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Protecting the African elephant: A dynamic bioeconomic model of ivory trade

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ABSTRACT

A dynamic bioeconomic model of ivory trade is used to investigate the efficacy of conservation payments, tourism benefits, quota regimes and a trade ban on the protection of the African elephant (*Laxadonta africana*). The model consists of four ivory exporting regions and one demand region. Results indicate that a trade ban might not be successful in maintaining elephants, even if it increases the costs of marketing ivory and leads to a stigma effect that reduces demand. Indeed, trade in elephant products may offer some hope for the elephant, but only if there exist effective institutions that translate in situ protection into economic values.

1. Introduction

Ivory trade has occurred since at least Old Testament times – King Solomon's ships brought back ivory from Africa (I Kings 10:22) and his palace was inlaid with ivory (I Kings 22:39). Ivory was commercially exploited by the Romans and later by Arab traders and Europeans. Between 1890 and 1900, nearly 3.7 million kg of ivory were traded in London and 60 000 elephants reached European markets annually (Blanc et al., 2003, p. 15). By the late 1900s, a complex combination of commercial trade and human–elephant interactions were causing a serious decline in populations, and elephants were increasingly 'confined' to protected areas. In Ivory Coast, for example, there were an estimated 4840 elephants in 41 isolated groups in 1984, but this had declined to some 270 elephants in 20 isolated groups by the early 2000s; numbers were reported to be declining at a rate of 300 poached and 90 legally killed elephants per year between 1976 and 1984, with poaching continuing to the present (Fischer, 2005).

The World Conservation Union (IUCN) Species Survival Commission has tracked elephant numbers for the past 20 years (Table 1). A comparison of first and subsequent estimates suggests that populations in some areas may have fallen by half between 1981 and 1987 (Said et al., 1995, p. 1); researchers speculate that the African elephant (*Laxadonta africana*) declined from 1.2 million to 600 000 in one decade (Barnes et al., 1999; Blanc et al., 2003).

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regulates commercial trade in endangered species using a ranking scheme: Appendix I lists species banned from international trade; Appendix II lists those that may be traded but for which export permits (issued at the discretion of the exporting state) are needed and Appendix III includes species that are threatened and could become endangered in the future. Importing countries agree not to trade in species (or their products) listed in Appendix I, but only promise to ensure that proper export permits accompany imports of species listed in Appendix II.

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Table 1 – African elephant stocks and elephant range by region

Year and category	Central Africa	East Africa	Southern Africa	West Africa	Total
1989	275 600	110 650	203 300	18 380	609 919
1995					
Definite	7320	90 482	170 837	2760	286 234
Probable	81 657	16 707	16 402	1376	101 297
Possible	128 648	19 999	18 983	5035	155 944
Speculative	7594	1084	21 825	5554	36 057
Total	225 219	128 272	228 047	14 725	617 264
1998					
Definite	7322	83 770	196 845	2489	301 773
Probable	27 104	22 698	17 057	644	56 196
Possible	27 613	17 216	22 623	6228	60 780
Speculative	63 469	1495	190	3442	68 596
Total	125 508	125 179	236 715	12 803	521 809
2002					
Definite	16 450	117 716	246 592	5458	402 067
Probable	32 263	17 702	23 722	1188	59 024
Possible	64 477	22 511	26 098	3039	99 813
Speculative	82 563	5738	7508	3498	99 307
Total	195 753	163 667	303 920	13,183	676 523

Notes: Sources: 1989 data – ITRG (1989); 1995 data – Said et al. (1995); 1998 data – Barnes et al. (1999); 2002 data – Blanc et al. (2003). Totals may not sum due to the method used to develop population estimates. A list of countries included in each region is available in each of the cited documents.

Since illegal ivory appeared to cross African range state borders with impunity, public confidence in Appendix II controls failed and, in 1989, the elephant was moved to Appendix I status despite a population of around 600 000 (Table 1), well above that normally needed to ensure survival.

Zimbabwe, Namibia, Botswana, Malawi and South Africa have generally opposed the Appendix I listing because they have relatively large elephant stocks, and elephants have become a nuisance in some parks. These countries lobbied unsuccessfully in the early 1990s to down-list their populations and re-open limited trade in ivory. Nonetheless, lobbying eventually resulted in a decision in June 1997 to permit Botswana, Namibia and Zimbabwe to sell off nearly 50 ton of stockpiled ivory on a one-time basis. This constituted less than 60% of the ivory that they had accumulated as a result of confiscations from poachers, natural mortality, culling and destruction of problem animals. The ivory was sold to Japan in 1999 at a price of US$103/kg. In 2002, another one-off sale of 60 ton by Botswana, Namibia and South Africa was approved, but appears not yet to have been completed. These one-off sales have re-opened debates about the role of trade and sustainable management of elephants.

The ivory trade ban remains controversial. Critics allege that a trade ban generates perverse incentives that endanger species. Banning trade makes elephant conservation a less attractive activity, inadvertently promoting conversion of elephant habitat to other uses. By reducing or eliminating revenues from elephant management and exploitation, a trade ban might undermine the incentive to enforce property rights to elephants (or their habitat) and to manage stocks carefully (Bulte et al., 2003). Conversely, supporters of the trade ban argue that enforcing property rights and sustainable harvesting regimes in semi-open access habitats is difficult and expensive. Hence, legal trade may stimulate illegal harvesting and facilitate the laundering of illegal ivory products.

Population data suggest that the ivory trade ban has had some success. The rapid decline in elephant abundance appears to have been halted, although the underlying data for any such conclusion are not very good. Estimates of elephant populations are contentious at best; few reliable estimates are available before 1989, with later estimates categorized as 'definite', 'probable', 'possible' or 'speculative' (Table 1). Further, the area surveyed has varied, being lowest for the 1998 estimates. Thus, population trends are indicative only.

The purpose of this paper is to investigate the potential effects of an ivory trade ban on elephant stocks compared to the situation where trade is permitted. As long as economic rents from exploitation remain in place (so marginal benefits of harvesting elephants and marketing ivory exceed marginal costs), a trade ban is unable to prevent all international sales of ivory. International poaching gangs will be able to capture some of the rent by marketing ivory, but marketing costs will likely be higher than with legal trade, while demand will be reduced because potential buyers may have a stigma against purchases of ivory (Fischer, 2004). Under legal trade, the marginal costs of providing ivory will be lower and the stigma factor will disappear as buyers assume that elephant populations are being managed sustainably.

