Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Economics and Management 54 (2007) 311–322
JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT
www.elsevier.com/locate/jeem

Compensation for wildlife damages: Habitat conversion, species preservation and local welfare

Erwin Bulte[a,b], Daniel Rondeau[c,*]

[a]*Development Economics Group, Wageningen University, P.O. Box 8130, 6700 EW Wageningen, The Netherlands*
[b]*Department of Economics, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, The Netherlands*
[c]*Department of Economics, University of Victoria, Victoria, BC, Canada V8W 2Y2*

Received 5 November 2003
Available online 29 June 2007

Abstract

We develop a model of hunting, farming and defensive action to study the environmental and economic consequences of introducing a program to compensate peasants of a small economy for the damage caused by wildlife. We show that the widespread belief that compensation induces wildlife conservation may be erroneous. Compensation can lower the wildlife stock, and may result in a net welfare loss for local people.

JEL classification: O13; Q1; Q2

Keywords: Compensation; Crop damage; Wildlife; Endangered species preservation; Bushmeat trade; Defensive hunting effort; Human–wildlife conflict

1. Introduction

Widespread poverty and weak institutions in many developing countries result in intense hunting pressure, the conversion and fragmentation of wildlife territories, and conflicts between humans and wildlife. In eastern and southern Africa, annual losses attributable to livestock predation range from 1% to 25% of potential revenue [6,9]. In Cameroon, elephant raids can destroy up to 70% of family production [17]. Farmers in Tanzania and Zimbabwe rank pests (including wildlife) first among 30 obstacles to the improvement of their quality of life [12]. In the Indian states of Jharkhand and Assam, human deaths due to confrontations with elephants rose to 300 between 2000 and 2004 in the first instance, and to 605 between 1994 and 2006 in the other [16].

The risk of wildlife-imposed damage provides strong incentives for farmers to hunt and defend their crops [2,3]. Most of the 265 elephants that have died in Assam between 1994 and 2006 were killed in retaliation for destroyed crops by angry villagers who used poison-tipped arrows and baits of poison-laced

*Corresponding author. Fax: +1 250 721 6214.
E-mail addresses: Erwin.bulte@wur.nl (E. Bulte), rondeau@uvic.ca (D. Rondeau).

0095-0696/$ - see front matter
doi:10.1016/j.jeem.2007.02.003

food [16]. Hunting can also yield bushmeat and other valuable commodities that provide external income [2]. Yet, human–wildlife conflicts remain a major obstacle to community support of conservation initiatives [4,12].

In recent years, the idea of compensating farmers for wildlife damages has gained in popularity among conservation groups and governments. Compensation can be relatively cheap to implement in poverty-struck areas and is readily accepted by local communities. The World Wildlife Fund for Nature states that: "one of the simplest ways to mitigate conflict without affecting elephant behavior or population size is to compensate people for the damage they have suffered or would have suffered had they not protected their crops" [17].[1] Some programs have been successful. Compensation for livestock depredation on Kenya's Mbirikani group ranch has all but eliminated the killing of lions [8], and subsidized insurance programs established in India and Nepal have been instrumental in re-establishing populations of the snow leopard's natural wild preys and decreasing retaliatory killings [Thomas McCarthy, Snow Leopard Trust, pers. comm.] [11]. Unfortunately, the performance of compensation programs has often been disappointing. Government-run schemes, in particular, have failed for a host of reasons including lack of funds, fraudulent claims, bureaucratic inadequacies, and the practical barriers that illiterate farmers from remote areas must overcome to produce a claim [17]. In practice, such institutional hurdles are critically important. But here we ignore them to show that even in their absence, basic features of economic and biological systems can lead to perverse results.

While there exists a literature on wildlife damage compensation [14,18], little has been said about situations where alternative labor opportunities present tradeoffs, and where both harvesting pressure and habitat size affect the wildlife stock. Our analysis is set in such a context. Our model builds on the work of Bulte and Horan [5] in that we bring together both threats to wildlife: hunting and habitat conversion. However, this paper differs from [5] along several dimensions: (i) our wildlife species is both a (valuable) resource and a pest that damages crops; (ii) local residents devote time to crop protection (defensive hunting effort that directly contributes to wildlife mortality); (iii) since we distinguish between hunting, farming and defending we cannot rely on a one-to-one relationship between farm labor and hunting labor; (iv) we specifically analyze damage compensation policies; and (v) we abstract from dynamic adjustment paths to focus on equilibrium outcomes.

Our objective is to develop a simple model that allows us to analytically identify conditions under which the introduction of compensation may raise or lower wildlife populations and local welfare. Two central results emerge: (1) compensation schemes that aim to reduce hunting mortality can in fact reduce the stock of wildlife; and (2) compensation programs can have ambiguous welfare effects on local people. Thus, a compensation program could lead to the most disastrous outcome of all: costly compensation resulting in a lower wildlife population and a fall in local welfare. These findings extend beyond the well-known result that victim compensation leads to an increase in the victim's activity, and a reduction in averting action. Although these factors are relevant, the perverse results arise from the presence of an ecological feedback loop.

2. A model of crop damage compensation

We develop a model for a small region of a developing country where property rights are not defined or enforced. The economy is made up of myopic households with open access to both land for agriculture and wildlife for animal products.

