this conflict can be quite substantial—from merely significant at the national or regional scale, to outright disastrous for individual households (Thouless 1994; Hoare 1995; Ngure 1995; WWF 2000). It is perhaps no surprise that outraged and frustrated farmers and pastoralists often seek revenge for such damages. Mishra et al (2003) mention a deep resentment among pastoralists against large carnivores in India and Mongolia. In practical terms, the risk of wildlife-imposed damage provides strong incentives for farmers to hunt in order to keep animal numbers and damages low (Bennett 2000). Hunting also yields bushmeat and other traded animal parts such as skins—commodities that are often highly valued locally or provide external income.[1] From a conservation perspective, the issue becomes particularly problematic when charismatic species like elephants, rhinos, lions, tigers, or snow leopards are involved. When wildlife damages are caused by these icons of the international conservation movement, and when nuisance killings contribute to their demise, international concerns and intervention often ensue.

To mitigate the incentives peasants have to kill wildlife, governments or nonprofit conservation organizations sometimes put in place compensation schemes whereby farmers are given money, seeds, or livestock to cover a

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[1] Despite the fact that wildlife can also confer tourism and trophy-hunting benefits to rural communities, Naughton, Rose, and Treves (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.

portion of the losses imposed by wildlife. In developing countries, such efforts have been met with mixed success.[2] Lack of funds, transaction costs, heavy bureaucracy, fraud, corruption, and moral hazard problems have been identified as potential reasons why compensation schemes might fail to achieve their conservation objectives (e.g., WWF 2000).[3] But sobering experiences have not tempered all expectations. Initiatives to compensate farmers for wildlife damages continue to be popular both among public and private agencies, and are in existence to promote the conservation of many different species on different continents (e.g., elephants, rhinos, and lions in Africa, snow leopards, tigers, and antelopes in India and East Asia, etc.).

In this paper, we develop a dynamic model to examine the consequences of introducing a compensation scheme on the size of a single wildlife stock and on the welfare of local peasants. We focus on the compensation of victims—a topic that goes back to Coase (1960). Baumol and Oates (1988) demonstrate that such payments induce entry of victims and thereby trigger excessive damages. Our model adds the complexity that the polluter (wildlife) and victim (farmers) both require land, and that land use choices by farmers impact the wildlife stock.

Our general equilibrium model embodies both major threats to wildlife in developing countries: hunting and habitat conversion for agriculture. We model an isolated rural economy in the tradition of Brander and Taylor (1998), and in some of its details the model is also related to that of Bulte and Horan (2003). Other relevant prior literature includes Wirl (1999) who analyses the management of land that can be used for forestry or converted to agriculture. He demonstrates that cycles of forest conversion and re-growth may be optimal. Swallow (1990; 1996) studies situations where habitat degradation is irreversible. Finally, there is also a 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, Rubinfeld, and Shapiro 1984; Innes 1997; Polasky and Doremus 1998; and Smith and Shogren 2002). To our knowledge, however, the economics literature has not yet considered the issue of wildlife damage compensation in a dynamic general equilibrium setting. This is our focus.

Our principal finding is that compensation schemes aimed at reducing hunting mortality can actually reduce the wildlife stock and have ambiguous welfare effects for local people. Hence, although compensation programs are well intended, they could lead to the most disastrous outcome of all: compensation that is costly for the sponsoring agency could result in a reduction in the wildlife population and a fall in local welfare (a loss-loss-loss outcome). The intuition for this result is quite straightforward. Compensation distorts relative commodity prices, increases the returns to agriculture, and encourages agricultural expansion. Thus, while compensation reduces the incentive to hunt for wildlife, the net conservation effect is ambiguous when the negative impact of increased habitat conversion is accounted for.

In the next section, we describe a dynamic model of wildlife damage, compensation and land use conversion in a small rural economy. We proceed by analyzing the consequences of compensation for land use, wildlife stocks and local welfare. Then we highlight the consequences of a transition from autarky to trade, which may be facilitated by compensation, and we reflect on the relevance and robustness of our theoretical results. In the penultimate section we highlight some policy implications.

The Compensation Model

In this section we outline the outline the model, focusing on both the economy (production and consumption) and the ecological features of the system. We look at dynamics as well as steady states.

Production

The economy is made up of myopic households with open access to both land for agriculture and wildlife for animal products. Labor

[2] In the United States, where property rights are well defined and administrative controls are in place, the Defenders of Wildlife's wolf and grizzly compensation funds have received praise for facilitating the reintroduction and conservation of wolves and grizzlies (www.defenders.org) (Nyhus et al. 2005; Mech 2000; Rondeau 2001).

[3] There are two different manifestations of moral hazard. First, and within the scope of this paper, compensation affects the incentive to plant crops in areas where wildlife damages are severe. Second, compensation serves as insurance and therefore attenuates the farmers' incentives for self-protection through defensive effort. Defensive effort is clearly a major issue, but not one we address in this model. Rollins and Briggs (1996) tackle important issues associated with moral hazard in relation to defense effort. Recent evidence regarding compensation for lion predation in Kenya and snow leopard predation in India and Mongolia and suggests that conservation agencies are now aware of potential moral hazard problems (Roach 2003; Mishra et al. 2003).

can freely flow from one activity to another in response to profit differentials. The assumption that property rights over land and wildlife are not enforced (or even defined) implies that we are considering the context of a less developed country, where conflicts between wildlife and farmers are most profound. The assumption that households respond in a myopic fashion to incentives facilitates the analysis but is not necessary for most of the results that follow.

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; and (2) economically interconnected, in that the opportunity cost of time spent growing crops is the foregone return from harvesting wildlife (and vice versa). This is consistent with the observations of Noss (1998, p. 166), who notes that hunting in an area of 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 for similar observations). In our economy, it follows that at any point in time, the proportion of land devoted to agriculture and the labor choice of households are endogenous. The (opportunity) cost of hunting effort is therefore endogenous also.

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 microfoundations 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 in response to households' labor allocation and land use decisions.