A dynamic bioeconomic mathematical programming model of ivory trade with four African exporting regions and one global importing region is developed to examine the issue in more detail. Africa is divided into regions based on the size of their elephant populations, the institutional and biological challenges to protecting elephant stocks, the extent of poaching and the importance of elephants in attracting tourists. The model is used to study the impacts of various institutional arrangements on elephant numbers. For example, if property rights to elephants and habitat can be clearly defined, African countries might be able to form a cartel that leads them to increase their holdings of elephants, while providing revenues to prevent poaching. Further, conservation payments from rich countries to range states or recognition by African states that elephants provide important tourism benefits might lead to the protection of elephants even with trade. These possibilities are investigated in the bioeconomic trade model.

2. Methods

2.1. A static model of ivory trade

We begin with a static spatial price equilibrium trade model (Fig. 1). Africa is the international source of ivory, as products from Asian elephants (*Elephas maximus*) are assumed to be sold only within the countries in which they are found and (illegally) harvested. Since the domestic African market is small with any worked ivory simply sold or smuggled abroad, ivory trade is assumed to take place between Africa as the excess supplier and the rest of the world. The African excess supply functions are denoted by S (Fig. 1), while the international excess demand for ivory (denoted *D*) is the demand left over after ivory supply from Asian elephants is taken into account.The excess supply function under free trade ($S^{\text{legal+illegal}}_{\text{Trade}}$) equals the horizontal sum of the legal ($S^{\text{legal}}_{\text{Trade}}$) and illegal ($S^{\text{illegal}}_{\text{Trade}}$) excess supply functions. Under free trade, amount q^* is traded at price P^*. Because of poached ivory, market equilibrium occurs at point v rather than point u with $q^*–q^L$ amount of illegal African ivory sold internationally (Fig. 1). The global benefits of ivory trade are given by the sum of the consumer and producer surpluses – area kvP^* under the demand function D_{Trade}, plus area xzP^* above the $S^{\text{legal}}_{\text{Trade}}$ function. The surplus associated with the poachers' supply curve, $S^{\text{illegal}}_{\text{Trade}}$, is lost due to open access elephant harvests.

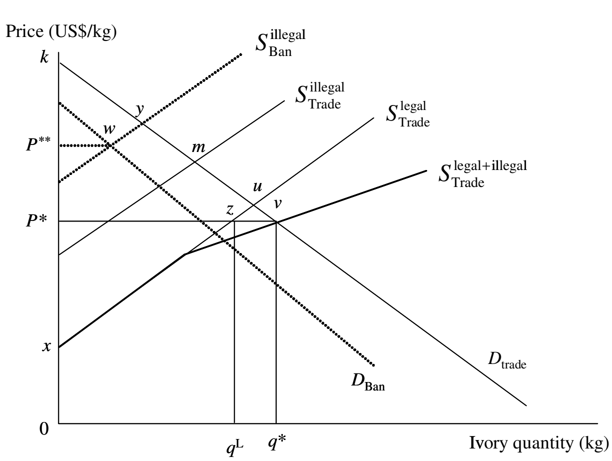

Fig. 1 – International ivory market under free trade and trade ban.

Poached ivory masquerades as legal ivory when there is free trade. But a trade ban does not halt trade in ivory, although it (1) shifts the poachers' supply function upwards to $S^{\text{illegal}}_{\text{Ban}}$ as the transaction costs of marketing ivory increase because costs of finding buyers and avoiding ban-imposed custom controls rise and (2) shifts the (excess) demand function inwards (from D_{Trade} to D_{Ban}) because the trade ban creates a stigma associated with the purchase of things made from ivory (Fischer, 2004). Under a trade ban, competitive equilibrium occurs at w, although it would occur at y if there were no stigma effect or m if there were also no added marketing costs for poachers. What worries many environmental groups is that removal of trade restrictions will reduce the stigma of buying ivory and facilitate marketing of ivory, implying greater elephant harvests (at equilibrium v rather than w).

An alternative to a trade ban is an effective quota, with quota trading used to allocate harvests efficiently – a cartel solution. The quota causes the legal supply curve to become vertical at the quota amount, although illegal marketing will continue unless halted by adequate enforcement (see van Kooten, 2006). A quota scheme creates revenues that could be used to finance monitoring and enforcement.

Tusks enter storage if they were confiscated from poachers or obtained from animals that died of natural causes or were culled. Since ivory has value and there are costs to wildlife programs, states with significant quantities of stored ivory will lobby to sell stocks, which is why CITES has permitted some one-off sales. The existence of stocks complicates the static model (Fig. 1). Along with the fact that elephants grow and reproduce, an analysis that includes ivory stocks is necessarily dynamic (since the user costs of current harvests on future populations and harvests must be taken into account). Hence, we construct a dynamic trade model. Finally, such a model needs to consider the non-market component of ivory trade, namely, the elephant's role as a flagship species for attracting tourists and the willingness of the international community to pay to protect elephants.

2.2. A dynamic bioeconomic model of ivory trade

Consider an idealized dynamic bioeconomic model in which the net benefits from ivory trade and elephant conservation are maximized over time. There is one net consuming region and *N* regions that 'produce' elephants and market ivory. Elephant poaching and the elephant's role in attracting tourists are taken into account as are payments from rich countries to range states for elephant conservation. The model is modified to examine the failure of conservation payments, the potential of a cartel and the effects of an ivory trade ban.

It is assumed that countries (but not poachers) can store ivory, which they will do under free trade as long as the expected increase in price exceeds the costs of holding stocks. Under a trade ban, stock holding is non-voluntary. Governments could threaten to release stockpiled ivory which might drive prices low enough to stop poaching, or it might be possible for a malicious agent to hoard sufficient ivory to make it worth their while to drive elephants to extinction (see Kremer and Morcom, 2000; Bulte et al., 2001). While theoretically plausible, hoarding turns out to be unattractive for realistic parameterizations of theoretical models, while extinction of elephants dominates conservation in most modeled scenarios.