2.1. Time and land constraints

A fixed human population is endowed with an amount of land L and a time endowment T. A portion $A \leqslant L$ of the homogenous land is used by villagers to grow crops while the remainder is left as untouched wildlife habitat H. Productive time is divided between agricultural labor, W, defending fields against wildlife, Z, and hunting in the wild, E. This defines the time constraint: $Z+W+E=T$.

[1] 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.

2.2. Agricultural production and revenue

A commodity such as maize or grains is grown with a combination of land, farm labor, and effort to prevent crop destruction by wildlife. Peasants can expand their agricultural production by converting natural habitat. For simplicity, W and A are assumed to be perfect complements in the ratio $W/A = \alpha > 0$. Hence, the decision to farm an area of size A requires agricultural labor in the quantity $W = \alpha A$. We normalize agricultural production so that, in the absence of wildlife damage, one unit of land and α units of labor produce one unit of grains. It follows that A is the economy's "potential" agricultural output (i.e. in the absence of damage).

The wildlife stock, X, destroys a proportion of the potential harvest. In the absence of defensive effort ($Z = 0$), a proportion $D(X)$ is lost, leaving the economy with a net supply equal to $G = A[1-D(X)]$. We assume $D(X) = bX$ 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.

Defensive effort reduces the extent of crop damage. It is defined as a method of damage prevention exerted in the direct vicinity of agricultural land that is lethal to wildlife. The benefits of such effort are twofold: it reduces wildlife damage by killing animals before they can destroy grains, and it yields meat and hides that can be sold. We specify the returns to crop damage prevention as increasing linearly in Z so that net agricultural output is $G = A(1-bX(1-\beta Z))$. The parameter β captures the positive effect of defensive effort, with β sufficiently small to ensure that $(1-\beta Z) > 0$.

The damage compensation mechanism most often implemented is based on a simple calculation. The quantity of grains lost to wildlife is estimated, valued at the prevailing market price, and a fraction, c, of the assessed value is paid out in compensation. Farmers producing a total quantity G collect in revenue the market price g per unit of grain supplied, plus a fraction c of the market value for the lost quantity ($cgAbX$), where g is the exogenous price of grain. Revenues from grain production are therefore equal to $gA[1 - bX(1 - c)(1 - \beta Z)]$.

Defensive action is lethal to wildlife and yields animal proteins and products. We model this yield in its most straightforward fashion with a linear Schaefer production function (the number of animals killed in defensive action is given by $q'XZ$, with $q' > 0$). Each animal is worth a constant value p. Therefore, defensive hunting provides the farmer with additional revenue of magnitude $pq'XZ$. Agents allocating time towards defensive effort reap these private benefits and ignore the fact that more hunting can reduce the stock of wildlife and damage to other peasants. It follows that total agricultural revenue is equal to $\pi^{W,Z} = gW[1 - bX(1 - c)(1 - \beta Z)]/\alpha + pq'XZ$.

2.3. Hunting in the wild: production and revenue

The alternative economic activity is harvesting wildlife from the wild, also described by Schaefer technology, $M = qEX$, where M is the amount of "meat" harvested, and q is a coefficient. We focus on the most interesting case where $q > q'$, so that the yield per unit of hunting effort is larger when individuals hunt in the animal's natural habitat than when they stand by their field.[2] At the fixed price p per unit of meat, revenues from hunting in the wild are $\pi^E = pqEX$.

2.4. The (partial) equilibrium allocation of labor

Households allocate labor between farming, defensive hunting and hunting in the wild in order to maximize their total revenue function

$$\pi = g\frac{W}{\alpha}[1 - bX(1 - c)(1 - \beta Z)] + pq'XZ + pqXE \tag{1}$$

[2] If $q' > q$, people would never choose to hunt in the forest—not only can they increase their animal harvest by hunting near their field, they also receive the bonus of reduced damages. Another way to have both regular hunting and defensive effort would be to allow for different wildlife densities in a spatial model.

subject to the time constraint $T = E + Z + W$. The problem being linear in the choice variables, it is solvable via a Lagrangean with Kuhn–Tucker slackness conditions to allow for corner solutions. For a more compact and intuitive presentation, however, we proceed directly from a comparison of the marginal returns to each of the three activities, respectively. They are defined by the following equations:

$$\frac{\partial\pi}{\partial W} = \frac{g}{\alpha}(1 - bX(1 - \beta Z)(1 - c)), \tag{2a}$$

$$\frac{\partial\pi}{\partial E} = pqX \tag{2b}$$

and

$$\frac{\partial\pi}{\partial Z} = \frac{gW}{\alpha}(\beta Xb(1 - c)) + pq'X. \tag{2c}$$

The comparison of marginal returns allows us to derive the labor market equilibrium conditions under which villagers specialize, or engage in different combinations of hunting, farming and defensive action. The hunting and defensive technology parameters q and q' help characterize these equilibria and Fig. 1 maps them keeping everything else constant (including the stock X). Our focus on $q \geqslant q'$ implies we limit our attention to combinations of q' and q on or above the 45° line.

