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

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

(Proposed Running Head:
Damage Compensation, Wildlife and Welfare)

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**Abstract:**

We 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 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. The conditions leading to a reduction of the wildlife stock are identified and the implications for current and planned compensation programs are discussed.

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

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

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

## 1. Introduction

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

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

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

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

Despite mixed results to date, governmental and non-governmental organizations continue to perceive the establishment of wildlife damage compensation funds as a potentially useful instrument to promote conservation through economic incentives. Echoing many hopeful feelings in the conservation community, the World Wildlife Fund for Nature (WWF) states that:

> "O*ne of the simplest ways to mitigate conflict without affecting elephant behaviour or population size is to compensate people for the damage they have suffered or would have suffered had they not protected their crops."* (WWF, 2000: 5).

Similar beliefs apply to the conservation of many other vertebrate species from tigers and leopards to monkeys and antilopes. Publicly and privately funded compensation programs have recently been implemented with the aim of reducing the illegal killing by farmers of snow leopards in Tibet and lions in Kenya. Compensation programs exist in India, Nepal, Kenya, Botswana, and Zimbabwe to alleviate the impact of damages caused mainly by elephants but also by rhinos. NGO's are contemplating new programs in China to protect tigers (WCS, 2002), as well as in Nepal and in several regions of Africa.

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

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

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

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

but respond to economic conditions and policies by myopically adjusting their land use and labor allocation between agriculture and hunting.

Compensation is paid from an external source (e.g. NGO) to cover wildlife damage. Like any insurance-like program, we should expect damage compensation to result in a reduction of the amount of defensive action (e.g. fencing plots, using chemical deterrents, guarding fields). Here, we purposely ignore defensive measures. This removes moral hazard from the model and puts the focus more clearly on hunting and land conversion as feedback channels that affect the wildlife stock. But since the presence of moral hazard is detrimental to the success of compensation programs, the cumulative effects of compensation are likely to be even worse than our results suggest.[2]

Three central results emerge: 1) compensation schemes aimed at reducing hunting pressure can actually reduce the wildlife stock when the economy is only partially open; 2) compensation has an unambiguously negative effect on the wildlife stock (and could lead to its extinction) if the economy is trading openly; and 3) compensation programs have ambiguous welfare effects on local people. In both the partially open and open economies, compensation can reduce local welfare. Our results show that although compensation programs are well intended, they could lead to the most disastrous outcome of all: compensation that is costly for the sponsoring agency resulting in a reduction in the wildlife population and a fall in local welfare.

In the next section, we describe a dynamic model of wildlife damage and land use conversion in a small rural economy. In Section 3, a simple compensation scheme funded by international conservation interests is introduced and its consequences for land tenure, wildlife stocks and local welfare are analyzed. Section 4 highlights the consequences of a transition from autarky to trade, which may be facilitated by compensation. Final remarks conclude.

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

## 2. An Economy Without Compensation

### 2.1 Production

We model an isolated rural economy in the 'tradition' of Brander and Taylor (1998). In some of its details the model is more closely related to that of Bulte and Horan (2003). The economy is made up of myopic households with open access to both land for agriculture and wildlife for animal product.[3] Labor can freely flow from one activity to another in response to profit differentials. The assumption that property rights over land and wildlife are not defined (or enforced) implies that we are considering the context of a less developed country, where the conflict between wildlife and farmers is 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 are the foregone returns from harvesting wildlife (and vice versa). For example, Noss (1998: 166) notes that hunting in an area in the Central African Republic is declining because of the "growing dependence on agriculture and the necessary time investment in clearing, planting, tending and harvesting fields" (see also Hill 2003). At any point in time, the proportion of land devoted to agriculture and the labor choice of households are therefore *endogenous* to the model. The (opportunity) cost of hunting effort is thus also endogenous to the model. The model extends work by Bulte and Horan along two important dimensions. First, the model explicitly models wildlife damage and is used to analyze the consequences of introducing a compensation scheme. Secondly, we derive the micro-foundations for macro behavior by analyzing a general equilibrium model over time, rather than postulating demand curves for key commodities or proceeding with a static model. Within this framework, we allow the

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

wildlife stock to change over time in response to labor allocation and land use decisions by households.

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

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

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

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

Thus, the model recognizes two sectors of production. An agricultural commodity such as maize or grains is produced with a combination of land and labor, while the inputs to wildlife harvesting are labor and a wildlife stock, the size of which we will denote by *X*(*t*).