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 $H(t)$. 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):

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

Households divide their productive time between agricultural labor, $W(t)$, and hunting effort, $E(t)$,[4] constraining the economy to

$$(2) \qquad W + E \equiv T,$$

where T is the aggregate time endowment. 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; and products derived from wildlife harvesting are obtained from 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 implies the decision to supply agricultural labor in the quantity

$$(3) \qquad W = \alpha A.$$

It is the strong assumption of constant returns to scale in agriculture that allows us to use this equality throughout in order to reduce the dimension of the model to a tractable problem of land use selection (we discuss the robustness of the results with respect to alternative specifications of the production function below).

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 (i.e., in the absence of wildlife 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, with $D(0) = 0$ and $D'(X) > 0$, leaving the economy with a net supply of crops equal to $G^S = A[1–D(X)]$. In what follows, we postulate 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

[4] 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 above).

not destroy all crops.[5] With this assumed functional form, the amount of crops brought to the market by producers is equal to:

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

Initially we assume that crops are traded locally by households who individually take the market price of food crops (g) as given (though in equilibrium, g will be 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 (below we explore the case where households do participate in regional markets). Dasgupta (1993, p. 226) refers to such villages as "self-contained enclaves of production and exchange."

The compensation mechanism most often implemented by international organizations 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. The most generous programs (those run by NGOs) 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 Rajastan, India, damages to fields by herbivores are fully compensated (Sekhar 1998). In contrast, only 10% of the market value of livestock losses to predators is covered by a program in Gujarat, India (Vijayan and Peti 2002). A similar percentage is granted to pastoralists losing crops to elephants in Simao, China (Zhang and Wang 2003).

It is worth noting that these programs pay compensation on the basis of the observed market price even though this equilibrium price accounts for the relative scarcity created by wildlife damage. Had the crops reached the market, the equilibrium price would have been lower as a result of a greater supply, and the crops destroyed may have been worth substantially less than the value at which they are assessed for compensation purposes. Nonetheless, 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.

We denote the fraction of losses covered by compensation with the parameter $d \leq 1$, determined by the fund manager and 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. This translates into total agricultural revenues equal to

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

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), we consider a harvesting model in which the yield is proportional to the level of effort devoted to harvesting, and an increasing function of the stock. Specifically, it is assumed that the harvesting technology has the form:[6]

$$(6) \qquad M^S = qXE,$$

where the amount of meat harvested, M^S, depends positively on the animal stock at time t, the hunting effort E deployed by villagers, and a constant catchability coefficient $q > 0$. The greater the value of q, the easier it is to harvest wildlife.

It is assumed that the meat obtained from hunting can be consumed by villagers or traded outside the local economy. Meat is not easily stored and a significant demand from larger cities in rural Africa and Asia makes it commercially viable to transport bushmeat to outside markets and sometimes across national boundaries.[7] Observations from the field support our assumptions. For example, Infield (1988) reports that 80% of the bushmeat harvested in the northern region of Korup

[5] In alternative modeling, we have applied the nonlinear damage function $D(X) = (e^{bx} - 1)e^{-bx}$ corresponding to a net production Ae^{-bx}. This formulation does not qualitatively modify the results.

[6] 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, but we return to this possibility below.

[7] 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).

National Parl (Cameroon) is destined for commercial markets. Eves (1996) reports that roughly 50% of Pygmy and Bantu households in a region of Congo earned money from meat sales. Muchaal and Ngandjui (1999) found that while cocoa cropping was the main occupation in Dja (Cameroon), hunting for bushmeat was the only other significant activity, with households retaining only 25% to 30% of their catch for their own consumption. Anstey (1991), notes that in rural Liberia, bushmeat is one of the only available protein sources and that hunting for bushmeat serves also to control crop damage and helps raise currency for local schools.

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 (on the commercialization of the wildlife harvest and trade in bushmeat, see Bennett (2000); Bowen-Jones (1998); Ape Alliance 1998). The important feature is that with a significant quantity of meat traded outside the village, the price of meat, p, is exogenously determined on the open market.[8] Making use of (2) and (3), we can express the quantity of labor devoted to wildlife hunting as $E = T - \alpha A$. With households taking the price of meat as given, total revenues in the hunting sector can be expressed as

$$(7) \qquad pM^S = pqXE = pqX(T - \alpha A).$$

Household Demand

We now turn to the villagers as consumers of the commodities available in the economy. We study the case in which households maximize a Cobb–Douglas utility function over the consumption of crops (G) and meat (M) subject to their income (see below for a discussion of alternative assumptions). Denoting the weight placed on the consumption of G by θ and household income by ω, solving the consumers' problem yields the usual demand functions:

$$(8) \qquad G^D = \frac{\theta\omega}{g}, \quad \text{and}$$

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

[8] In the absence of compensation for damage, this is equivalent to assuming that the economy is closed and that p is simply the numeraire against which other prices are evaluated.

The income level is obtained by summing revenues in agriculture and hunting (equations 5 and 7):

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

Market Equilibrium

At every instant, this economy generates 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:

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

The price 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 rather straightforward. The equilibrium price of grains increases with the wildlife stock because (i) a greater wildlife stock increases the returns to hunting (raising income and demand for grains), and (ii) increasing the number of animals increases crop damage, decreasing the amount of grains supplied on the market. To restore equilibrium, the price of crops must go up. For a given X, an increase in d increases the households' income and inflates the price. 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.

Labor Allocation and Its Dynamics

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

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

It is evident that average profits in agriculture are increasing in the compensation level. In the absence of compensation, the returns to agriculture fall to:

$$(12') \qquad \pi_G^{d=0} = \frac{\theta pqX(T - \alpha A)}{(1-\theta)\alpha A} < \pi_G.$$

It is worth observing that, in the absence of compensation ($d = 0$), the equilibrium profits in the agricultural sector 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 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), wildlife damage still makes them worse off. Greater damage simply lowers the economy's production possibility frontier without any offsetting advantage.

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

$$(13) \quad \pi_M = pqX.$$

In making their labor allocation at time t, individual households observe the wildlife stock and the profits per unit of effort previously realized. Since they neither have ownership of the land, nor any property rights to the stock of wildlife, their labor decision is myopic.[9] 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 the returns per unit of effort in the two sectors of the economy. 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

$$(14) \quad \frac{\partial E}{\partial t} = \dot{E} = \eta[\pi_M - \pi_G],$$

where $\eta > 0$ indicates how rapidly households increase their hunting effort when hunting returns per unit of effort exceed agricultural returns. By use of equations (2) and (3), differentiating the constraint $E = T - \alpha A$ with respect to time (noting that T is a constant), and substituting the result as well as equations (12) and (13) into equation (14) allows us to eliminate the labor variables and express equation (14) in terms of A and X alone. The dynamics of the economy can then be described entirely in terms of the rate of change in agricultural land:

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

Equation (15) indicates that everything else equal, laborers will move from hunting to agriculture (or vice versa) whenever the returns to agriculture exceed the returns to hunting (or vice versa). Furthermore, the rate of reallocation of labor between sectors increases with the size of the profit differential.