The objective in our model is to maximize the discounted net benefits to African range states of managing elephant herds and selling ivory over some planning horizon. Benefits are given by the producer surplus from marketing and selling ivory minus the costs of ivory storage, elephant harvest costs and the negative externality costs elephants impose on the ecosystem. Additional benefits come from tourism and conservation payments from developed countries to range states for the preservation of elephants. The objective function is written as

$$\underset{q_{j,t},h_{j,t}}{\text{Max}} \sum_{t=1}^{T} \beta^t \sum_{j=1}^{N} \left[q_{j,t} p^d(I, Q_t) - \int_0^{q_{j,t}} c(I, a)\,da + R(x_{j,t}) + M'(x_t)x_{j,t} - kh_{j,t} - sS_{j,t} - \delta x_{j,t} \right]. \quad (1)$$

Here, $q_{j,t}$ is the quantity of ivory at time t made available for sale on the international market by region j; $p^d(I, Q_t)$ is the inverse (excess) demand function for ivory; I is an indicator variable set equal to 1 when trade is prohibited and 0 otherwise; and $c(I, a)$, where a is an integration variable, is the marginal cost function associated with the production and marketing of ivory once elephants (denoted by x) have been harvested (denoted h). Thus, the first two terms in expression (1) constitute the quasi-rent accruing to ivory sellers. Notice that it is necessary to subtract from quasi-rent the costs of harvesting elephants and other opportunity costs taken into account by the other terms in (1). In expression (1), k is the per unit cost of harvesting animals and s is a fixed cost of holding ivory stocks (S). The cost of harvesting elephants is not density-dependent as elephants are quite large and assumed to be easily tracked.

Given the importance of elephants in attracting tourists, which is of greater relevance in some regions of Africa than others, $R(x_{j,t})$ is a function linking elephant numbers to a region's tourism benefits. On the other hand, $M'(x_t)$ represents the marginal willingness to pay (WTP) or marginal monetary transfer from those in developed countries (e.g., North America, Europe) to African range states for the (in situ) conservation of elephants at time t, with $x_t = \sum_{j=1}^{N} x_{j,t}$. While positive, the marginal monetary transfer $M'(x_t)$ is non-increasing as elephant populations rise. Although the amount of the transfer to any region depends on the elephants in that region, as evidenced by the term $M'(x_t)x_{j,t}$, citizens outside Africa are not concerned about the specific locations of elephant herds, so that $M'(\cdot)$ is a function of the total number of elephants on the continent, x_t. Finally, δ is a measure of the damage that each elephant imposes on the ecosystem and $\beta = 1/(1 + r)$, where r is the social rate of discount, is used to discount future returns.

Specification (1) assumes that a single decision maker chooses the optimal numbers of elephants to harvest in, and ivory to sell from, each region in each period over the planning horizon. The decision maker is assumed to exhibit rational expectations, taking into account the effect that current harvests and ivory sales have on future prices and elephant/ivory stocks. These assumptions are typical of economic models and represent a 'best' case where agents act rationally. We assume that the decision maker maximizes African wellbeing, but one could just as well have the decision maker optimize global welfare, in which case the sum of consumer plus producer surpluses would be maximized rather than just the producer surplus (or quasi-rent). A global decision maker would take into account the surplus accruing to consumers of ivory products, thus selling more ivory and harvesting more animals. Therefore, because the optimal population of elephants to conserve is slightly higher for the African as opposed to global perspective, we take the African perspective.

Given elephant poaching and illegal ivory sales, range states are assumed to take into account poached supply, but the rents accruing to poachers are ignored in decisions concerning the management of elephant stocks. We denote the harvest of elephants by poachers in region j at time t by $h^p_{j,t}$. It is assumed that ivory from poached elephants is marketed in the same period elephants are killed, minus ivory that is confiscated. Thus, the amount of illegal ivory sold by region j at time t is given as $q^p_{j,t} = \gamma(1-\xi)h^p_{j,t}$, where γ is a parameter that converts elephants to ivory and ξ is the rate at which illegal elephants/ivory are confiscated. The confiscation parameter ξ is assumed to be constant as a result of fixed-cost, anti-poaching programs. Range states can increase confiscations by spending more on anti-poaching effort, but such effort is taken as exogenous in the current model.

At any time, the stock of ivory in a given region, $S_{j,t}$, will depend on the stock in the preceding period plus additions to the stock minus any sales of ivory. As already noted, stocks of ivory are held only by range states. States harvest elephants to eliminate troublesome animals, cull animals because there are too many for the particular ecosystem or harvest elephants for the purpose of selling their ivory. In addition, they obtain ivory incidentally due to natural mortality and confiscations from poachers. The stock dynamics are given by

$$S_{j,t+1} = S_{j,t} + \gamma(h_{j,t} + \xi h^p_{j,t}) - q_{j,t} \quad \forall j, t = 1, \ldots, T-1 \quad \text{(ivory stock holding dynamics)}, \quad (2)$$

where γ converts elephants to ivory (as noted above). Countries can sell ivory or hold it until a later period, but sales of ivory cannot exceed available stocks in any period,

$$q_{j,t} \leqslant S_{j,t} \quad \forall j, t \quad \text{(sales of legal ivory cannot exceed available stock)}. \quad (3)$$

A similar constraint must be imposed on sales of poached ivory, except that any ivory not sold by poachers in a given year is assumed to be lost (presumably an additional cost of doing 'business'). For clarity, we express this constraint as

$$q^p_{j,t} \leqslant \gamma(1-\xi)h^p_{j,t} \quad \forall j, t \quad \text{(sales of illegal ivory cannot exceed that from poached elephants minus confiscations)} \quad (4)$$

Given the assumption underlying constraint (4), this implies that illegal sellers have some notion of the price of ivory on global markets.

The growth and harvest of elephant populations is given by

$$x_{j,t+1} - x_{j,t} = g(x_{j,t}) - h_{j,t} - h^p_{j,t} \quad \forall t, t = 1, \ldots, T-1$$
$$\text{(elephant population dynamics)}, \tag{5}$$

where $g(x_{j,t})$ is the elephant growth function that is discussed further below.Three additional constraints need to be included in the mathematical formulation:

$$Q_t = \sum_{j=1}^{N}(q_{j,t} + q^p_{j,t}) \quad \forall t \qquad \text{(adding up)}. \tag{6}$$

For each region, opening stocks of ivory and elephants need to be identified,

$$S_{j,0} = \bar{S}_j, x_{j,0} = \bar{x}_j \quad \forall j \qquad \text{(initial conditions)}. \tag{7}$$

Finally, non-negativity constraints need to be imposed,

$$q_{j,t}, q^p_{j,t}, S_{j,t}, x_{j,t}, h_{j,t}, h^p_{j,t} \geqslant 0 \quad \forall j, t \qquad \text{(non-negativity)}. \tag{8}$$

The dynamic bioeconomic model constitutes a mathematical programming model where objective function (1) is solved subject to constraints (2)–(8). It can be used to investigate the effects of poaching and different institutional arrangements on elephant conservation, thereby providing insights as to which policies might be most effective in protecting elephants. In particular, by setting $I = 0$ (no ivory trade ban) and $h^p = 0$ (no illegal elephant harvests), the preceding mathematical program can be used to examine the consequences for elephant conservation of an African continent with developed-country institutions that prevent poaching and enable free trade. This can be contrasted to the real-world case where elephant poaching and illegal ivory sales occur.