For instance, agents completely specialize in agricultural production if the marginal return to W (2a) exceeds both the marginal return to hunting (2b) and defensive action (2c). Computing these conditions defines critical values $\hat{q}$ and $\hat{q}'$:

$$q \leqslant \hat{q} = \frac{g(1 - bX(1 - c))}{pX\alpha} \tag{3a}$$

and

$$q' \leqslant \hat{q}' = \frac{g(1 - bX(1 - c)(1 + \beta T))}{pX\alpha}. \tag{3b}$$

If the given values of q and q' are such that both conditions are met with strict inequality, the equilibrium is a corner solution where all labor is devoted to farming. It is worth noting that $\hat{q} > \hat{q}'$ since $(1-c) > 0$ and $\beta T > 0$. When $q = \hat{q}$, the returns to farming and hunting are both linear and independent of each other (this is due to the assumptions of linear production technologies and exogenous prices). Thus, given X, at any point on the horizontal line where $q = \hat{q}$, any division of labor such that $W+E = T$ (including $(W, E) = (T,0)$ or $(0,T)$) constitutes a labor market equilibrium. Along the $q = \hat{q}$ line, the 'farm only' equilibrium is a special case

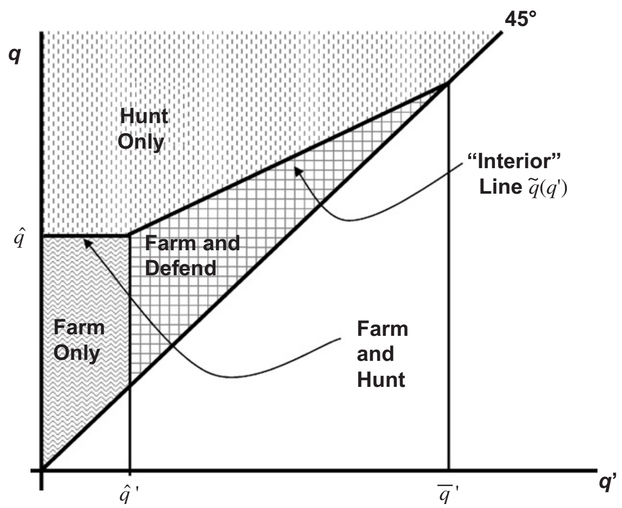

Fig. 1. Equilibrium labor allocation in the (q, q') space.

of the 'farm and hunt' equilibria that emerge when $q = \hat{q}$ and $q' < \hat{q}'$. Since the equilibria on the $q = \hat{q}$ and $q' = \hat{q}'$ loci are knife-edge corner solutions, we come back to them only briefly in the analysis that follows.[3] We focus instead on the equilibria characterized by both farming and defensive hunting, where a compensation program is more likely to be contemplated.

For a combination of farming and defensive action to be optimal, the marginal returns to W and Z (Eqs. (2a) and (2c)) must be equal and exceed the marginal return to hunting (2b). Equating (2a) and (2c), substituting for $T = W + Z$ and solving produces an optimal division of labor:

$$W^*_{\mathrm{FD}} = \frac{g(1 - bX(1 - c)(1 - \beta T)) - pq'X\alpha}{2b\beta(1 - c)gX} \geqslant 0 \tag{4a}$$

and

$$Z^*_{\mathrm{FD}} = \frac{pq'X\alpha - g(1 - bX(1 - c)(1 + \beta T))}{2b\beta(1 - c)gX} \geqslant 0. \tag{4b}$$

Substituting the expression for Z^* into the condition $\partial\pi/\partial W \geqslant \partial\pi/\partial E$ (or equivalently, substituting W^* into $\partial\pi/\partial Z \geqslant \partial\pi/\partial E$) defines the upper boundary of the 'farm and defend' equilibrium area of Fig. 1. It is given by

$$q \leqslant \tilde{q}(q') = \frac{g(1 - bX(1 - c)(\beta T - 1) + pq'X\alpha)}{2pX\alpha}. \tag{5}$$

The right hand side (RHS) of (5) defines a line in the (q, q') space anchored at the top-right corner of the farm only area (where $q' = \hat{q}'$ and $q = \hat{q}$), and with a slope of 1/2. For combinations of q and q' below that line and greater than $\hat{q}'$, it is optimal to allocate labor between farming and defending. The $\tilde{q}(q')$ line itself is the combination of points at which the marginal revenues from all three activities are equal. However, it is easy to show that for a given X, a labor allocation in which there is a strictly positive quantity of all three occupations would be difficult to maintain.[4]

Finally, specialization in hunting takes place whenever $q \geqslant \hat{q}$ and $q \geqslant \tilde{q}(q')$ and $q \geqslant q'$ as represented in Fig. 1. We return to this case below.

2.5. *Biological and economic equilibrium*

Closing the model requires considering the effects of alternative labor allocations on the wildlife stock. The wildlife stock is in equilibrium if growth is equal to off-take from hunting and defensive action. We postulate logistic natural growth (i.e. growth is a quadratic function of the stock) and that biological carrying capacity is a linear function of un-developed land $H = L - \omega A$. The parameter ω represents how poor a substitute agricultural land is for natural habitat and is no larger than one. For $\omega = 1$, farmland is completely incompatible with wildlife. On the other hand, peasant–wildlife conflicts most often exist because farmland provides an easy source of food for wild animals. It is therefore likely that agricultural land is, to some extent, a substitute for habitat. It is an imperfect substitute when $0 < \omega < 1$, and a perfect substitute when $\omega = 0$.[5]

[3]The situation in which (3b) holds with equality ($q' = \hat{q}'$) while (3a) holds as an inequality ($q < \hat{q}$) is the corner solution where total revenues from the 'farming only' equilibrium are identical to the revenues obtained by optimally allocating labor between farming and defensive action. In other words, the vertical boundary of the 'farming only' area at $q' = \hat{q}'$ corresponds to $Z = 0$ in the optimal allocation of labor between Z and W.