As is characteristic of many rural African situations, we assume that access to land is free and that peasants deciding to increase the scale of their agricultural production can do so by expanding production onto previously unoccupied land. In what follows, we assume that the inputs to agricultural production are perfect complements with a fixed labor requirement per unit of land equal to $W/A = \alpha > 0$. Therefore, the decision to farm an area of size *A*, necessarily implies the decision to supply agricultural labor in the quantity

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

We exploit this equality throughout to reduce the dimension of the problem to one of land use selection. By an appropriate choice of unit of measure, we normalize production so that, in the absence of wildlife damage, one unit of land and $a$ units of labor produce one unit of crops. "Potential" agricultural production in the absence of damage can therefore be expressed simply as $A$. However, the wildlife stock, *X*, does consume, trample or otherwise destroy a proportion $D(X)$ of the potential harvest, leaving the economy with a net supply of crops equal to $G^S = A\left(1 - D(X)\right)$. It is assumed that the net amount of crop harvested is a decreasing function of the wildlife stock, with $D(0) = 0$. In what follows, 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 not destroy all crops.[4] With this assumed functional form, the amount of crops brought to the market by producers is then equal to

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

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

$$gG^S(t) = gA\left(1 - bX\right). \tag{5}$$

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: [5]

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

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[4] In alternative modeling, we have applied the nonlinear damage function $D(X) = (e^{bx} - 1)e^{-bx}$, corresponding to a net production $Ae^{-bx}$ without detecting significant qualitative changes to our results.
[5] 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.

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

It is assumed that harvested meat, a relatively valuable commodity, is actively traded both within and outside of the local economy (as opposed to the case of locally traded food crops). The bushmeat trade may be run by an emerging class of specialized traders (not modeled here) visiting villages in pursuit of meat, and may or may not be legal—see Bennett and Robison (2000:17) on the "commercialization of the wildlife harvest". The important feature is that the price of meat, *p*, is exogenously determined on an open market. This assumption is consistent with the growing trade in bushmeat observed throughout the developing world, across national borders or otherwise.[6] In the absence of compensation for damage, this is equivalent to assuming that the economy is closed and that *p* is the numeraire against which other prices are evaluated. This equivalence will no longer hold when external compensation is introduced because external money coming in the local economy will trigger imports of meat. We explore these implications later.

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

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

**2.2 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. Denoting the weight placed on the consumption of *G* by $q$ , and household income by $w$ , we find the usual demand functions that solve the consumers' problem:

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[6] 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).

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

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

The income level is obtained by summing revenues in agriculture and hunting (Eqs 6 and 7):

$$w = gA(1-bX) + pqX\,(T - a\,A). \tag{10}$$

**2.3 Market Equilibrium**

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

$$g^* = \frac{q\,pqX\,(T - a\,A)}{A(1-bX)(1-q)}. \tag{11}$$

The equilibrium price of crops increases with a greater preference for grains, $q$ , the animal stock level, the overall income derived from hunting (*p*,*q*), and the level of damage to crops *b*.

Two factors explain why the equilibrium price of grains increases with the wildlife stock. First, a greater wildlife stock increases the returns to hunting. This increases households' income and the aggregate demand for grains. At the same time, the increase in the number of animals increases crop damage, decreasing both the amount of grains supplied on the market and agricultural revenue. For an equilibrium, closing both gaps requires an increase in the equilibrium price of crops.

On the other hand, the equilibrium price decreases with total crop production, with greater preferences for meat, and with an increase in the labor requirement per unit of land, $a$ . This last effect is explained from the fact that, keeping *A* constant, a greater agricultural labor requirement implies less time available for hunting and depresses hunting revenue. The smaller total household income that results reduces the demand for grains and decreases the equilibrium price of crops.

## 2.4 Labor Allocation and its Dynamics

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

$$\pi_G = \frac{\theta\, pqX\left(T - \alpha A\right)}{\left(1-\theta\right)\alpha A}. \tag{12}$$

It is worth observing that 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 unit-elastic Cobb-Douglas demands results in a price adjustment that exactly offsets the revenue lost to wildlife damage. Since households are producers and consumers at the same time (and they have to pay more for the crops they consume), it is of course still true that wildlife damage makes them worse off. 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:

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

In making their labor allocation at time *t*, individual households observe the wildlife stock and the profits per unit of effort previously realized. Since they neither have ownership of the land, nor any property rights to the stock of wildlife, their labor decision is myopic.[7] 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

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[7] 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 dominates this literature (for an exception, see Berck and Perloff 1984). Baland and Platteau (1996, 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".

dynamics of the natural system. Specifically, suppose that the time rate of change in labor devoted to hunting is given by

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

where $\eta > 0$ represent how rapidly households increase their hunting effort when hunting returns per unit of effort exceed agricultural returns. By use of (2) and (3), differentiating the constraint $E = T - a\,A$ with respect to time (noting that $T$ is a constant), and substituting the result as well as (12) and (13) into (14) allows us to eliminate the labor variables. We can now equivalently describe the dynamics of the economy in terms of the rate of change in land use. Specifically, the rate of change in agricultural land is given simply as a function of the current wildlife stock and the current surface of land in agriculture:

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

Equation (15) indicates that everything else equal, laborers will move from hunting to agriculture (or vice versa) whenever the returns to agriculture exceed the return 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 we do not assume 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 farmer as well as and those of others. However, since their allocation decisions are driven by a comparison of *private* returns, they ignore this aspect. Nuisance control is a public good benefiting all farmers alike, and if the number of farmers increases such that damages are spread over enough farmers, then the private returns to nuisance control diminish.[8]

### 2.5 Wildlife Population Dynamics

[8] Our model does not 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 thereby frees up labor for agricultural expansion – consistent with the dynamics in our model.