It is important to stress that no assumption is made that peasants specialize in either hunting or cropping—they could well do both and remain diversified producers. Therefore, in their role as hunters they contribute to reducing their own damage as farmers as well as those of others. However, since their allocation decisions are driven by a comparison of private returns, they ignore the public good aspect of hunting. As the number of farmers increases, the damages are spread and the private returns to nuisance control diminish.[10] The model is readily extended to incorporate defensive hunting effort—the possibility to shoot wildlife as it approaches the farm. For example, while cultivating their fields, farmers may carry a gun to shoot animals in sight. This activity does not require extra labor, but will obviously affect wildlife mortality. The implications of defensive hunting are discussed further below.

Wildlife Population Dynamics

To close the model, we must 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

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[9] The assumption of myopic behavior is a strong one, as would be the opposite case of rational expectations in this context. Yet, the assumption of myopic behavior is common. Baland and Platteau (1996, p. 211) provide one possible reason why peasants may ignore the effect of their harvesting on future stocks—peasants may believe that such a link simply does not exist. Some traditional societies shared a "magical pre-rationalist" view of the world, where resource flows were given and determined by "supernatural agencies (deities or cosmic forces) in charge of catering to human needs."

[10] Our model does not explicitly include retaliation killing by frustrated farmers—such emotional responses are ignored for convenience, but we recognize they may be important in reality. However, note that including revenge motives would not alter the main results of the paper. Compensation likely alleviates the need for revenge killings and frees up labor for agricultural expansion—consistent with the dynamics in our model.

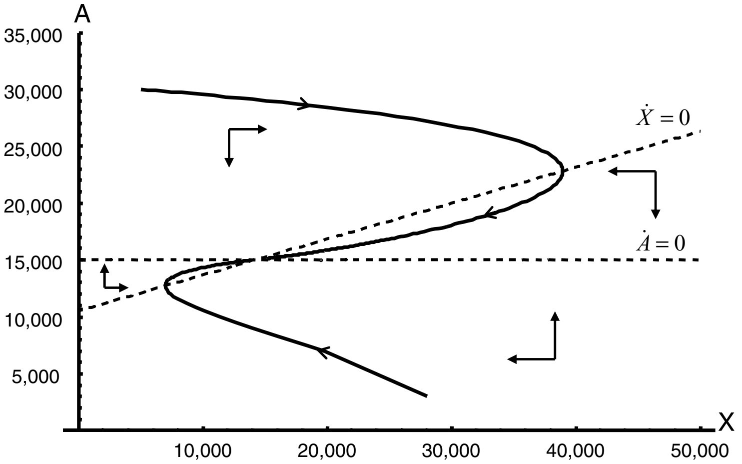

Figure 1. Dynamics of the economy: No compensation, Cobb–Douglas utility, linear damage, and dominant hunting effect

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 equation (1), biological growth of the stock is then given by $F(X) = rX(L - A - X)$. Subtracting hunting mortality provides the differential equation for the instantaneous net rate of growth as a function of the current stock and habitat level (and implied hunting pressure):

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

The population increases (decreases) whenever the biological replenishment rate is greater (smaller) than the hunting off-take.

Transitions and Equilibria

Equations (15) and (16) form a system of differential equations in X and A. This system has a trivial steady state at $(X, A) = (0, L)$ and an interior steady state for other parameter configurations. In the general case with compensation, profits in both sectors are equal whenever the following holds:

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

Along this isocline, the labor market is in equilibrium and there is no incentive to stray away from current patterns of land use. This isocline is a horizontal line in the absence of compensation ($A|_{\dot{A}=0} = \theta T/\alpha$ for d=0). Figures 1 and 2 present phase diagrams with sample time paths for the system defined by equations (15) and (16) and assuming zero compensation ($d = 0$). In these diagrams, each corresponding to a different set of parameters, the horizontal lines define the A isocline, or the combinations of stocks and agricultural land base for which profits are equal in both sectors of the economy.

For $d > 0$, $\partial A/\partial X|_{\dot{A}=0} = (bdT\theta)/\alpha(bx - 1)^2 > 0$. The isocline has a positive slope in the (X,A) space as illustrated in figures 3 and 4. An increase in X increases average profits per unit of hunting effort and reduces the supply of grains (increasing its equilibrium price). To maintain the equilibrium, additional agricultural acreage is required. Note also that $\partial^2 A/\partial X \partial d|_{\dot{A}=0} = bT\theta/\alpha(bx - 1)^2 > 0$, indicating that as the level of compensation increases, the slope of the isocline becomes steeper.

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. It is obtained by setting equation (16) equal to zero and solving for A:

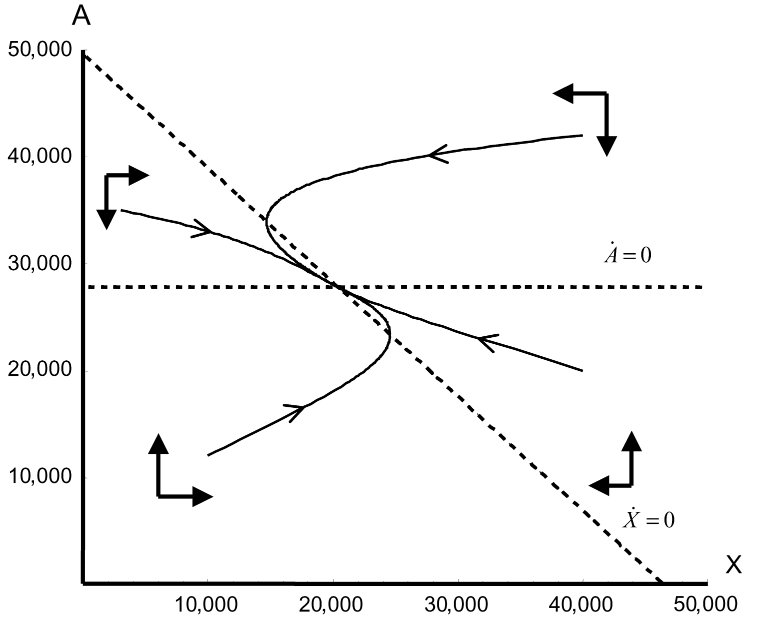

Figure 2. Dynamics of the economy: No compensation, Cobb–Douglas utility, linear damage, and dominant habitat effect