[4]In an interior equilibrium, all three marginal revenue expressions must be equal. However, from such an allocation, it is always possible to reduce the amount of hunting labor and increase farming and defensive action in a way that maintains the equality of the margins for farming and defensive action. This reallocation leaves the marginal revenue from hunting unchanged (pqX), but marginal revenue for farming and defensive action increase, leading to greater total revenue. Thus we should expect that individuals who take the wildlife stock as given will not choose an interior solution since they can always do better.

[5]It is conceivable that farmland could be strictly better for wildlife than natural habitat ($\omega < 0$). Since farmland is less likely to provide adequate shelter to many species, we do not analyze this case.

It follows that the wildlife is in equilibrium if natural growth is exactly offset by hunting and defensive off-take[6]:

$$rX(L - \omega A - X) - qEX - q'ZX = 0, \tag{6}$$

where $r>0$ is a growth parameter. The different domains of Fig. 1 represent particular equilibrium allocations of land and labor for different combinations of hunting and defensive hunting technologies defined by the parameters q' and q. For the labor allocation equilibrium to be an equilibrium of the entire economy, it must also be the case that the wildlife stock is in equilibrium as defined by (6).

In a "Crop Only" labor equilibrium, hunting and defensive effort would, by definition, be equal to zero. Solving (6), the equilibrium wildlife stock is then:

$$X_{\mathrm{C}}^{*} = L - \frac{T}{\alpha}. \tag{7a}$$

Not surprisingly, this equilibrium stock is independent of hunting parameters or prices. In the "Crop Only" region this wildlife stock is uniquely defined. However, this is not necessarily the case in other regions of Fig. 1.

In the "Hunt Only" region, W and Z are equal to zero and the steady state wildlife stock is given by

$$X_{\mathrm{H}}^{*} = L - \frac{qT}{r}. \tag{7b}$$

Therefore, each value of q defines a different equilibrium wildlife level. A more effective hunting technology (greater q) yielding a lower equilibrium stock.

Finally, in regions where labor is divided between two occupations, the equilibrium stock is derived from an equality of the relevant marginal revenue functions (two of Eqs. (2a)–(2c)), along with (6) simultaneously holding. In the "Crop & Defend" region, the wildlife stock is also in equilibrium if

$$X_{\mathrm{CD}}^{*} = L - \frac{T}{\alpha} + \left(\frac{r - \alpha q'}{r\alpha}\right) Z^{*}, \tag{7c}$$

where Z^{*} is defined in Eq. (4b). Note that increasing the defensive hunting technology parameter q' has an ambiguous effect on the size of the equilibrium wildlife population. To see this, note that

$$\frac{\partial X_{\mathrm{CD}}^{*}}{\partial q'} = \left(\frac{r - \alpha q'}{r\alpha}\right) \frac{\partial Z^{*}}{\partial q'} = \frac{(r - \alpha q')p}{2rbg\beta(1 - c)}. \tag{8}$$

For $r>\alpha q'$, $\partial X_{\mathrm{CD}}^{*}/\partial q' > 0$. But for $r<\alpha q'$ we see that $\partial X_{\mathrm{CD}}^{*}/\partial q' < 0$. We return to the nature of this fundamental ambiguity below, when we explore the implications of introducing a compensation scheme for wildlife damages.

3. Increased compensation, conservation and welfare

We are now ready to tackle the central question of this paper: how does compensation for wildlife damages affect the wildlife stock? To analyze the effect of compensation we consider in turn the effect of compensation on labor, and the effect of the labor reallocation on the wildlife stock.

Fig. 2 provides a visual representation of the effect of increasing the level of compensation, c, on the equilibrium allocation of labor. For ease of reference, the dotted lines of Fig. 2 replicate the original delimitations of the labor equilibrium regions of Fig. 1.

Increasing the level of damage compensation, c, makes growing cereals more profitable. It follows that greater hunting efficiency is required before one engages in hunting or defensive action:

$$\frac{\mathrm{d}\hat{q}}{\mathrm{d}c} = \frac{gb}{p\alpha} > 0 \tag{9a}$$

[6] If growth is described by the function $F(X) = rX(K-X)$, and if k as the maximum density that can be supported by a unit of land (so that $K = kH$), an appropriate choice of units of measure for K will yield the correspondence $k = 1$ and biological growth can be expressed by $F(X) = rX(L - \omega A - X)$.