To close the model, we must finally consider the evolution of the wildlife stock over time. Many stocks of wildlife, ungulates in particular, grow naturally according to a quadratic growth curve corresponding to a logistic population path bounded from above by the carrying capacity of the habitat.

Suppose that at time $t$, the environment is capable of carrying a maximum of $K$ animals. The biological rate of growth of the stock can then be described by the quadratic function $F(X) = rX(K–X)$ where $r$ is a positive parameter. In our problem, and as in Swanson (1994), the total carrying capacity of the land is a function of the amount of habitat, $H$, available at time $t$. Define $k$ as the maximum density that can be supported by a unit of land so that $K = kH$. With an appropriate choice of units of measure for K, we set $k$=1. Using Equation 1, we obtain that the biological growth of the stock is given by $F(X) = rX(L–A–X)$. The net rate of growth of the stock is finally obtained by subtracting the rate of hunting success from the natural growth:

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

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

**2.6 Transitions and Equilibria**

Equations (15) and (16) constitute a system of differential equations in $X$ and $A$. This system has a trivial steady state at $(X, A)=(0, L)$. For parameter configurations with an interior steady state, it is easy to show that:

$$(X^*, A^*) = \left( \frac{rL - \frac{\theta T}{\alpha} - qT(1-\theta)}{r}, \frac{\theta T}{\alpha} \right).$$

Figures 1 and 2 present phase diagrams with sample time paths for the system defined by equations 15 and 16. In these diagrams, each corresponding to a different set of parameters, the horizontal lines define the $A$ isocline, the combinations of stocks and agricultural land base for which profits are equal in both sectors of the economy. In the absence of compensation, profits in both sectors are equal whenever

$$A\Big|_{\dot{A}=0} = \frac{\theta T}{\alpha}. \qquad (17)$$

Along this isocline, the labor market is in equilibrium and there are no incentives to stray away from the current pattern of land use.

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

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

The slope of this isocline is determined exclusively by the sign of the denominator. For $qa > r$ (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 (16) and set it equal to zero. For the non trivial case where $X$>0, increasing *X* modifies the rate of change in stock density by a quantity directly related to *r* (a greater *r* implies a larger change in the growth rate as *X* increases). A greater stock also increases the productivity of labor devoted to hunting wildlife. $qa > r$ indicates that the gain in hunting productivity is large relative to the change in stock growth. Offsetting this gain in productivity thus requires reducing the amount of natural habitat and is accomplished by transferring labor from hunting to agriculture. This generates an upward sloping *X* isocline, a situation that we characterize as one where the "hunting effect" dominates.

On the other hand, when $qa < r$ as in Figure 2, the increase in harvesting productivity associated with an increase in *X* is small relative to the change in the stock's growth rate, and is insufficient to maintain an equilibrium in the natural system. A greater stock thus requires an increase in hunting effort (and consequently a decrease in land used for cropping), resulting in a downward sloping $X$ isocline. We refer to these topologies as situations where the "habitat effect" dominates. In what follows, we are particularly (but not exclusively) interested in cases where the habitat effect dominates. It is a likely scenario for many fast-growing and hard-to-catch nuisance species and it is also the situation for which the most interesting set of results emerges.

The solid lines appearing on the phase diagrams are actual numerical solutions to the system of differential equations. They trace the evolution of the system over time for given sets of parameter values and initial conditions. Each trajectory begins at the point furthest away from the steady state and follows the direction fields indicated by the arrows. They asymptotically reach 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, both Figures display a stable node. [9]

**3. Outside Compensation for Wildlife Damage**

We now turn to an analysis of the impact of introducing a compensation scheme that pays farmers directly for the losses that they incur from wildlife intrusions in their fields. We are specifically thinking about a compensation mechanism put in place, funded and administered by an international NGO such as the World Wildlife Fund or the Wildlife Conservation Society. As indicated earlier, these and other environmental groups have already established such funds and consider them to be a useful tool in promoting environmental conservation. This being said, the model applies just as well to any compensation scheme, with the caveat that we limit our analysis to situation where the compensation funds come from outside of the area where they are received rather than being funded from tax or other levy paid by local residents.

[9] All computations were performed and graphs drawn with Mathematica, by numerically solving the system of differential equation. For Figures 1 and 4, parameter values are p=10, q=0.000025, L=50000, T=10000, r=0.000003, b=0.00001, $\eta$=300, $\theta$=0.75, $\alpha$=0.5. For Figures 2 and 3, p=10, q=0.000025, L=50000, T=10000, 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.

The crop damage compensation mechanism most often discussed and implemented is based on a simple calculation. The physical quantity of crops lost to wildlife is estimated and its value is assessed at the prevailing market price. The most generous programs (those run by NGO's) cover up to 100% of assessed losses, although, in general, African damage compensation programs run by governments rarely pay more than a small fraction of losses. In what follows, we denote the fraction of losses covered by compensation with the parameter *d*, determined by the fund manager and held constant over time.