2.3. Model extensions

An assumption in objective function (1) is that monetary transfers from rich countries to range states for elephant conservation are possible. These types of payments have been promoted by agencies such as the CITES Secretariat (Bulte et al., 2003). While monetary transfers are rarely if ever made, how they occur is nonetheless important. We rule out lump-sum transfers based on rich countries' total willingness to pay, for example, as these do not directly and explicitly link monetary payments to elephant conservation. Monetary transfers need to be based on marginal WTP, $M'(x_t)$, as in the objective function (1). The only problem is that, because they face a downward sloping marginal money transfer function, range states can maximize revenue from conservation payments by reducing elephant stocks (in the same way that a monopoly firm sells less than a perfectly competitive one in order to gain a higher price and thereby maximize revenue). To avoid this, rich countries could simply pay range states a fixed amount per elephant – so that $M'(x) = M^0 \geqslant 0$, where M^0 is a constant that would equal zero if no conservation payments are made.

If range states recognize that the benefits they gain from tourism are directly tied to elephant numbers, then tourism benefits, given by $R(x_{j,t})$, have the same kind of impact on elephant conservation as monetary transfers from rich countries. As noted earlier, the only difference is that, while rich countries do not care where elephants are protected, range states are keen to protect elephants in their own jurisdiction as tourism benefits accrue locally and not in other states. We investigate the impact that recognition of tourism benefits has on elephant conservation, and compare this with the impact of monetary transfers.

We also examine what would happen if African range states could form an ivory cartel, maximizing their overall wellbeing from sales of ivory while somehow allocating elephant harvests and ivory exports in a manner acceptable to all countries. In that case, an efficiency condition needs to be added to the constraints in the mathematical programming model. It requires that marginal costs of harvesting elephants and marketing ivory in each region equal or exceed overall marginal revenue,

$$c(0, q_{j,t}) + \frac{k(0)}{\gamma} \geqslant Q_t \frac{\partial p^d(0, Q_t)}{\partial Q_t} + p^d(0, Q) \quad \forall j, t$$
$$\text{(marginality condition} : MC_j \geqslant MR). \tag{9}$$

Damage from elephants is ignored in this marginality condition, but not the marginal cost of harvesting elephants. The cartel determines how much ivory is sold on the market in each period from each of the N regions, as well as how many elephants to harvest in each region.

Finally, we consider the case of the ivory trade ban ($I = 1$). In order to study the effect on elephant herds in the various African regions, we need to take the perspective of the criminal gangs. To implement this aspect of the model, it is necessary to assume that poachers somehow maximize quasi-rents from marketing ivory, and that rents are not dissipated via open access. However, we assume that poachers do not form a cartel. If they were somehow able to exert market power, less ivory will be sold than under the assumptions below and fewer elephants will be killed. The trade ban case considered here might be regarded as an intermediate-case, trade-ban scenario – intermediate between the worst case of open access and a poaching-cartel outcome.

The forgoing mathematical program is modified in this case so that there are no legal sales of ivory or elephant harvests, and the objective function (1) is replaced by

$$\underset{q^p_{j,t}, h^p_{j,t}}{Max} \sum_{t=1}^{T} \beta^t \sum_{j=1}^{N} \left[q^p_{j,t} p^d(1, Q_t) - \int_0^{q^p_{j,t}} f_j(1, a) da - \kappa h^p_{j,t} \right], \tag{10}$$

where $f_j(\cdot)$ is the poachers' marginal cost of marketing ivory from region j and κ is their cost of harvesting elephants under a trade ban. In this case, elephants are not truly an open access resource, but a derived demand. All of the forgoing constraints (2)–(8) remain in place (but with $q_{j,t} = h_{j,t} = 0$), although the ivory stock holding equation (2) is needed only to keep track of how much ivory range states will be required to hold involuntarily over time. While only governments are assumed to store ivory, future research might be able to separate illegal and legal stock holding, thereby enabling criminals to hold ivory stocks as a hedge against unforeseen future price changes, for example.

2.4. Data and model parameterization

Given lack of quality data, parameterization of the model is particularly challenging. It is discussed in greater detail in van Kooten (2006), with a summary provided below.

Fischer (2004) reports that raw ivory was trading for about \$150/kg in the pre-ban period, with price peaking at over \$1200/kg shortly after the ban's imposition and then settling at some \$450/kg thereafter. The only information about quantities traded pertains to reported seizures of ivory and data on ivory carving (Table 2). The first year for which seizures are reported is 1989, the year of the trade ban; the average number of annual seizures of illegal elephant products increased by 120% after 1989, but there is no real discernable trend in seizures afterwards. Hunter et al. (2004) use observations on ivory carvers in various regions of Africa and Asia to estimate that between 6433 and 16 185 African elephants (123–349 Asian elephants) are still supplied illegally to the market each year. This implies that 44.4–111.7 ton of illegal ivory from African elephants still enter the market annually, or about one-tenth of what was marketed (legally and illegally) under free trade. Using this information, the following excess demand function was constructed:

$$p^d(I = 0) = 720 - 0.0005q. \quad (11)$$

According to (11), at a real pre-ban price of \$150/kg, some 1140 ton of ivory would be traded. What then would be sold under a trade ban assuming the demand curve changes due to a stigma effect? If the pre-ban demand function (11) continued to describe the situation, the market price of ivory would be \$664–\$698/kg. As it is reported to be nearer \$450/kg, we assume that the intercept on the post-ban excess demand curve has shifted down by approximately this difference so that the trade-ban excess demand function can be written as

$$p^d(I = 1) = 500 - 0.0005q. \quad (12)$$

At a price of \$450/kg, only 100 ton of African ivory would be sold internationally, well within the range estimated by Hunter et al. (2004).

On the supply side, Africa is divided into four regions that represent different elephant economics and elephant subspecies – the savanna elephant (*Laxodonta africana africana*) and the forest elephant (*Laxodonta africana cyclotis*). The forest elephant is difficult to view and is found primarily in West and Central Africa (Table 1). The savanna elephant is an important flagship species for the tourism industry, but it threatens the ecosystem carrying capacity in Southern Africa. Van Kooten (2006) developed the intercept and slope parameters for the legal and illegal supply (marginal cost) functions (Table 3).