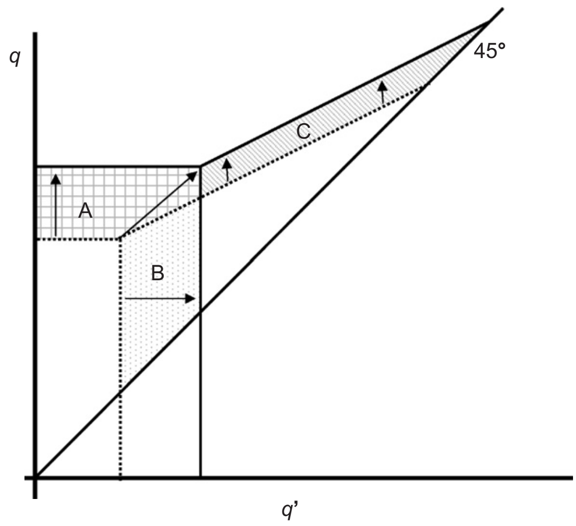

Fig. 2. Equilibrium labor allocation with increased compensation.

and

$$\frac{\mathrm{d}\hat{q}'}{\mathrm{d}c} = \frac{gb}{p\alpha}(1+\beta T) > 0. \tag{9b}$$

Note the difference between the extent of the shifts in $\hat{q}$ and $\hat{q}'$. The additional term in Eq. (9b) is an expression of moral hazard.[7] Compensation not only increases the value of planting crops, it also reduces the benefits of defensive action, further pushing the minimum value of q' at which engaging in defensive action is optimal.

The implication of Eqs. (9a) and (9b) is that a more generous compensation program results in an expansion of the ‘‘Farm Only’’ region, both vertically and horizontally. For a given hunting technology only marginally above the $\hat{q}$ line (represented by area A in Fig. 2), the increase in compensation level makes farming more attractive and will result in a switch from hunting only to farming only. For defensive hunting technologies only marginally to the right of the $\hat{q}'$ line (represented by area B), the increase in compensation makes the yield to farming greater than to defensive effort. The result is once again a switch to a ‘‘Farming Only’’ equilibrium.

Increased compensation also affects the boundary separating the ‘‘Farm & Defend’’ and ‘‘Hunt Only’’ regions in a way that favors agriculture. While the slope of the threshold line $\tilde{q}(q')$ is unaffected by a change in c, the vertical intercept $q = g(1 - bX(1-c)(1-\beta T))/2\alpha pX$ shifts up. Since this line passes through the $(\hat{q}', \hat{q})$ corner of the ‘‘Farm Only’’ area, this result also serves to establish that the increase in c unambiguously shifts the corner into what was previously the Hunt Only region as depicted in Fig. 2.

An economy in region C has a hunting technology, q, that is just sufficiently good to make hunting only the initial equilibrium labor allocation. In area C, animals are sufficiently easy to catch around fields (q' is large enough) that increasing compensation tips the equilibrium from hunting only to a combination of farming and defensive hunting.

3.1. Compensation, system equilibria and impact on wildlife

Prior to a change in compensation level, the economy is located at a single point in Fig. 1 and characterized by the underlying optimal vector (W^*, Z^*, E^*, X^*). In this linear model, the impact of increasing the

[7] Important issues associated with moral hazard have been tackled by [13]. Compensation payments for Snow Leopard and Lion depredation require the maintenance of ‘‘good husbandry practices’’ suggesting that conservation agencies are increasingly aware of potential moral hazard problems [10].

compensation level on the equilibrium can either be subtle or involve a non-marginal departure from one corner solution to another.

More importantly, the impact of compensation on the equilibrium wildlife stock is ambiguous. The amount of land cultivated increases at the expense of wildlife habitat, lowering the equilibrium wildlife stock—the *habitat effect*. But a shift of labor towards farming reduces wildlife mortality from hunting, which increases the equilibrium wildlife stock—the *hunting effect*. Habitat and hunting effects "pull" the system in opposing directions.

This general property of the system is most cleanly illustrated for a situation where the system's optimal equilibrium changes from "Hunting Only" to "Farming Only" following a change in c (perhaps the introduction of compensation to entice people to stop hunting and take up agriculture). Whether the "farm only" stock $[L-(\omega T/\alpha)]$ is greater or smaller than the "hunt only" stock $[L-(qT/r)]$ depends on the relative magnitude of $r\omega/\alpha$ and q. This critical relationship originates from the terms $(rX\omega W/\alpha)$ and $(-qXE)$ of (6). The expression $r\omega/\alpha$ is the marginal impact of decreasing W on the stock's rate of growth (expressed in percentage of the stock after dividing both sides by X), and $-q$ is the marginal effect of increasing E on the rate of hunting mortality. If $q>r\omega/\alpha$, we say that a "hunting effect" prevails. Shifting one unit of labor from hunting to farming results in an increase in survival rate in the wild that exceeds the decrease in natural growth attributable to habitat loss. If the converse is true, we say that a "habitat effect" dominates.

Clearly, if farmland is a perfect or better than perfect substitute for natural habitat ($\omega \leqslant 0$), the hunting effect dominates and the stock is unambiguously greater in the farming only domain than in the hunting only regime. Everything else constant, the habitat effect is more likely to dominate when farmland is a poor substitute for habitat, for species that are hard to catch (low q, such as monkey species) or that have high potential replenishment rates (high r-members of the duiker family, a common African ungulate prey species). Similar logic applies for areas B and C—the reshuffling of labor from defense or hunting towards farming necessarily involves opposing effects.[8]

Similar characterizations of the impact of changing regime at the optimum can be conducted for situations where the system's equilibrium switches from areas A or B in Fig. 2. From an applied policy perspective, however, the economy in which a damage compensation program is most likely to be introduced is where farmers spend time defending their crops with lethal means.