Retracing the steps followed in Section 2, farmers producing a total quantity $G^s$ of crops (as per Equation 4), will now collect in revenue the market price for the quantity supplied, plus a fraction *d* of the market price for the lost quantity $\left(dgAbX\right)$. This translates into total agricultural revenues equal to

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

Two features of this compensation scheme are noteworthy. First, recall that in the absence of compensation, the equilibrium price perfectly compensates for quantities lost to animal damage. This leaves farmers with profits before compensation that are not affected by the wildlife stock. Compensation is paid nonetheless to make up for the income loss measured in real terms—the price of crops goes up which makes consumers (i.e. all households) worse off. Secondly, the fund manager pays compensation on the basis of the observed market price $g^*$ even though the equilibrium price accounts for the relative scarcity created by wildlife damage. Had the crops reached the market instead of having been destroyed, the equilibrium price would have been lower and the crops worth less than the value at which they are assessed for compensation purposes.[10]

While the input ratio in agriculture is not distorted in our model economy, this simple compensation system nonetheless shifts the economic incentives faced by households. The question is whether or not this deliberate shift of incentives achieves its intended objective of

[10] 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. Even if this was technically feasible, doing so may appear arbitrary to farmers and erode their trust in the compensation system.

increasing the stock of wildlife. With total household income now reflecting increased agricultural revenue brought by compensation, we can re-compute the equilibrium price of crops as:

$$g^{*C} = \frac{q\, pqX\,(T - a\,A)}{A\left[(1-bX)(1-q)-q\,dbX\right]}\,. \qquad (11')$$

Equation (11') indicates that keeping everything else constant and increasing the level of compensation increases the price of grains. This is a natural adjustment given that an increase in income due to compensation shifts the demand for crops up while the actual quantity produced in the economy is held constant.

The higher price of crops, combined with the direct compensation payments to farmers, makes the farming sector relatively more attractive than the hunting sector. Specifically, while the expression for profits per unit of effort in hunting remains unchanged (13), the rate of profits per unit of effort in the agricultural sector (obtained by substituting the equilibrium price into (5') and dividing by $W = a\,A$) increases to:

$$p_G^{C} = \frac{q\, pqX\,(T - a\,A)(1-bX+dbX)}{a\,A\left[(1-bX)(1-q)-q\,dbX\right]} > p_G\,. \qquad (12')$$

With households dynamically adjusting their labor allocation in response to observed profit differentials, the law of motion for land in agriculture in the presence of compensation becomes

$$\dot{A}^{C} = \frac{h\, pqX}{a}\left\{\frac{q\,(T - a\,A)(1-bX+dbX)}{a\,A\left[(1-bX)(1-q)-q\,dbX\right]} - 1\right\}. \qquad (15')$$

It is easily verified that setting *d*=0 reduces (15') to (15) as we should expect. Since the dynamics of the natural system with harvesting remain unchanged, the law of motion for *X* embodied by (16) is again used to complete the characterization of the dynamics of the bio-economic system. As the law of motion for *X* is unaffected by compensation, the *X* isocline is unchanged. In particular, the case in which the hunting effect prevails leads to the same isocline as was drawn in Figure 1.

The combinations of $A$ and $X$ that lead to an equilibrium in the labor sector have been affected, however. The expression for the new (non-linear) isocline is

$$A\Big|_{\dot{A}=0} = \frac{qT\left(1-bX+dbX\right)}{a\left(1-bX\right)}. \qquad (17')$$

For a strictly positive $d$, the isocline has a positive slope in the ($X$,$A$) space indicating that to maintain the equilibrium return to labor in the two sectors, an increase in $X$ must be accompanied by an increase in acreage devoted to agriculture (i.e. a decrease in the amount of wildlife habitat). Furthermore, as $d$ increases, the slope of the isocline becomes increasingly steep. This is explained by the fact that for a small proportion of losses covered by compensation ($d$ close to zero), an increase in $X$ increases both hunting and agricultural returns in approximately equal amounts, requiring only a small adjustment in agricultural labor. With a more generous compensation scheme (i.e. $d$ closer to unity) an increase in the stock increases income through two separate channels, hunting and compensation. The increase in demand for grains that results is then greater than with a smaller $d$, but the price increase is no longer profit neutral because of compensation payments. Returns to agriculture now exceed the returns to hunting and a greater supply of grains to the market is required to re-establish the equilibrium. This occurs by increasing the amount of labor and acreage devoted to agricultural production. This establishes the positive slope of the A isocline when d>0.

**3.1 Compensation and the Conservation of Wild Stocks**

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

Figure 3 illustrates the situation in which the habitat effect dominates and where damage is fully compensated for ($d$=1). Presenting the full compensation case is without loss of generality since for intermediate cases with partial compensation the $A$ isocline lies between the $A$ isoclines of Figs 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. 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 example), the steady state becomes a stable spiral. Although the steady state of Figure 2 remains a fairly strong attractor, the spiraling motion can be observed along the upper trajectory. 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.[11]

The effect of compensation when the hunting effect dominates is more complex, since it gives rise to the possibility of multiple steady states.[12] Figure 4 replicates the economy of Figure 1 but with a 50% compensation level. Several properties are worth noting. First, even though there can be multiple steady states, the equilibrium is always unique with myopic

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

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

agents and fully determined by initial conditions.[13] Second, the stable steady state with a low stock and low agricultural use lies above the steady state without compensation. Furthermore, the properties of the equilibrium have not been disturbed and remain stable. This is therefore an example where compensation can, as intended, provide incentives to preserve wildlife. (But note that *increasing* the compensation parameter $d$ in the context of multiple equilibria – shifting the $A$ isocline up – implies that the 'high' wildlife equilibrium stock must fall.)