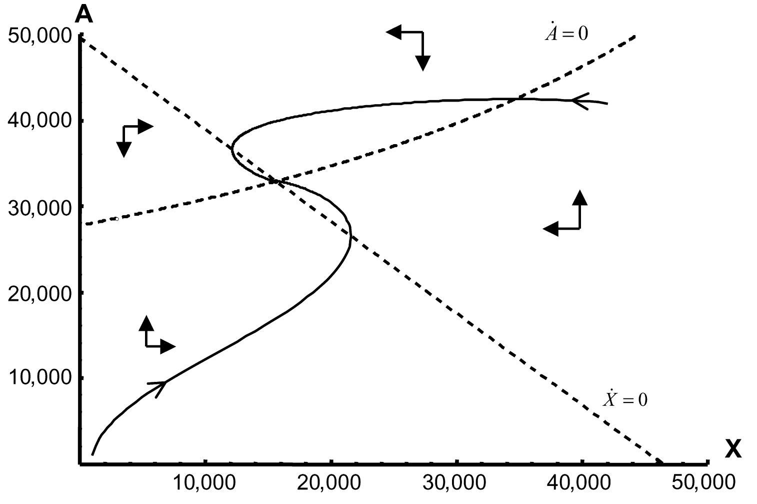

Figure 3. Dynamics of the economy with full compensation ($d = 1$), Cobb–Douglas utility, linear damage, and dominant habitat effect

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

The slope of this isocline is determined exclusively by the sign of the denominator. For $q\alpha > r$ (figure 1), the X isocline will be positively sloped, meaning that in order to maintain 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, refer to equation (16) and set it equal to zero. For the nontrivial 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 wildlife. $q\alpha > r$ 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

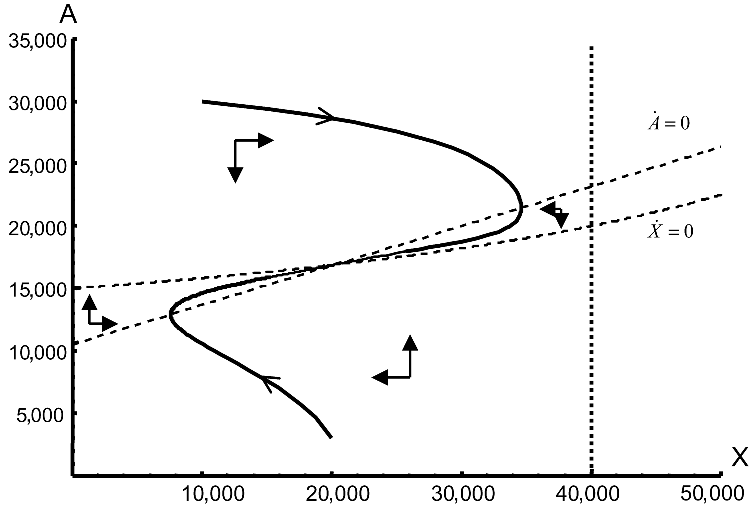

Figure 4. Dynamics of the economy with 50% compensation ($d = 0.5$), Cobb–Douglas utility, linear damage, hunting effect

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 those situations. It is a possible scenario for fast growing and hard-to-catch (forest) nuisance species, and it is also the situation for which the most interesting set of results emerges.

The solid lines appearing on all 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 the steady state. In both the hunting and habitat effect cases, the steady state is either a node or a spiral but is always asymptotically stable. For the chosen set of parameters, figures 1 and 2 display a stable node.[11]

The Consequences of Compensation

How does compensation affect conservation and welfare? In this section we explore these issues in detail.

The Conservation of Wild Stocks

The first derivative of equation (17) with respect to d yields the expression $[\theta TbX]/[\alpha(1 - bX)]$. This is equal to zero if $X = 0$ but positive otherwise under the maintained assumption that damages never exceed more than 100% of potential production. The introduction of compensation payments therefore implies that the A isocline moves in a counter-clockwise 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. Figure 3 illustrates the situation in which the habitat effect dominates and damage is fully compensated

[11] 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 $P = 10$, $q = 0.000025$, $L = 50{,}000$, $T = 10{,}000$, $r = 0.000003$, $b = 0.00001$, $\eta = 15$, $\theta = 0.75$, $\alpha = 0.5$. For figures 2 and 3, $P = 10$, $q = 0.000025$, $L = 50{,}000$, $T = 10{,}000$, $r = 0.00007$, $b = 0.00001$, $\eta = 300$, $\theta = 0.5$, $\alpha = 0.18$. The type and local stability property of the steady states have been computed precisely from the eigenvalues of the linearized system. These data have been selected for illustrative purposes only.

for ($d = 1$). For intermediate cases with partial compensation the A isocline lies between the A isoclines of figures 2 and 3.

In assessing the impact of compensation when the habitat effect dominates, two observations are worth making. The first and most important is that 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. This is directly the result of the greater (negative) impact of habitat conversion on the stock than the (positive) effect of reduced hunting. Second, in addition to reducing the stock level, compensation could have the effect of introducing cyclical dynamics. Recall that for the parameters employed, the steady state of the economy without compensation was a stable node (no more than one isocline is ever crossed along a particular adjustment path). With full compensation (in fact, with compensation d greater than approximately 0.45 in our numerical example), the steady state becomes a stable spiral. Therefore, while the economy converges toward a locally stable steady state both in the presence and absence of compensation, 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.[12]

The effect of compensation when the hunting effect dominates is more complex. Figure 4 replicates the economy of figure 1 but with a 50% compensation level. Only the part of the phase plane where $X < (1-\theta)/b(1-\theta+\theta d)$, yields feasible solutions. At this value of X, the price of meat [and the denominator of equation (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 $X = 40{,}000$. To the right of the singularity, prices of the agricultural commodity are negative. The long run equilibrium of this system is a stable node on the left side of the singularity, which is characterized by a greater stock with than without compensation. This illustrates that compensation can, as intended, provide incentives to preserve wildlife.