3.2. Labor reallocation within the farm-and-defense area

The equilibrium does not need to switch from one domain to another when introducing compensation payments. These drastic changes in regime are movements from one corner solution to another and need not occur. For instance, a small increase in compensation in an economy with a very large q (far above the lower boundary of the "Hunting Only" region) would offer insufficient incentives for hunters to begin farming.

On the other hand, true marginal changes are observed in economies that are located strictly inside the boundaries of the "Farm and Defend" area. To analyze this situation, consider a system of two equations. The first, or (10) below, is the equilibrium condition when labor is allocated between farming and defending (i.e. (2a) = (2c)). The second, or (11), is the equilibrium wildlife stock under the same regime:

$$g\left(\frac{1}{\alpha}-(1-c)D_W\right)+g(1-c)D_Z-pq'X=0 \tag{10}$$

and

$$r\left(L-\frac{\omega W}{\alpha}-X\right)-q'(T-W)=0. \tag{11}$$

[8]The reader might wonder what happens if NGOs and governments do not afford compensation to households who illegally cultivate public property and lose crops due to wildlife incursion. If such a scheme were credible and enforceable, it would have no impact on conservation—it freezes the allocation of land and labor and the habitat effect cannot emerge. Without either an extensive or intensive margin, compensation offers no new incentive to stop hunting even with complete compensation.

We use D_W and D_Z in Eq. (10) to denote the partial derivatives of the crop damage function $D(W,Z,X) = (W/\alpha)(bX(1-\beta Z))$ with respect to W and Z. To investigate the impact of compensation on the entire system, we totally differentiate (10) and (11). Making use of the fact that $\mathrm{d}W = -\mathrm{d}Z$, and $W_{XX} = W_{ZZ} = 0$ we then write the result in matrix form[9]:

$$\begin{pmatrix} 2g(1-c)D_{WZ} & g(1-c)(D_{ZX}-D_{WX})-pq' \\ q'-\left(r\omega/\alpha\right) & -r \end{pmatrix}\begin{pmatrix} \mathrm{d}W \\ \mathrm{d}X \end{pmatrix} = \begin{pmatrix} g(D_Z-D_W) \\ 0 \end{pmatrix}\mathrm{d}c. \tag{12}$$

Careful inspection reveals that under our maintained assumptions, all of the terms in the 2×2 matrix are negative, with the exception of the term $q'-(r\omega/\alpha)$. This expression is critical for understanding the effect of compensation on the wildlife stock. When $q' > (r\omega/\alpha)$ an increase in agricultural labor (and land) has a smaller negative effect on natural growth of the stock than the positive effect that accompanies the identical decrease in defensive hunting effort. Thus, this expression mathematically defines the habitat and hunting effects and is an important element determining whether compensation has a positive or negative impact on the stock wildlife. Using Cramer's rule on (12), this impact is measured as

$$\frac{\mathrm{d}X}{\mathrm{d}c} = \frac{\left(q'-(r\omega/\alpha)\right)g(D_W-D_Z)}{\delta}, \tag{13}$$

where δ is the determinant of the 2×2 matrix on the left hand side (LHS) of (12).

If the hunting effect dominates, so that $q'-(r\omega/\alpha)>0$, then $\delta>0$ and $\mathrm{d}X/\mathrm{d}c>0$. In this case, compensation has the intended effect of increasing the equilibrium wildlife stock. Increased compensation makes the marginal revenue from farming greater than that from defending, but the stock increases to re-establish the biological and labor allocation equilibrium. In net, the gains in wildlife numbers resulting from a reduction in defensive hunting pressure outweigh the losses associated with habitat conversion.

If the habitat effect dominates, so that $q'-(r\omega/\alpha)<0$, then the numerator of (13) is negative. The signs of δ and $\mathrm{d}X/\mathrm{d}c$ are, however, both ambiguous. When the habitat effect dominates, increasing the level of compensation could be favorable or detrimental for the stock of wildlife. Of particular interest are the conditions (in addition to the necessary dominance of the habitat effect) under which $\mathrm{d}X/\mathrm{d}c<0$. That is, when increasing/introducing compensation leads to a decrease in the wildlife stock it is meant to protect. This perverse result eventuates when $\delta>0$, or if

$$2g(1-c)D_{WZ} < (g(1-c)(D_{WX}-D_{ZX})+pq')\left(\frac{q'-(r\omega/\alpha)}{r}\right). \tag{14}$$

The last term on the RHS is the partial $\mathrm{d}X/\mathrm{d}W$ required to sustain a biological equilibrium. This is multiplied by an expression that originates from $\left(\frac{\mathrm{d}}{\mathrm{d}X}(g(1-c)(D_W-D_Z)+pq'X)\right)$, which can be interpreted as the extent to which the marginal cost (note the presence of prices) of substituting W for Z changes with an increase in X about the equilibrium. Thus, the RHS of (14) is the change in the relative marginal value of W and Z resulting from a change in the stock.