However, for relatively low initial acreage and high stock, the amount of wildlife decreases under hunting pressure, causing households to shift their labor away from agriculture at an increasingly rapid rate. This further reduces the amount of land devoted to agriculture and reinforces the decay of both the stock and agricultural land. This process is self-reinforcing and leads to a degenerate solution in which agriculture is abandoned. No producer wishes to supply crops since time spent hunting provides greater income. As a result, local welfare goes to zero as the supply of grains shrinks.

### 3.2 Compensation and Local Welfare

In general, the welfare effects are more complex than for the degenerate solution described above. For example, 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 the compensation level, $d$. Given the Cobb-Douglas utility defined over $G = A[1–bX(1–d)]$ and $M = qX(T – \alpha A)$ the expression for the change in steady state utility is

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

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

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. This establishes that compensation has an ambiguous effect on local welfare.

Figure 5 plots the instantaneous steady state welfare level for the habitat effect case illustrated in Figures 2 and 3. In this example, local welfare in steady state can be improved by the inflow of cash compensation in the economy. However, it is worth noting that the rate of welfare with full compensation (*d*=1) is actually lower than when no compensation payments are made (*d*=0). In general, a weaker habitat effect ($q\alpha$ not much smaller than *r*) can produce an everywhere positive relationship between *d* and steady state welfare, while a strong habitat effect can produce an everywhere negative relationship (even at *d*=0). For intermediate cases the inverted U shape of Figure 5 materializes.

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 is quite a damning result since it indicates that it is possible for well intended compensation programs to lead to the worst possible outcome of all: the compensation program is costly to its sponsors, it promotes habitat conversion, it reduces the stock of wildlife, and it lowers the welfare of local people!

**4. Compensation and Regional Trade**

In this section we examine another potential effect of compensation. Transfers to the village from an external source may induce a transition from partial autarky to regional trade. Sadoulet and de Janvry (1995: 149) explain how this works. Assume that trading commodities at regional markets entails transaction costs. The existence of such costs implies village households face different selling and buying prices for commodities. The width of the price margin (or band) is determined by the magnitude of the transaction costs. These may be considerable for perishables.[14] In section 2 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 in section 3, this will affect both demand for and supply of crops. As a result, a new price emerges. While this new price may still be within the price ban defined by transaction costs (as assumed in section 3), 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 labour in farming is henceforth:

$$p_G = \frac{j\,[1+(d-1)bX\,]}{a} \qquad (12")$$

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

$$\dot{A} = \frac{h}{a}[p_G - p_M\,] = \frac{h}{a}[\frac{j\,(1+(d-1)bX)}{a} - pqX\,]\,. \qquad (15")$$

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

$$X^{**} = \frac{j}{a\,pq + j\,(1-d)b}\,. \qquad (17")$$

This isocline is vertical in the X-A space, implying a unique equilibrium, regardless of whether the *X* isocline slopes up or down. Figure 6 presents the combination of two phase

[14] As argued above we have assumed above that trade in meat is possible (but it will obviously not happen in the absence of a compensation program or trade in crops). Bushmeat is a relatively valuable commodity. In certain regions a specialized class of bushmeat traders has emerged that is willing to incur these costs. Transaction costs as a percentage of the value of the commodity (say, per kilogram) are relatively modest.

planes for the case where the habitat effect dominates. On this phase diagram are drawn a single $X$ isocline denoting the biological equilibrium (which is independent of $d$), and two $A$ isoclines: the horizontal one where $d$=0 (as in Figure 2) and the vertical isocline corresponding to the new economy after full compensation has been introduced ($d$=1).

The key feature illustrated by Figure 6 is that the *qualitative nature* of the equilibrium has changed after the introduction of compensation. Whereas the steady state of the partial autarky case is stable, the steady state of the small open economy is a saddle point equilibrium. 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 open economy system will completely specialize over time into one of the two sectors of economic activity. For initial conditions above the relevant separatrix (which includes the original steady state without compensation), the economy eventually specializes into agriculture, driving the stock to extinction in the process. From initial conditions below the separatrix, households abandon agriculture, eventually devoting all labor resources to hunting.[15]

What is the effect of compensation on conservation in this context? It is clear from Figure 6 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 and local extinction of wildlife will be the result. This is the case drawn in Figure 6. 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 $\varphi$ relative to other key parameters.

The ranking of income levels from specialization in hunting and cropping is ambiguous and again depends on the terms of trade and the magnitude of $\varphi$. Consistent with

[15] 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.

the autarky case of Section 3, we therefore conclude that compensation can result in either higher or lower wildlife stocks, and either higher or lower local welfare.