To describe the fecundity, mortality and growth characteristics of elephants, we specify the following linear function:

$$x_{j,t+1} = (1 + g)x_{j,t}, \quad \text{with } x_{j,t} \leqslant K_j \qquad \forall j, t, \quad (13)$$

where g is the growth rate in elephant stocks and K_j is the elephant carrying capacity in region j. We set g = 0.067 (Millner-Gulland and Leader-Williams, 1992) and initial elephant populations equal to the 2002 regional totals (Table 1). The carrying capacity of each region is determined from information about elephant range and the proportion of range that is protected. For the forest elephant, it is assumed that unprotected range has a carrying capacity of 0.15 elephants/km^2, while it is 0.25 elephants/km^2 for protected range. The carrying capacity for savanna elephants is assumed to be 0.20/km^2 for unprotected and 0.35 for protected range (Table 4). The estimated continental carrying capacity of about 974 000 elephants (Table 4) is lower than numbers existing in the early 1970s (some 1.2 million), but elephant range has also decreased significantly due to human encroachment.

Milliken (1997) estimates that there are some 462.5 ton of verifiable and legitimately held stocks of ivory in Africa, and another 243 ton of undeclared (perhaps illegal) ivory, or a total of 705.5 ton. These values can be updated (Table 4). A constant rate of confiscations of 5% is assumed, so $\xi = 0.05$. The costs of holding ivory stocks consist of the forgone opportunity cost (given by the discount rate) and a physical cost of holding ivory, taken to be s = \$0.50/kg each period. Millner-Gulland and Leader-Williams (1992) estimate poaching costs to be about \$180 (=κ)/elephant; legal harvesting costs are assumed to be one-third this amount (k = 60).

Table 2 – Seizures of elephant products and demand for poached elephants by region[a]

Region	Seizures of elephant products (average per year)[b]		Number of ivory carvers[c]	Estimated number of elephants poached per year[c]	
	1989	1990–2003		Minimum	Maximum
Africa	112	140.9	627	4648	11 710
Central Africa	0	2.0	198	1770	4453
East Africa	34	36.4	35	216	545
Southern Africa	70	98.9	132	841	2122
West Africa	8	1.0	152	1119	2821
Asia[d]	6	59.5	379 (655)	1785 (123)	4475 (349)
Europe	169	206.9	n.a.	n.a.	n.a.
North America	0	206.6	n.a.	n.a.	n.a.
Oceania	10	35.4	n.a.	n.a.	n.a.

a Central and South America and other regions are excluded because seizures reported to ETIS were insignificant; n.a. indicates not applicable, not known or not provided.
b *Source:* Calculated from data in Milliken et al. (2004). Year 2004 data are omitted because not all information was available at the time this table was constructed.
c *Source:* Hunter et al. (2004).
d Carvers working with ivory originating from Africa are indicated with those using Asian elephant products provided in parentheses; annual number of African elephants required, with Asian elephants in parentheses.

Table 3 – Postulated regional ivory supply functions: legal and illegal

Region	With ivory trade						Under trade ban		
	Legal supply			Illegal supply			Illegal supply		
	% of market	Intercept	Slope	% of Market	Intercept	Slope	% of market	Intercept	Slope
Central	25	30	0.00054	60	45	0.00070	60	60	0.00650
East	20	10	0.00079	15	35	0.00307	15	45	0.02700
Southern	50	50	0.00022	20	75	0.00150	20	85	0.01825
West	5	20	0.00292	5	35	0.00920	5	45	0.08100

Table 4 – Importance of African elephant range by region

Item	Central Africa	East Africa	Southern Africa	West Africa	Continent
1. Total area (km^2)	5 365 550	6 182 037	5 973 020	5 096 660	22 617 267
2. Elephant range area (km^2)	2 060 763	969 113	1 680 130	219 868	4 929 874
3. Range as % of total	38%	16%	28%	4%	22%
4. % of total area protected	5%	4%	4%	2%	8%
5. % of range in protected area	12%	24%	13%	40%	16%
6. Elephants per km^2 of range	0.095	0.169	0.181	0.060	0.137
7. Average carrying capacity	0.162	0.236	0.220	0.190	0.198
8. Elephant carrying capacity	333 844	228 711	369 629	41 775	973 959
9. Ivory stocks in 1996 (kg)	204 138	170 677	316 938	13 747	705 500
10. Confiscated ivory (kg)	16	291	791	8	1106
11. Total ivory stocks (kg)	204 154	170 968	317 729	13 755	706 606
12. Assumed ivory stocks (kg)	250 000	200 000	400 000	50 000	900 000

Notes: Source for rows 1–5: Blanc et al. (2003); *rows 6–12*: own calculation. Values in row 7 assume that for forest elephants (Central and West Africa) carrying capacity is 0.15 elephants/km^2 in unprotected range and 0.25/km^2 in protected range. For savanna elephants (East and Southern Africa), capacities are assumed to be 0.2 for unprotected and 0.35 for protected range. Numbers in row 9 represent the allocation of total ivory stocks at the end of 1996 in proportion to each region's elephant numbers. Row 10 represents estimated confiscations of ivory per year multiplied by eight years (assuming approximately 0.5 kg/seizure but doubling that to take account of culls, killing of nuisance animals, etc.). Row 11 is the sum of rows 9 and 10. Row 12 constitutes the assumed levels of ivory stocks in each region for initializing the model.

Average tusk weight has dropped significantly since 1970, probably because older animals with larger tusks were killed first, so current stocks of elephants tend to be much younger. Scully (2002, p. 123) points out that it took 55 elephants to obtain 1 ton of ivory in 1979, compared to 113 elephants around 1990 – a decline from 18.18 to 8.85 kg/animal. Not only is tusk size and elephant age declining, but more are born without tusks. The average number of tusks per African elephant is 1.88, and we assume γ = 7.5 kg of ivory per elephant. Bulte and van Kooten (1996) assume that elephants impose a constant cost (δ = $165) on the ecosystem determined by the amount of forage that an elephant consumes annually.

The elephant is considered a charismatic flagship species for tourism in East and Southern Africa. The estimated gain to Kenya from wildlife tourism in 1995 was $45 million (Earnshaw and Emerton, 2000; Bulte et al., 2001). If this is more than tripled to $150 million, then, based on 150 000 elephants in East Africa and assuming marginal benefits are zero at the extant population, the linear marginal tourism benefit function is calculated as follows: Let m be the vertical intercept of $R'(x)$. Then, based on the formula for the area of a triangle, m = (assumed total tourist-related benefits)/(½ × elephant population). The slope of $R'(x)$ is simply the negative of m divided by the elephant population. Thus, $R'(x) = 2000–0.0133x$ for East Africa. Van Kooten (2006) derives the marginal benefits for other regions as: $R'(x) = 1680–0.0056x$ for Southern Africa; $R'(x) = 200–0.0010x$ for Central Africa and $R'(x) = 267–0.0178x$ for West Africa.