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

Compensation and Local Welfare

In the case where 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 d. Given the Cobb–Douglas utility defined over $G = A[1 + (d-1)bX]$ and $M = qX(T - \alpha A)$ the expression for the change in steady state utility is

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

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 while the content of the second square brackets ($\partial M^*/\partial d$) is negative. Compensation, it follows, has an ambiguous effect on local welfare. Indeed, numerical simulations confirm that an inverted U-shaped relationship between the equilibrium level of utility and the compensation level can emerge.

In situations where the steady state welfare level is lowered by compensation, it is still possible for compensation to temporarily improve local welfare. However (and whether or not discounting is used to obtain a sum of welfare over time), if peasants' labor response to profit differentials between farming and hunting is sufficiently rapid, the economy will quickly converge toward the new steady state and the long term welfare loss of the new steady state with compensation will outweigh any temporary gains made along the adjustment path. This, we believe, is quite a damning result. Combining our findings thus far, we find it 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, reduces the stock of wildlife, and it lowers the welfare of local people.

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, p.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. Above we implicitly assumed that local markets for crops clear at a price located within this price band. Then, trading crops between the village and regional market is unprofitable.

This may change after implementation of a compensation program. Through the mechanisms analyzed above, this will affect both demand for and supply of crops. As a result, a new price emerges. This new price may still be within the price band defined by transaction costs (as assumed thus far), but this need not be the case. The endogenous price may also leave the price band. In these circumstances, regional trade (at fixed prices) becomes 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 the village stays "open" after implementation of the compensation program. For local workers, the average return per unit of labor in farming is henceforth:

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

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

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

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

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

This isocline is vertical in the $X - A$ space, implying a unique equilibrium, regardless of whether the X isocline slopes up or down. Figure 5 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

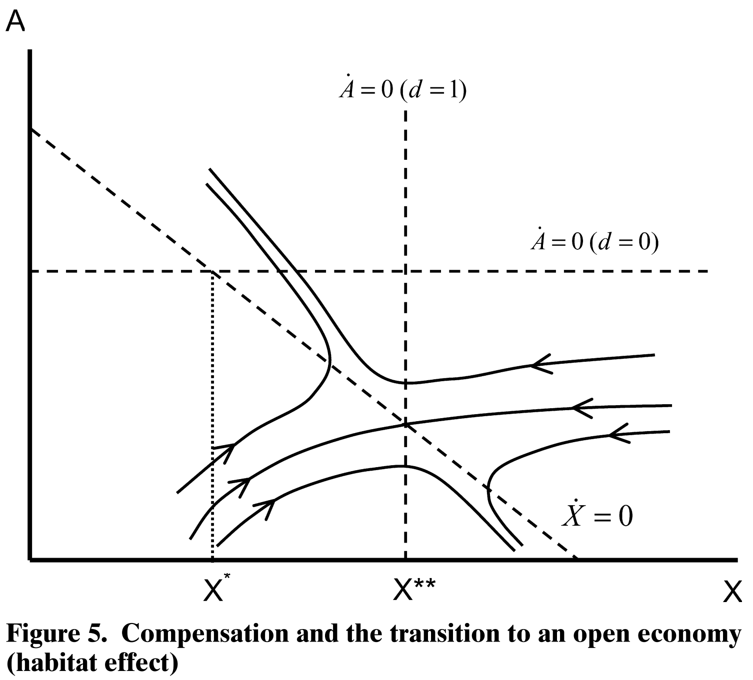

Figure 5. Compensation and the transition to an open economy (habitat effect)

$d = 0$ (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 5 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 open economy follows the separatrix to the saddle, the system will completely specialize over time into one of the two sectors of economic activity. For initial conditions above the relevant separatrix (which, as drawn here, includes the original steady state without compensation), the economy eventually specializes into agriculture, driving the stock to its minimum (possibly extinction) given the residual habitat left when all labor is devoted to agriculture. From initial conditions below the separatrix, households abandon agriculture, eventually devoting all labor resources to hunting.[13]

What is the effect of compensation on conservation in this context? It is clear from figure 5 that this impact will be ambiguous. Specifically, when the pre-compensation equilibrium wildlife stock X^* is smaller than the open economy stock X^{**} as defined by (17'), then specialization in cropping will result, raising the possibility of extinction of the local wildlife stock (if $\alpha T \geq L$). Conversely, for $X^* > X^{**}$, specialization in hunting will be the outcome, resulting in a thicker wildlife stock. Which case eventuates depends on the magnitude of φ relative to other key parameters.

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

Red Flag or Red Herring?

For a dynamic general equilibrium model to yield some analytical results, simplifying assumptions are obviously necessary. It is therefore useful to pause and reflect on whether or not the potential negative consequences of compensation are a serious red flag for policy makers and NGOs, or a mere theoretical oddity—a red herring without real life implications. We tackle this question from two angles. First, we explore the robustness of our central result (that compensation can lead to a lower stock) to relaxed assumptions. In one instance (alternative utility functions) our analysis relies on new analytical results. However, since analytical results for alternative specifications are typically elusive, we rely on basic principles, our understanding of the inner workings of the model, and numerical solutions to alternative formulations to argue that the ambiguous effect of compensation on the stock is a robust result. Second, we consider the empirical relevance of the result. Essentially, the question is whether there exist systems where the technical relationship $r > \alpha q$ holds. It is difficult to answer this question without an in-depth study of the economic and biological characteristics of a specific system. Yet, based on minimal information we argue that our result is more than a theoretical curiosity.

Robustness: Demand Specification

The model represents an economy with two food goods providing utility through a Cobb–Douglas function. The first question one may ask is whether the results are robust to changes in demand structure. We explored this question with a double log-linear utility function of the form $U(G, M, Y) = \psi\, Log\, G + \kappa Log\, M + Y$, where Y is a composite good. Such a function seems particularly relevant since at low income levels, poor households purchase meat and grains only, while beyond a certain threshold most or all marginal income is spent on the composite good (possibly manufactured goods).