## 5. Concluding Comments

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

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

The potential for such unintended consequences of compensation schemes are explained from the fact that compensating for agricultural damage does not only reduce the immediate incentives to hunt animals. Compensation is also an agricultural subsidy that encourages the conversion of natural habitat into agricultural fields. Whenever the removal of habitat has a greater effect on the stock than the reduction in hunting effort that accompanies a shift toward agriculture, the stock will be negatively affected. In these circumstances, it follows logically that rather than subsidizing agricultural production through compensation, conservationists should prefer a tax or some other mechanism designed to reduce agricultural output.

The impact of taxing agriculture can be inferred by considering cases with $d<0$. When the habitat effect dominates the hunting effect, a marginal tax on residual agricultural output triggers larger wildlife stocks. From this perspective, the "urban bias" that is often encountered in agricultural policies in the third world could be a conservationist blessing in disguise. If compensation transfers are to be provided, it might be advisable to make them conditional on cooperation at the village level. This would imply a transition from a non-cooperative model to a cooperative one that internalises the external effects of open access to land and wildlife.

One related final caveat is worth noting. We have assumed throughout that access to land and wildlife resources is 'open' for all households, and remain open even after the compensation scheme is implemented. It is well known however, that the definition and enforcement of property rights is endogenous and dependent on relative prices (e.g., De Meza and Gould, 1992; Hotte et al, 2000). It is therefore conceivable that compensation programs that drive up crop prices could change the social fabric that supports the types of equilibria discussed above. Compensation could favour the transition from open access to land towards the establishment of private property rights and perhaps foster better resource husbandry.

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

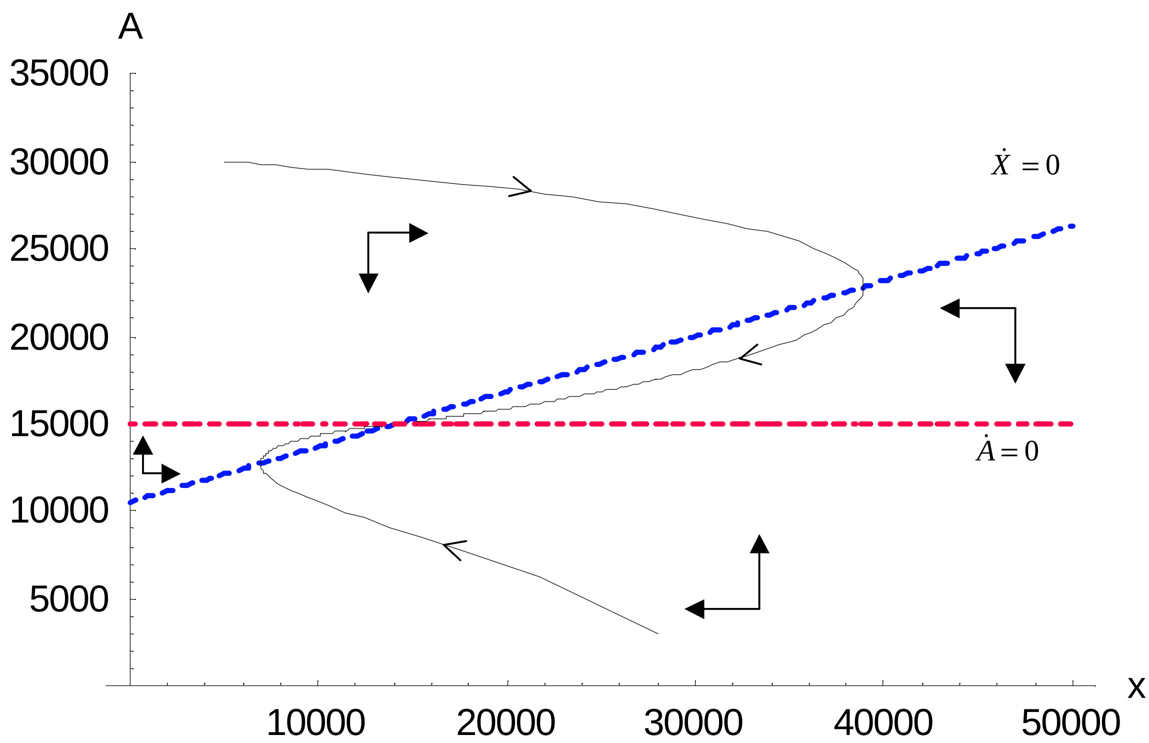

**Figure 2**
**Dynamics of the Economy - No Compensation**
**Cobb-Douglass Utility, Linear Damage, Dominant Habitat effect**