Lastly, it is necessary to determine the benefits from conserving elephants. These benefits accrue primarily to people in developed countries and represent their annual WTP to preserve African elephants. Assume that the marginal WTP function is linear, $M'(x) = a–bx$, and that people are unwilling to pay to preserve elephants beyond extant numbers. Consider two cases that are labeled 'Lo' and 'Hi' according to the amount households are willing to pay each year for elephant conservation. Use the same method of calculation as described in the previous paragraph. Then, for the 'Lo' scenario assume a = 3600, b = 0.0053, so that, for the current stock of 676 500 elephants, M = $1222.6 million with each of 200 million households in North America and Europe contributing some $6.11/year; and, for the 'Hi' scenario, assume a = 5400, b = 0.0079, so that M = $1845.4 million with each household paying $9.23/year. For these values, marginal WTP intersects the abscissa at 679 945 elephants for the 'Lo' scenario and 683 44 for the 'Hi' scenario.

As noted earlier, if the marginal WTP schedule is downward sloping so that less is paid for each elephant as more are protected, range states will reduce their elephant herds to maximize the monetary transfer. As an alternative, therefore, we assume that rich countries provide fixed transfers of $175 and $260/animal in the 'Lo' and 'Hi' scenarios, respectively. These payments constitute about 10% of total willingness to pay.

3. Results

The outcomes of different strategies are examined using a series of mathematical programs coded in GAMS and solved using the CPLEX quadratic programming solver (Brooke et al., 2005). The simulations are for 200 years, although data are reported only for 50 years. This is done to eliminate the 'end-point effect': it is optimal to harvest the entire stock of animals in the last several periods if they have no value beyond the end of the planning horizon. Model details are given in van Kooten (2006). Given the richness of the model, only a limited number of scenarios and variables are explored here. Since the major concern is the conservation of elephants in the wild, the focus is on animal numbers.

3.1. *Free trade in ivory*

Consider the case of free trade and, to avoid confusion between monetary transfers and tourism benefits, initially exclude conservation payments. For comparison purposes, consider first a world where range states have economic institutions (not to be confused with developed country preferences) similar to those of developed countries so that poaching is not a problem. Would developed-country institutions that eliminate poaching benefit the African elephant? A comparison of optimal elephant stocks, harvests and sales of ivory under free trade with and without poaching for discount rates of 5% and 20% (with inclusion of tourism benefits, but not monetary transfers) is provided (Fig. 2). For both discount rates, if there are no poachers, range states maximize wellbeing by immediately drawing down elephant herds to get onto the optimal dynamic path. For a 5% discount rate, optimal stocks are slightly higher under free trade with poaching than without poaching, although the difference is very small and the two paths eventually converge (Fig. 2a). The optimal elephant stock is just under 550 000 elephants. At a discount rate of 20%, the optimal population falls to 300 000 or less, with the optimal stock now lower in the case of poaching by about 40 000.

When poachers are present, states take into account sales of illegal ivory by reducing legal harvests to such an extent that illegal harvests nearly replace all state-sanctioned harvests, which fall to zero regardless of the discount rate, although sales of legal ivory from stockpiles continue (Fig. 2b and c). Total harvests are nearly the same whether poachers are present or not, although harvests in the 5% scenario are higher than those in the 20% scenario (not shown), mainly because high harvest levels early on in the high-discount rate scenario (as future harvests are worth less) lead to fewer harvests in later periods as elephant stocks have been depleted. Note the spike in legal and illegal harvests around the 10th and 12th periods, respectively, for the no poaching and poaching cases (Fig. 2b). This is due to the rapid depletion of ivory stocks, which fall to nearly zero in the case of poaching and approach zero in the longer run if there is no poaching (Fig. 2c).

Surprisingly, poaching seems to have little impact. In the absence of poaching, optimal elephant numbers will be only

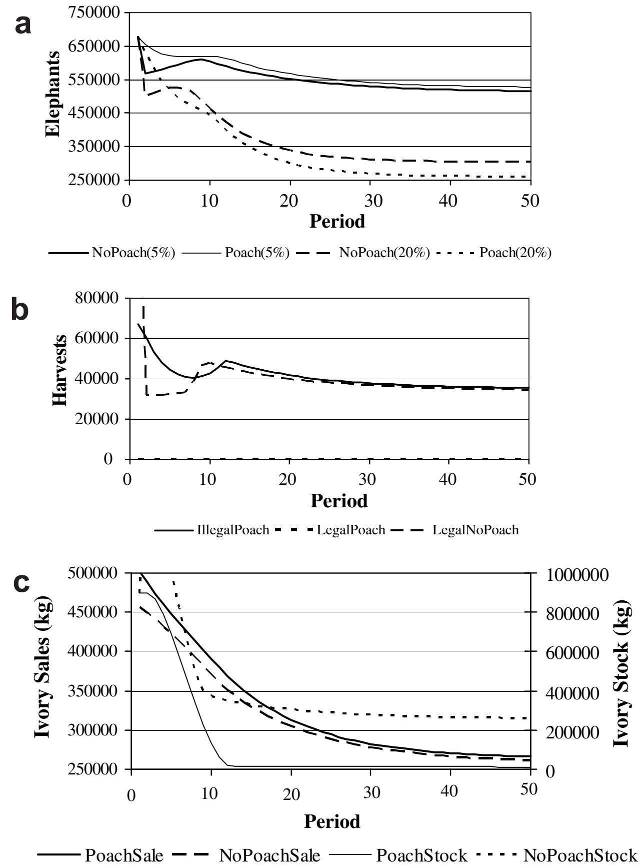

Fig. 2 – In this simulation of ivory trade, range states take into account the tourism benefits elephants provide as a flagship species, but there are no monetary transfers from rich countries. A comparison is made between the case where poaching occurs and where it is effectively prevented, and discount rates of 5% and 20% are compared. (a) Optimal elephant populations under trade, with tourism benefits, no conservation payments, 5% and 20% discount rates, with and without poaching: NoPoach refers to the case where poaching is prevented, while Poach refers to free trade but with poaching taking place. Discount rates for scenarios are given in parentheses. (b) Legal and illegal elephant harvests under trade, with tourism benefits, no conservation payments, 5% discount rate, with and without poaching: IllegalPoach refers to harvests by poachers, LegalPoach refers to the nearly negligible legal harvests when poachers are present, and LegalNoPoach refers to legal harvests when poaching is prevented. (c) Ivory stocks and ivory sales under trade, with tourism benefits, no conservation payments, 5% discount rate, with and without poaching: ivory stocks and ivory sales when poaching occurs (Poach) and when it does not occur (NoPoach) for a 5% discount rate only.