For low income, the system is simply a linear monotonic transformation of the Cobb–Douglas case. Therefore, all of our previous results follow. At higher income levels, all marginal revenues are spent on Y; richer households increase their consumption of other imported goods once their caloric needs are satisfied. Even then, however, changes in the compensation level still affect relative prices, land use, the stock and therefore the stationary state of the system. It is easily verified that all of our equations can be re-derived

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

with the log-linear utility function. Upon doing this, we find that the A isocline still has a nonnegative slope in the (X, A) space, and that this slope is increasing in d as before. More importantly, adopting any other utility function does not influence the X isocline. Thus, the definitions of hunting and habitat effects remain intact and, as before, compensation can lead to a smaller or larger stock depending on which effect dominates. It is for this reason that we can ascertain more generally that our results are not specific to the utility function we postulated.

Robustness: Production Specification

The model is based on the assumption of Leontief production in agriculture. This imposes constant returns to scale and does not allow input substitution. Though we were not able to obtain analytical results with alternative production functions, we can infer from the analysis above (and confirmed numerically) that the main results carry over to more general production functions.

The thrust of the argument starts with equation 5 and the observation that damage compensation is equivalent to an output subsidy. Like a direct price support measure, compensation provides an incentive to increase total output, but it does not distort the marginal rate of transformation between inputs in the short term. The initial impact of compensation on wildlife will therefore depend on whether the habitat or hunting effect dominates. In the long run, as the stock rises or falls, the opportunity cost of agricultural labor will also rise or fall. Eventually, the labor/land ratio in agriculture falls (rises) when the hunting (habitat) effect dominates, attenuating the Leontief result. Depending on the elasticity of input substitution, this second order effect may be large or small, but numerical simulations with substitution and decreasing returns to scale confirm that the fundamental ambiguity identified above remains.[14]

Robustness: Defensive Hunting

One of the realities of agrarian systems with wildlife damage is the killing of wildlife as a defensive measure. Consider an alternative model in which the only wildlife mortality is the result of farmers shooting wildlife around their farm while tending to their fields. Without hunting in the wild and without a meaningful opportunity cost for time spent defending one's crops, no effort could be freed up to push the extensive frontier. In this case, compensation could reduce defensive killings without encouraging any expansion of the extensive margin. The stock effect would then be unambiguously positive.

On the other hand, if there is a significant opportunity cost of time spent defending crops, compensation should, as previously seen, free up labor, result in agricultural expansion, and bring about the tension between hunting and habitat effects. Considering cropping and defensive hunting simultaneously bring about nonseparability and nonlinearities in the crop production function that makes it difficult to solve the model analytically. However, we have produced results using the profit function $g\alpha A[1 - b(1 - d)Xe^{-(T-\alpha A)}] + pqX(T - \alpha A)$ that clearly hints (analytically) to the relevance of the relationship between r, q, and α; and that numerically produces an equilibrium characterized by $\partial X/\partial d < 0$ for parameters resembling those used for figure 3.

Yet, it is a fact that much of the hunting for wild animals takes place in the wild (Bennett 2000; Bowen-Jones 1998); Eves 1996; Infield 1988). If both types of hunting were incorporated in the model, the smaller the amount of time devoted to "costless" hunting, the greater the likelihood that the habitat effect will dominate any positive effect on the stock from a reduction of defensive hunting. Compensation would reduce both defensive hunting mortality and bushmeat mortality but also reduce the available habitat. The net effect on conservation would therefore remain ambiguous.

Robustness: Migration and Population Growth

We have considered a village of a given size, with a constant time constraint, T. In reality, population size might change because of (consumption-dependent) fertility, changes in infant mortality, or migration. When subsistence cannot be assured, famine sets in

[14] Moving away from Leontief production affects the structure of the model in nontrivial ways. First, farmers must now maximize profits over their input mix. This, in turn, requires that there be ongoing maintenance or rental costs λ for land (else all land would go to production instantaneously). Our numerical calculations were obtained using the profit function $gA^{\varphi} W^{\beta} (1 - bX + bdX) + pqX(T - W) - \lambda A$, where $0 < \varphi + \beta < 1$.

and the population can be expected to decline. In contrast, the population may increase when conditions are favorable. Would such population responses accentuate or attenuate the effect of compensation?

Consider the case of migration. Compensation raises income from agriculture where it is implemented. By creating a positive differential between income in this region and others, the short term should see a net inflow of people in the compensated region. This would accentuate the habitat effect identified in the model. Since migration leads to more land conversion than in the original model, this additional pressure on remaining habitats would mitigate or could even reverse any potential positive effects that compensation may have (when the hunting effect dominates) and further deteriorate the net impact of compensation on conservation.

The long-term consequences of compensation in this context may nonetheless be negligible. Migration arbitrages away differences in returns to labor across space. Depending on the structure of the economy, the degree to which it is opened, and the scale of migration, a global interior equilibrium with compensation (if it exists) may leave per capita hunting and cropping revenues unchanged, so that there would be no change in wildlife stock (i.e., $X* = w/pq$, where w is the fixed regional wage rate). Of course, the possibility of extinction and corner solutions in this expanded model should not be ruled out, but it is difficult to imagine how allowing for endogenous population changes could favor the compensating agency's conservation objective.

Empirical Relevance: Does The Habitat Effect Ever Dominate?

Even if the theoretical ambiguity remains, it is natural to ask whether the analysis is relevant in practice. One of the differences between our stylized model and common hunting practices in natural systems is that hunters often target multiple species that share the same habitat (Noss 1998; Muchaal and Ngandjui 1999). Thus, our model is better suited to the analysis of systems where a single species is prevalent or dominates the system. Unfortunately, we have not been able to uncover a region for which sufficient data is available to conduct a full empirical validation of our model. To do so would therefore require primary data collection, a task beyond the scope of this paper. Yet, a simple example should suffice to convince oneself that under realistic conditions either the habitat or hunting effect could dominate.

We consider the case of wildebeest hunting and subsistence farming in the Serengeti, Tanzania. Johannesen (2006) and Johannesen and Skonhoft (2004) describe the local economy of an area of Tanzania consisting of small-scale farmers involved in agricultural crop production and wildlife hunting (primarily wildebeest). As in our postulated model, it is reported that local peasants do not have property rights over the wildebeest stock, grow crops for subsistence (or at least to a certain extent), and suffer from wildlife trampling and eating their crops.