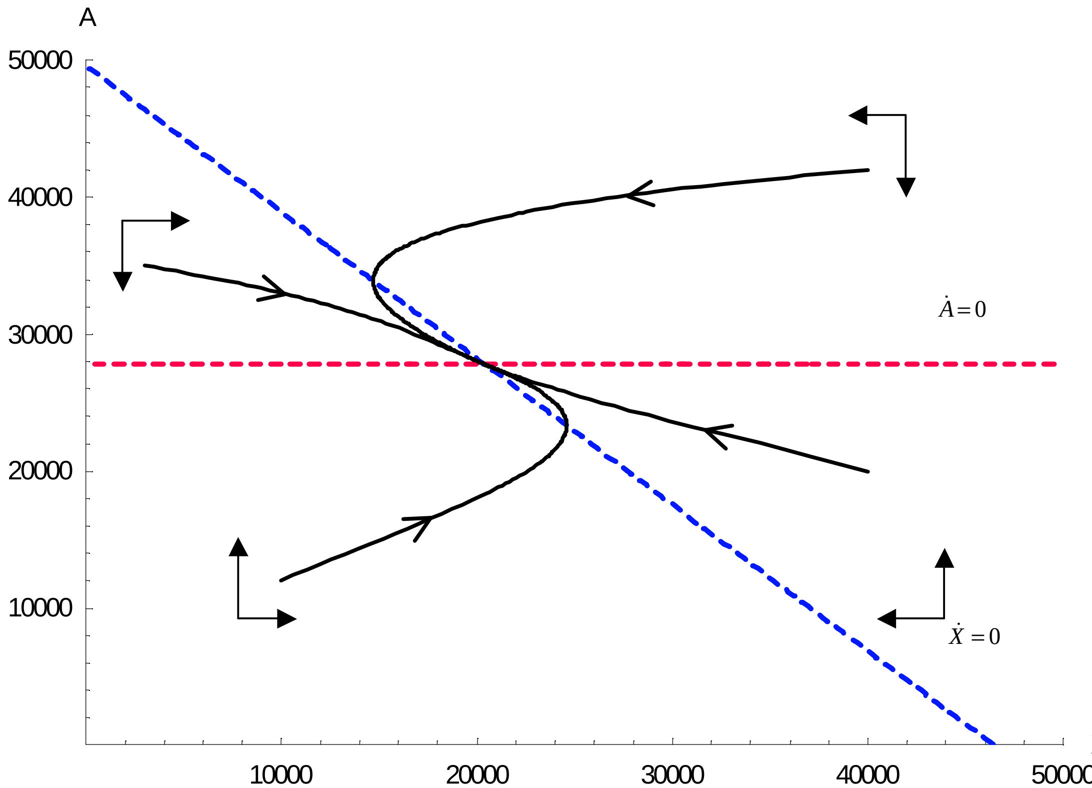

**Figure 3**
**Dynamics of the Economy with Full Compensation (d=1)**
**Cobb-Douglass Utility, Linear Damage, Dominant Habitat effect**

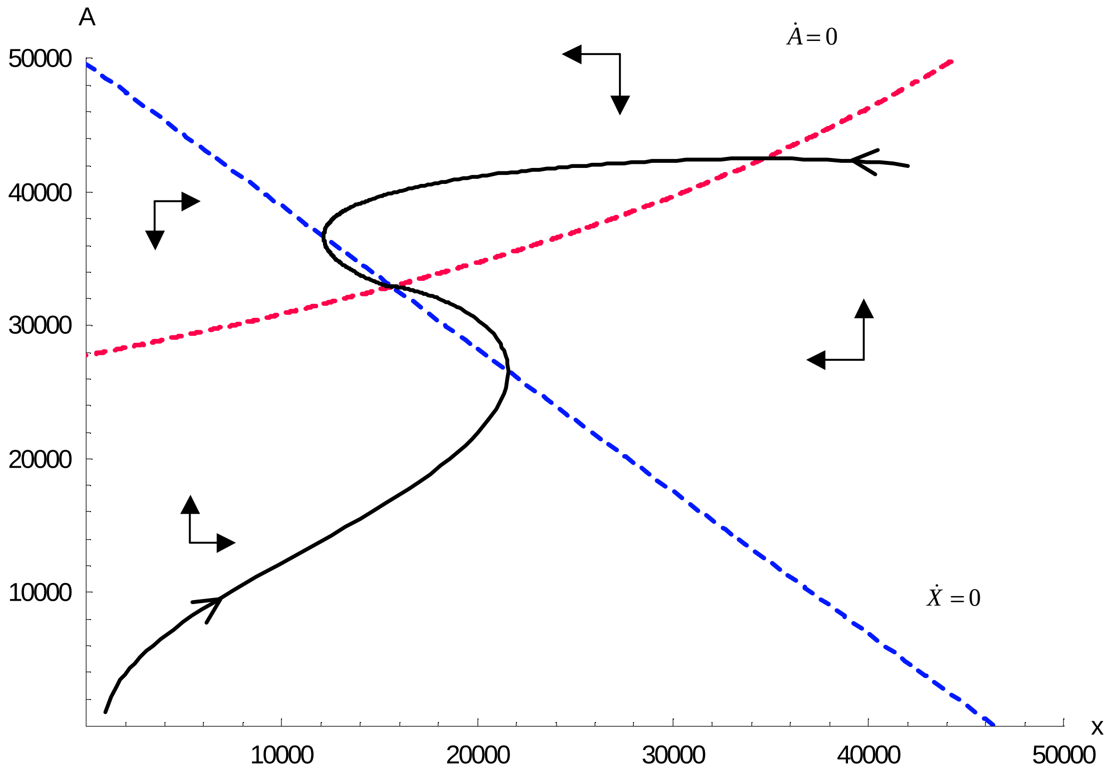

**Figure 4**
**Dynamics of the Economy with 50% Compensation (d=0.5)**
**Cobb-Douglass Utility, Linear Damage, Hunting effect**