The term on the LHS originates from $-g(1-c)D_{WZ}\,\mathrm{d}Z + g(1-c)D_{ZW}\,\mathrm{d}W$ with $\mathrm{d}W=-\mathrm{d}Z$. It measures the impact of modifying the labor input on the marginal cost (value of damage) of reallocating a unit from Z to W (keeping X constant). Thus, if the crop damage function were separable in W and Z so that $D_{WZ} = D_{ZW} = 0$, the LHS of (14) would always be equal to zero and the predominance of the habitat effect would be sufficient to conclude that $\mathrm{d}X/\mathrm{d}c<0$.

More generally, however, compensation impacts the marginal value product of both occupations. As a result, unlike in [15], dominance of the habitat effect would no longer be sufficient for compensation to lead to lower equilibrium wildlife levels. When the compensation level is raised, the marginal return to farming increases above that of defending. The habitat effect pushes the stock lower, exacerbating the disequilibrium. Maintaining the equilibrium conditions require either a subsequent decrease in W, an increase in X, or both. If the difference in marginal revenue between W and Z is more sensitive to a change in X than to a reallocation of labor, a relatively small stock adjustment will suffice to keep the system in equilibrium and the net effect of

[9]Differentiating (11) yields $(-r\omega/\alpha)\mathrm{d}W - r\mathrm{d}X + q\mathrm{d}W = 0$. Rewriting as an expression for $\mathrm{d}X/\mathrm{d}W$ reveals an ambiguous sign reflecting once again the opposing habitat and hunting effects.

compensation on the number of wild animals will be positive. Thus, for compensation to result in a lower equilibrium stock requires both the dominance of the habitat effect and that the marginal revenue from farming and defending be more sensitive to a change in labor allocation than to a change in stock.

3.3. Compensation and welfare

It can be verified that the impact of increasing compensation on income is also ambiguous. Consider the simplest case where the economy is in the interior of the 'farm-and-defend' area so that it remains diversified after compensation. Differentiating (1) with respect to c, recalling that $E = 0$ and $W = T - Z$, yields

$$\frac{\partial \pi}{\partial c} = \frac{gbX(T-Z)}{\alpha}(1-\beta Z) + \left(\frac{gb(1-c)(T-Z)}{\alpha}(\beta Z - 1) + pq'Z\right)\frac{\mathrm{d}X}{\mathrm{d}c} + \left(pq'Z - \frac{g}{\alpha}(1 - bX(1-c)[1-\beta(2Z-T)]\right)\frac{\mathrm{d}Z}{\mathrm{d}c}. \tag{15}$$

From (15), it is evident that compensation works on welfare through several channels. The household receives the compensation transfer (a gain). However, this gain is offset by a change in the wildlife stock, and we have shown this effect to be ambiguous. When the stock becomes smaller (i.e., the habitat effect dominates and condition (14) holds), wildlife damages fall (a gain) but the benefits from defensive efforts go down (a loss). For a sufficiently high meat price the latter effect dominates the former. Finally, compensation triggers a re-allocation of effort from defense to farming (the third term in Eq. (15)). The result is a further reduction in wildlife harvest benefits, but also an increase in agricultural output. The aggregate impact of the transfer, the stock effect and the reallocation effect is ambiguous. The intuition for adverse welfare effects in the presence of compensation is that households ignore the wildlife stock effect when expanding their fields—a second best story.

4. Discussion and conclusions

This paper developed a simple model with three occupations and showed that when households can adjust their allocation of labor between farming, hunting and defending their crops, the conservation and welfare impacts of compensating farmers for damage caused by wildlife are generally ambiguous. This ambiguity is owed to the fact that while a decrease in defensive hunting is favorable to the wildlife stock, labor is released to an expansion of agriculture that is detrimental to wild animals. It is well understood that the compensation of victims tends to produce an inefficient amount of "victim activity" [1]. While this is certainly true in our model, the additional linkage of farmers and wildlife through a shared habitat can lead to a program's outcome being exactly the opposite of its intent.

The model reveals two important factors that can mitigate the ecological-economic feedback loop. The first is the extent to which farmland is a substitute for natural habitat. Compensation is more likely to work as intended when farm fields are good rather than poor substitutes for habitat. The other is the fact that when peasants farm and defend, compensation increases the marginal revenues from farming and provokes a reallocation of labor towards farming. If this marginal effect is large relative to the impact of adjusting X on marginal revenues, the new equilibrium will be characterized by a small readjustment of labor and a decrease in stock. But this need not be the case.

The ambiguous results extend well beyond policies to compensate victims. We noted, for instance, that improvements in hunting technology (increases in q or q') can have an ambiguous impact on the equilibrium wildlife stock. In a similar vein, we should expect the fundamental ambiguity to survive in far richer and detailed models than the one developed here. As long as there is a tradeoff in the allocation of labor between hunting and farming, and as long as both activities have adverse impacts on the stock (here through hunting and habitat conversion), compensation programs and other policy will need to assess the relative importance of the two opposing forces. This is also shown in the context of a simpler model without defensive action (but with dynamics and general equilibrium prices) in [15].

What lessons can be drawn from this analysis? First, the choice of economic instrument should depend on local circumstances and be based on an understanding of the relative effects of labor reallocation on hunting mortality and habitat loss. Compensation is a mechanism to help species threatened by lethal attacks, not by habitat conversion. Under the right circumstances (i.e. the hunting effect dominates), it can be an effective second best measure. But it follows logically from our analysis that if the habitat effect dominates and if the net effect of increasing compensation is to reduce the stock and welfare, a conservation program ought to be concerned with penalizing agriculture and land conversion rather than subsidizing it through compensation payments.