While there is no program in place to compensate peasants for wildlife damages, the available data do allow us to explore the relative magnitudes of the habitat and hunting effects.

Johannesen and Skonhoft (2004) do not consider changes in available habitat in their characterization of the biological growth function for the stock. They postulate a standard logistic growth function of the form $F(S) = \gamma S[1 - (S/K)]$. In order to obtain the habitat-dependent growth function we employ, $F(X) = rX(L - A - X)$, it is therefore necessary to apply the conversion described above. In particular: $r = \gamma k/L$ where, as before, γ is the intrinsic growth rate (or 0.3 in the case of wildebeest hunting), k is the maximum density per unit of land (75) and L is the land base (and following the normalization, $X = S/k$). From the data provided by Johannesen and Skonhoft (2004), we compute $q = 0.0008$ and $r = 22.5/L$. It is further reported that five households occupy an area of 0.15 km^2, so full occupancy requires 33 households per km^2. This translates into an estimate of α at some 66 workers per km^2.

Recall that the habitat effect dominates if $r > \alpha q$. This condition will hold if the ecological economic system is of size $L \leq 42{,}600$ hectares (426 km^2), which clearly belongs to the realm of possibilities. Johannesen (2006) provides an alternative estimate of the number of workers required to tend one square kilometer of crops in the same Serengeti boundary region. Her estimate of $\alpha = 26$ would indicate that the habitat effect dominates the hunting effect if the area considered is $L \leq 108{,}100$ ha (1,081 km^2). This is a substantial area, and it certainly seems possible that either the habitat or hunting effect may dominate for plausible parameter values

(Bulte and Horan 2003 develop comparable arguments along similar lines).

Policy Implications

Assuming governments and (international) NGOs are interested in conservation of wildlife in developing countries, how should they go about their business? Notwithstanding our previous discussion about the highly stylized nature of the model, we provide a few observations about policy interventions and sketch implications for the choice of instruments.

The first observation is that the choice of instrument(s) should critically depend on local circumstances. Compensation promises to be effective only under certain circumstances relating the species growth rate, its susceptibility to changes in hunting effort and habitat loss and the labor/land intensity of agricultural production. Small bioeconomic systems can vary greatly along these parameters, hence the importance of properly assessing the local situation. Resource availability also matters. The habitat effect is more likely to bite if compensation is introduced in an area where land is readily available for conversion. This may not always be the case—wild habitat may be monitored, and enforcement may prohibit intrusions.

It can be said that when the habitat effect dominates, the species is more susceptible to habitat loss than to hunting pressure. Thus, the most effective conservation measures will be those that protect land or provide disincentives to convert habitat into plots. As we previously alluded to, it is necessary to realize that compensation for wildlife damage amounts to an agricultural price subsidy (as do some other instruments), hence its failure. When the habitat effect dominates, an incentive-based conservation initiative should have the effect of penalizing rather than subsidizing agricultural production. In addition to taxation as commonly understood (which may not always be feasible) this can be achieved through more intensive enforcement of property rights to the land (should they not reside with the villagers but with the government).[15]

Alternatively, a policy maker could levy a tax on land conversion or use it simultaneously with a compensation program if retaliation or defensive hunting is a significant problem. Policy interventions should be directed towards making the activity that has the smallest impact on wildlife relatively more attractive. Indeed, if the habitat effect dominates, it may be worthwhile to consider encouraging hunting, for example through facilitating the trade in this commodity. As a referee noted, a dominating habitat effect also carries the implication that anti-poaching efforts may be counterproductive if they lower the return to poaching and push out the extensive agricultural margin. However, such efforts are only sensible when they do not lead to a net inflow of migrants from other areas.

If interventions other than damage compensation are politically or otherwise unfeasible, making compensation payments available only to existing farmers or for land already in agricultural production may alleviate the main concerns identified above. Yet, one should wonder about how credible such a commitment to limit compensation would be.

There are intervention options beside subsidizing or taxing agriculture and hunting. For example, it might be sensible for NGOs to develop alternative employment opportunities to divert labor away from land-using activities in general, easing the pressure imposed on both habitat and wildlife. Such indirect interventions have attracted the attention of NGOs as they aim to redirect labor and capital away from uses detrimental to wildlife, and encourage commercial activities that supply ecological services as a byproduct (e.g., ecotourism). However, Ferraro (2001) and Ferraro and Simpson (2002) criticize this approach, arguing that direct payments for the creation and conservation of nature are more cost effective and efficient.

Finally, if compensation transfers are to be provided, it might be advisable to make them conditional on individual and village-wide conservation actions and institutional reforms that aim to internalize the external effects of open access to land and wildlife. While we have assumed open access to land and wildlife throughout the paper, it is well known that the definition and enforcement of property rights can emerge endogenously and depend on relative prices (e.g., De Meza and Gould 1992; Hotte, van Long, and Tian 2000). It is therefore conceivable that compensation programs that drive up crop prices could change the social fabric that supports the types of dynamics described above. Compensation could

[15] The impact of an agricultural tax in our model can be inferred by considering cases with $d < 0$. In the habitat effect case, such a tax triggers adjustments towards more hunting, increasing the wildlife stock.

favor the transition from open access towards the establishment of private property rights, or make enforcement of preexisting but unexercised property rights worthwhile, perhaps fostering better resource husbandry.

Concluding Comments

Poverty and natural resource dependence in rural areas throughout the world have resulted in many conflicts between humans and wildlife, with casualties on both sides. One response by conservationists worried about the long-term fate of wild animals has been the promotion of so-called Integrated Conservation 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 abstract from these important issues and argue that the situation may in fact be worse; compensation may not only be administratively ineffective, it could also depress wildlife stocks for reasons that are deeply rooted in the structure of the ecological economic system. In addition, compensation could also have negative consequences on local welfare. This would amount to particularly dismal outcome where donors lose (because they fund the compensation payments), peasants lose (because their welfare goes down) and conservation loses (because wildlife stocks fall). It is our opinion these outcomes call for attention to local conditions in considering the desirability of implementing a wildlife damage compensation scheme.