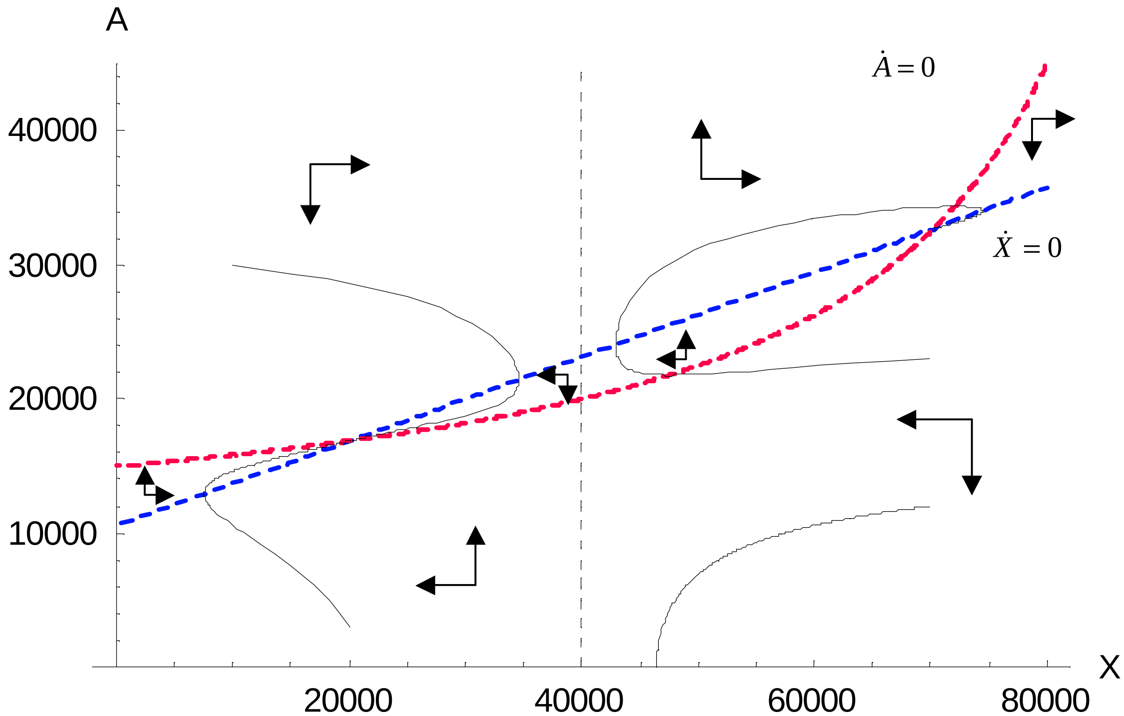

**Figure 5**
**Possible Relationship between Compensation Level and the Rate of Welfare Accumulation in Steady State**
**Dominant Habitat Effect**

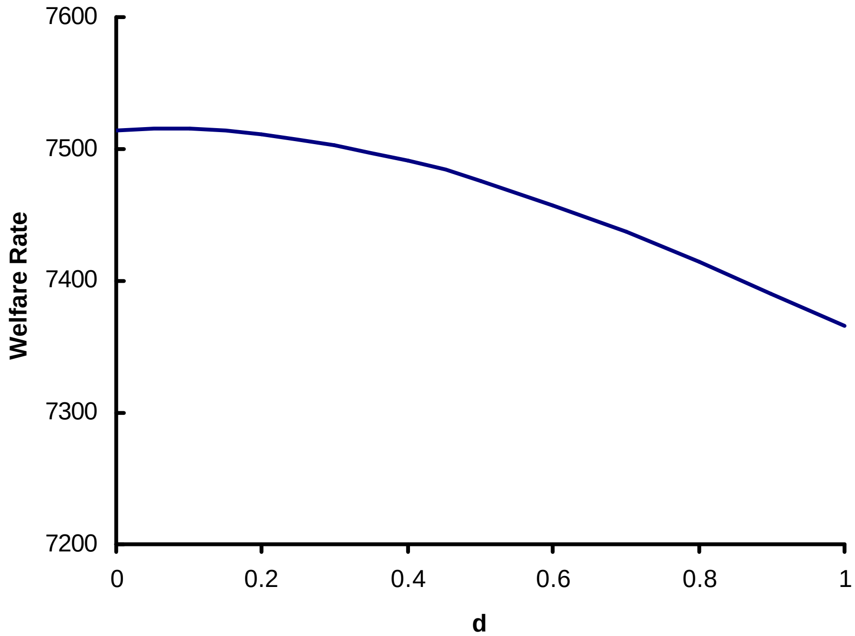

**Figure 6**
**Compensation and the Transition to an Open Economy (Habitat Effect).**