Other intervention options exist. For example, it may make sense to create alternative employment unrelated to land or wildlife. Such "indirect intervention" methods are also currently in favor with NGOs as they are seen to re-direct labor and capital away from uses 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 criticizes indirect approaches and argues that "direct payments" for the conservation of nature are more efficient and effective [7]. Indirect mechanisms are probably more likely to suffer from negative feedback channels and unforeseen consequences.[10] Direct conservation performance payments based on wildlife abundance or production of forage (conservation of habitat) can more effectively align the objectives of local residents and of the sponsoring agency. Unfortunately, such measures can be impractical or far more costly than compensation.

There are encouraging signs in Kenya and India that making compensation payments conditional on good husbandry practices, compliance with complementary conservation objectives (e.g. land reserves without agriculture), and to the provision of additional goods and services for the entire community can defeat the moral hazard problem and leverage local social norms to deter retaliatory killings. Structuring compensation payments within a multi-faceted quasi-contractual relationship between an interested NGO's and local communities living with wildlife may still be a pragmatic approach to safeguarding endangered threatening wildlife. But it is no panacea.

Acknowledgment

We are indebted to Robert Innes for urging us to develop this paper, and to him and two referees for their insightful comments. The research was supported by grants from the Social Sciences and Humanities Research Council of Canada, the Royal Dutch Academy of Arts and Sciences (K.N.A.W.), and the Netherlands Organisation for Scientific Research (N.W.O.). It was completed while Daniel Rondeau was an OECD fellow and visiting scholar at the LAboratoire Montpelliérain d'Économie Théorique et Appliquée (LAMETA), INRA-Montpellier, France. Financial support from the OECD and INRA is gratefully acknowledged.

References

[1] W. Baumol, W. Oates, The Theory of Environmental Policy, second ed, Cambridge University Press, Cambridge, 1988.
[2] R. Bennett, Food for Thought: The Utilization of Wild Meat in Eastern and Southern Africa, Traffic East/Southern Africa, IUCN, Nairobi, 2000.
[3] R. Bigalke, Functional relationships between protected and agricultural areas in South Africa and Namibia, in: H. Prins, J. Grootenhuis, T. Dolan (Eds.), Wildlife Conservation by Sustainable Use, Kluwer Academic Publishers, Dordrecht, 2000.
[4] C. Boyd, R. Blench, D. Bourn, L. Drake, P. Stevenson, Reconciling interests among wildlife and people in Eastern Africa: a sustainable livelihoods approach, Nat. Res. Perspectives 45 (1999), ODI, London, UK.
[5] E.H. Bulte, R. Horan, Habitat conservation, wildlife extraction and agricultural expansion, J. Environ. Econ. Manage. 45 (2003) 109–127.
[6] F. Deodatus, Wildlife damage in rural areas with emphasis on Malawi, in: H. Prins, J. Grootenhuis, T. Dolan (Eds.), Wildlife Conservation by Sustainable Use, Kluwer Academic Publishers, Dordrecht, 2000.
[7] P. Ferraro, Global habitat protection: limitations of development interventions and a role for conservation performance payments, Cons. Biol. 15 (2001) 990–1000.

[10] For example, Liu et al. [10] 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.

[8] T. Hill, Investing in a Sustainable Future. An Economics-Based Approach to Human-Wildlife Conflict Resolution in Pastoralist Africa. Maasailand Preservation Trust, 2006.
[9] R. Jackson, R. Wangchuk, People–wildlife conflicts in the trans-Himalaya. Paper presented at Management Planning Workshop for the trans-Himalayan Protected Areas, Ladakh, 2000.
[10] J. Liu, M. Linderman, Z. Ouyang, L. An, J. Yang, H. Zhang, Ecological degradation in protected areas: the case of Wolong Nature Reserve for giant pandas, Science 292 (2001) 98–101.
[11] C. Mishra, P. Allen, T. McCarthy, M. Mudhusudan, A. Bayarjargal, H. Prins, The role of incentive programs in conserving the snow leopard, Cons. Biol. 17 (2003) 1512–1520.
[12] L. Naughton, R. Rose, A. Treves, 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, Switzerland, 1999.
[13] A. Noss, The impacts of BaAka net hunting on Rainforest Wildlife, Biol. Cons. 86 (1998) 161–167.
[14] K. Rollins, H. Briggs, Moral hazard, externalities and compensation for crop damages from wildlife, J. Environ. Econ. Manage. 31 (1996) 368–386.
[15] D. Rondeau, E.H. Bulte, Wildlife Damage and Agriculture: A Dynamic Analysis of Compensation Schemes, American Journal of Agricultural Economics, forthcoming.
[16] C. Siebert, An Elephant Crackup? The New York Times Magazine, October 8, 2006.
[17] WWF, Elephants in the Balance: Conserving Africa's Elephants, 2000. 〈www.panda.org/resources/publications/species/elephants/index.html〉.
[18] J. Yoder, Estimation of wildlife-inflicted property damage and abatement based compensation program claims data, Land Econ. 78 (1) (2002) 45–59.