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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, IUCN. Gland.

Anstey, S. 1991. *Wildlife Utilisation in Liberia*. WWF International. Gland.

Ape Alliance. 1998. *The African Bushmeat Trade, A Recipe for Extinction*. Cambridge, Flora International.

Baland, J., and J. 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* 23:1073–84.

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

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

Blume, L., D. Rubinfeld and P. Shapiro. 1984. "The Taking of Land: When Compensation Should Be Paid?" *Quarterly Journal of Economics* 100:71–92.

Bowen-Jones, E. 1998. *A Review of the Commercial Bushmeat Trade with an Emphasis on Central/West Africa and the Great Apes*. Report to Ape Alliance, Cambridge.

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.

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(1):109–27.

Clark, C.W. 1990. *Mathematical Bioeconomics*. New York: Wiley.

Coase, R. 1960. "The Problem of Social Cost." *Journal of Law and Economics* III:1–44.

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

De Meza, D., and J.R. Gould. 1992. "The Social Efficiency of Private Decisions to Enforce Property Rights." *Journal of Political Economy* 100:561–80.

Deodatus, F. 2000. "Wildlife Damage in Rural Areas with Emphasis on Malawi." In H. Prins, J. Grootenhuis, and T. Dolan, eds. *Wildlife*

Conservation by Sustainable Use. Dordrecht: Kluwer Academic Publishers, pp. 115–40.

Eves, H. 1996. *Socio-Economic Study 1996 Nouable-Ndoki National Park Congo*. New York: World Conservation Society.

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

Ferraro, P., and R.D. Simpson, 2002. "The Cost-Effectiveness of Conservation Payments." *Land Economics* 78:339–53.

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

Hoare, R. 1995. "Options for the Control of Elephants in Conflict with People." *Pachyderm* 19:54–63.

Hotte, L., N. van Long, and H. Tian. 2000. "International Trade with Endogenous Enforcement of Property Rights." *Journal of Development Economics* 62(1):25–54.

Infield, M. 1988. *Hunting, Trapping and Fishing in Villages Within and on the Periphery of the Korup National Park*. Washington DC: World Wildlife Fund.

Innes, R. 1997. "Takings, Compensation and Equal Treatment for Owners of Developed and Undeveloped Property." *Journal of Law and Economics* 40:403–32.

Johannesen, A.B. 2006. "Designing Integrated Conservation and Development Projects (ICDPs): Illegal Hunting, Wildlife Conservation and the Welfare of the Local People." *Environment and Development Economics* 11(2):247–67.

Johannesen, A.B., and A. Skonhoft. 2004. "Property Rights and Natural Resource Utilisation: A Bioeconomic Model with Numerical Illustrations from the Serengeti-Mara Ecosystem." *Environment and Resource Economics* 28(4):469–88.

Mech, L. 2000. "Wolf Restoration to the Adirondacks: The Advantages and Disadvantages of Public Participation in the Decision." In V. Sharpe, B. Norton, and S. Donnelley, eds. *Wolves and Human Communities: Biology, Politics, and Ethics*. Washington DC: Island Press, pp. 13–22.

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* 17:1512–20.

Muchaal, P., and G. Ngandjui. 1999. "Impact of Village Hunting on Wildlife Populations in the Western Dja Reserve, Cameroon." *Conservation Biology* 13:385–96.

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. Gland.

Ngure, N. 1995. "People-Elephant Conflict Management in Tsavo, Kenya." *Pachyderm* 19:20–5.

Noss, A. 1998. "The Impacts of BaAka Net Hunting on Rainforest Wildlife." *Biological Conservation* 86:161–7.

Nyhus, P., S. Osofsky, P. Ferraro, F. Madden, and H. Fischer. 2005. "Bearing the Costs of Human-Wildlife Conflict: The Challenge of Compensation Schemes." In R. Woodrofe, S. Thirgood, and A. Rabinowitz, eds. *People and Wildlife: Conflict or Coexistence*. 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(1):22–47.

Roach, J. 2003. "Lions vs Farmers: Peace Possible?" *National Geographic News.* Available at hhttp://news.nationalgeographic.com/news/2003/07/0716_030716_lions.html.

Rollins, K., and H. Briggs. 1996. "Moral Hazard, Externalities and Compensation for Crop Damages from Wildlife." *Journal of Environmental Economics and Management* 31(3):368–86.

Rondeau, D. 2001. "Along the Way Back from the Brink." *Journal of Environmental Economics and Management* 42(2):156–82.

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

Sekhar, N.U. 1998. "Crop and Livestock Depredation Caused by Wild Animals in Protected Areas: The Case of Sariska Tiger Reserve, Rajasthan, India." *Environmental Conservation* 25:160–71.

Smith, R., and J. Shogren. 2002. "Voluntary Incentive Design for Endangered Species Conservation." *Journal of Environmental Economics and Management* 43(2):169–87.

Swallow, S.K. 1990. "Depletion of the Environmental Basis for Renewable Resources: The Economics of Interdependent Renewable and Nonrenewable Resources." *Journal of Environmental Economics and Management* 19(3):264–80.

——. 1996. "Resource Capital Theory and Ecosystem Economics: Developing Nonrenewable Habitat with Heterogeneous Quality." *Southern Economic Journal* 63(1):106–23.

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 Economic Papers* 46:800–21.

Thouless, C., 1994. "Conflict between Humans and Elephants on Private Land in Northern Kenya." *Oryx* 28:119–27.

Vijayan, S., and B.P. Peti. 2002. "Impact of Changing Cropping Patterns on Man-Animal Conflicts Around Gir Protected Area with Specific Reference to Talala Sub-District, Gujarat, India." *Population and Environment* 23:541–59.

Wirl, F. 1999. "De- and Reforestation: Stability and Limit Cycles." *Environmental and Resource Economics* 14(4):463–79.

WWF. 2000. *Elephants in the Balance: Conserving Africa's Elephants*. Gland, Switzerland. Available at www.panda . org / resources / publications / species /elephants/index.html

Zhang, L., and N. Wang. 2003. "An Initial Study on Habitat Conservation of Asian Elephant (*Elephas maximus*), with a Focus on Human Elephant Conflict in Simao, China." *Biological Conservation* 112:453–9.