very slightly higher than when poachers are present. The key factor is earnings related to in situ stocks. Because tourism benefits are significant, range states simply adjust to the activities of poachers. In the first few years of free trade, range states sell off as much of their stockpiled ivory as is optimal, reducing stocks to nearly zero in 10–12 years, depending on whether the respective cost of holding stocks is low (s = \$0.50/kg) or high (\$5/kg). Once stocks have been reduced, legal ivory is occasionally sold as range states participate in the market only to sell off any ivory stocks they may have accumulated as a result of confiscations, but rarely kill elephants for that purpose. Almost all ivory sold internationally comes from illegal harvests. Range states only lose to poachers the surplus associated with the sale of ivory, but, by accommodating poachers and essentially eliminating legal harvests, they more than make up for this loss through tourism benefits.

Under free trade and in the absence of states' recognition of the contribution elephants make to tourism (or monetary transfers from rich countries), there is a 'race to the bottom' as it is optimal to drive the elephant to extinction (Fig. 3). While it takes some 40 years for the elephant to disappear at a discount rate of 5% (Fig. 3), it takes less than 10 years if the discount rate is 20% (not shown). Given that real rates of discount in developing countries tend to be high (perhaps 20% or higher), this result provides strong support for the possibility that elephant populations declined by half during the 1980s and that the ivory trade ban prevented the total demise of the species.

3.1.1. *Tourism benefits versus conservation payments*

Although not shown here, if countries receive payments for preserving elephants and take into account the tourism benefits that elephants provide, the effect of poaching on elephant numbers is nearly insignificant. In the absence of tourism benefits, conservation payments can prevent elephants from going extinct. As the simulation results (Fig. 3) indicate, to protect the elephant it really does not matter whether it takes payments by rich countries or recognition by range states that elephants contribute to tourism revenues. Rather, as long as a meaningful link is made between elephant numbers and their non-market value, it is optimal for countries to protect elephants and keep them from going extinct.

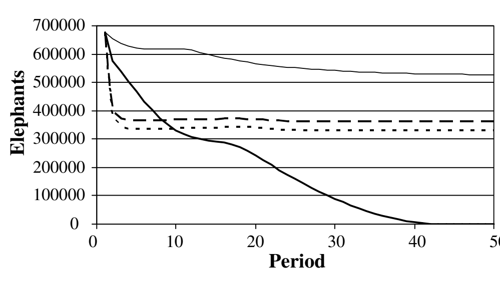

Fig. 3 – For a 5% discount rate, simulated elephant populations fall to zero in 40 years if neither tourism revenues nor conservation payments from rich countries occur. Populations stabilize quite quickly if 'Lo' conservation payments based on the marginal payment schedule (as opposed to a fixed payment per elephant) are provided by rich countries, but stabilize at a higher level if only tourism revenues are taken into account. Adding conservation payments to tourism benefits leads to lower stocks than if tourism revenues alone are considered, because countries reduce elephant herds to maximize the revenue from rich countries.

Interestingly, when conservation payments vary according to how many animals are in place, optimal stock levels are lower than when only tourism benefits are taken into account. The introduction of conservation payments actually reduces the optimal stock level (Fig. 3). Indeed, it is optimal for countries to reduce their stocks of elephants in the first several periods so as to increase the total transfer from rich countries (as the 'price' increase offsets the reduced numbers for which payment is made). This is more pronounced for a low as opposed to high discount rate (comparison not shown). This result holds because (some) range states recognize that they can influence the per animal conservation payment by manipulating elephant stocks. The alternative is for rich countries to provide a fixed conservation payment per elephant. A fixed conservation payment of \$175/elephant ('Lo' scenario) has an enormous impact on the optimal stock of elephants, generally raising it above that associated with a 'variable' payment based on ('Lo' scenario) marginal willingness to pay (Fig. 4).

Finally, taking into account in situ values does not guarantee that the elephant survives in all regions. The following scenario is provided (Fig. 5): 'Hi' conservation payments (\$260/elephant), recognition of tourism benefits and a low discount rate. In this case, it is optimal to allow the elephant to go extinct in Central and West Africa. Nonetheless, the good news is that extinction can be avoided and the elephant's long-term survival assured even when the future is heavily discounted, but only if non-market benefits are 'sufficiently large' and such benefits are actually tied to animal numbers (as occurs when states are paid for each animal conserved). In the absence of the 'non-market benefit effect', the crucial question is: Can an ivory cartel or a trade ban mitigate the species' demise?

3.1.2. *Ivory cartel*

It is assumed that, if range states can form an ivory cartel, they can also cooperate to eliminate poaching (perhaps using genetic coding to ensure that only 'approved' ivory enters the market). Further, since the formation of a cartel constitutes a signal that African range states are concerned only about their own wellbeing and are fully self reliant, conservation

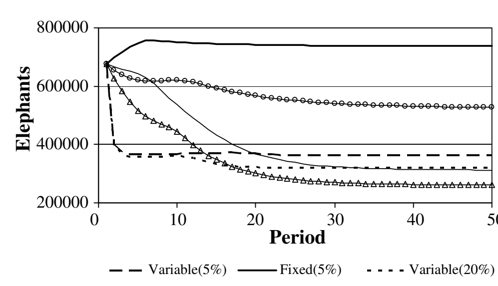

Fig. 4 – Elephant stocks are simulated for two differing ways of calculating the monetary transfer from rich countries for elephant conservation: (i) a 'Variable' payment per elephant determined from the 'Lo' marginal payment schedule and (ii) a 'Lo' 'Fixed' payment of \$175/elephant. The case of no payment ('None') is also included. Tourism benefits are included and discount rates of 5% and 20% are considered.

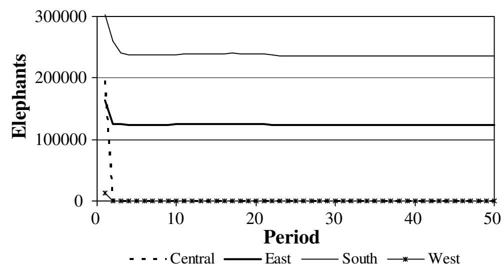

Fig. 5 – Simulated optimal elephant stocks for the four African regions when a 'Hi' marginal conservation payment scheme is employed, tourism benefits are included, and a 5% discount rate is used.

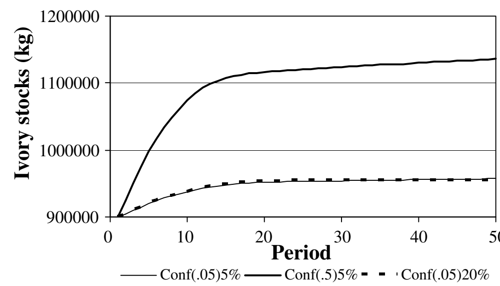

Fig. 6 – Simulated stockpiles of ivory under an ivory trade ban for confiscation rates of 5%, denoted 'Conf(.05)', and 50%, denoted 'Conf(.5)', and for discount rates of 5% and 20%.

payments from developed countries for in situ elephants are ignored. Under these assumptions, an ivory cartel does not ensure the elephant's survival. A cartel is only effective in protecting the elephant if tourism and/or conservation values are taken into account, suggesting there is little difference between the cartel and no cartel results.

3.2. *Ivory trade ban*

The simulation results indicate that a trade ban on ivory is unlikely to be successful in conserving the African elephant. Regardless of the discount rate used, poaching will cause the elephant to go extinct in less than 20 years (van Kooten, 2006), despite the fact that the demand curve has shifted inwards as a result of the so-called stigma effect. That is, as modeled here, the stigma effect brought about by the trade ban is not a sufficient condition for protecting the elephant. Indeed, for the extant parameters of the illegal, trade-ban supply functions, even an increase in the confiscation rate from 5% to 50% is unable to protect the elephant. This is clear from the rising stockpiles of ivory that occur in range states. These quickly come to an equilibrium (indicating extirpation of the elephant since stockpiled ivory cannot be sold), with the equilibrium higher when poaching gangs use a lower discount rate (which is unlikely) (Fig. 6). Not surprisingly, the confiscation rate is much more important than the discount rate.

While on-the-ground attempts to increase policing of poachers (through an increase in the confiscation rate) appear to have some effect, actions to control the international movement of ivory might be even more effective. Such policing would effectively raise the ivory marketing supply function so that it no longer intersects demand, or does so at extremely high ivory prices. In our model, we find that, by increasing the intercept terms on the illegal supply functions for the trade ban case (Table 3), it is possible to reduce trade and increase elephant populations, ceteris paribus. This needs to be investigated further, however, using data from CITES monitoring of ivory seizures by participating countries (Bulte et al., 2006). But monitoring of ivory seizures is not a sufficient condition; range states and international organizations must also be vigilant in enforcing a trade ban, or else it is unlikely to be effective.

Unless illegal harvesting is almost halted entirely, one problem with a trade ban remains; it leads to increasing stockpiles of ivory as a result of anti-poaching enforcement (confiscations) and culling of animals. Since range states are currently unable to sell these stocks without permission, stockpiles will rise: In the current simulations, legally-held ivory stockpiles could rise by between 5% and more than 20%. If the trade ban is effective, however, stockpiles could potentially rise much more in the long run. As a result, some range states will continue to agitate for continued sales of ivory and the existence of stockpiles is likely to continue to be a major irritant in international negotiations.

4. Discussion and conclusions

The forgoing analysis provides one very important conclusion: Unless the contribution of living elephants to the well-being of citizens in range states (via tourism revenues) or in rich countries (through their willingness to pay to ensure the existence of elephants now and in the future) is taken into account, the elephant is most likely to remain a species under threat of extinction. This is not enough, however. Range states must act upon the link between elephants and tourism benefits and/or citizens in rich countries must make effectual payments for elephant preservation. Any solution that involves payments to range states or a requirement on their part to increase monitoring and enforcement is bound to involve some risk. The reason is that African range states generally lack the institutions and governance structures that characterize developed countries (Bulte et al., 2003). Low incomes, lack of property rights, government corruption and other characteristics of these countries do not bode well for their ability to prevent further declines in elephant populations, as least not without the vigilance of developed countries and the aid of international agencies.

Given that in many (if not all) range states tourism benefits are unlikely to be realized, the role of non-African countries is clearly crucial. One option implemented by the international community (with the support of most African states) has been a trade ban. While the stigma and supply-side effects of a trade ban are important, their existence remains speculative. Research of a different kind than that reported here is required to determine if they are indeed real. If they are not real and/or organized gangs of poachers are able to mitigate increases in supply-side costs or even reduce them, the trade ban cannot be relied upon on its own (as evidenced by the results of this study). If tourism benefits are also not realized, monetary transfers tied to the numbers of elephants that range states conserve are required. The payment schedule will have a large impact on range states' optimal elephant numbers, and the subsequent effort that range states make in managing herds (Fig. 4). In the case of international transfer payments, it will be necessary to design an appropriate incentive scheme that does not enable states to reduce elephant numbers in order to maximize monetary transfer payments.

The results of our model are indicative only. Further research is certainly warranted to make the relations in the model more realistic. The demand function in the analysis is essentially static and should be a function of time, but it is not clear whether demand should be modeled as shifting outwards or inwards over time – whether on a global level increasing aversion to the killing of elephants outweighs other factors that might increase the demand for elephant products (e.g., increasing desire for bush meat). The relationship between the legal and illegal takings of elephants needs to be investigated in greater detail, as does the potential for a return to some form of quota system. Uncertainty is also a major problem. Not only are the relations developed in this paper fraught with uncertainty, but the data available to researchers are in many cases sparse and not very reliable. Methods that explicitly address uncertainty in model parameters (e.g., chance constrained or fuzzy programming) are one means of addressing uncertainty. These and other considerations certainly warrant further investigation in the context of this type of modeling exercise.

In some ways, the elephant is similar to the bison that once roamed the Great Plains of North America. Despite the emergence of institutional entrepreneurs who exploited the natural resources available on the frontier, the bison was doomed because the land was much more valuable in cattle than bison production, even if the bison could somehow be domesticated (Anderson and Hill, 2004, pp. 94–102). Likewise, elephant range in Africa is often a less valuable use of land than agriculture. Land in elephant habitat must somehow become more competitive if elephant populations are not about to decline even further in the future.

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