Elephant Economics in the Rough: Modelling Ivory Trade

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ABSTRACT

Trade in ivory is banned under CITES in an effort to protect the African elephant. The trade ban is supported by some range states, most notably Kenya, because they see the ban as an effective means for protecting a 'flagship' species, one that attracts tourists and foreign aid. It is opposed by some states, mainly in southern Africa, because their elephant populations are exceeding the capacity of local ecosystems with culling and other sources have resulted in the accumulation of large stocks of ivory. They argue that ivory trade will benefit elephant populations. The question of whether an ivory trade ban will protect elephant populations is addressed in this paper using a dynamic partial-equilibrium model that consists of four ivory exporting regions and a single demand region. Results indicate that a trade ban can be successful in maintaining elephant populations if the ban leads to a stigma effect that reduces demand and increases the marginal costs of marketing ivory. Surprisingly, elephant populations are projected to crash if range states can operate an effective quota scheme that even excludes poaching. However, free trade in ivory can be made to protect the elephant if western countries make effective side payments to range states based on in situ numbers of elephants.

Key Words: economics of elephant conservation; economics of ivory trade; trade bans; cartels and quota

I. BACKGROUND

Ivory has been a traded commodity 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 in ancient times and later by Arab traders and Europeans. ... Between 1890 and 1900, nearly 3.7 million kg of ivory were traded in the London market alone, ... and some 60,000 elephants reached European markets every year during that period" (Blanc et al. 2002, p.15). Ivory exports from Africa had increased by 400% between 1850 and 1875, but losses in West Africa were particularly high, with the region referred to as the 'ivory coast' for good reason (Fischer 2005). As human population expanded during the 20th Century, elephants were increasingly ‘confined’ to protected areas, so much so that those areas were considered to be overpopulated by the mid 1900s.[1] Beginning sometime in the 1960s or early 1970s, speculation grew that a complex combination of commercial trade and human-elephant interactions were causing a serious decline in elephant numbers. In Ivory Coast, for example, there were an estimated 1790 savanna and 3050 forest elephants in 41 isolated groups in 1984, but this declined to approximately 270 total elephants in perhaps 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).[2]

Iain Douglas-Hamilton was the first to compile data on elephant range, numbers and trends in the 1970s and 1980s (Burrill and Douglas-Hamilton 1987; Douglas-Hamilton 1977-1979, 1993), but the first continent-wide population estimates became available in 1987 and are reported in Table 1 as 1989 estimates (see ITRG 1989).[3] A comparison of first and subsequent estimates suggests that elephant populations may have more than halved between 1981 and 1987 in some areas (see Said et al. 1995, p.1); researchers speculate that the African elephant (*Laxadonta africana*) declined in population from 1.2 million to 600,000 elephants in one decade, although the evidence is sparse (Barnes et al. 1999; Blanc et al. 2002). The magnitude of the estimated drop in numbers is difficult to believe because of the large scale of killings this would have entailed.

Trade in ivory became regulated under the 1973 United Nations’ Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). CITES regulates commercial trade in endangered species using a ranking scheme for species: Appendix I contains species banned from international commercial trade; Appendix II lists species that may be traded but for which export permits need to be issued (at the discretion of the exporting state); and Appendix III includes species that are threatened and could become endangered in the future. Importing countries agree not to trade in species (or parts of or products from species) listed in Appendix I, and ensure that proper export permits accompany imports of species listed under Appendix II. States can apply sanctions on species listed under Appendix III at their discretion.

Several modifications have been made to CITES that have had an impact on the status of the African elephant. In 1981, a provision was added at New Delhi (Conference Resolution 3.15) that would permit transfer of certain populations from Appendix I (no trade) to Appendix II (limited trade) for the purposes of sustainable resource management, a provision that became known as the ‘ranching criterion’. In 1985, Resolution 5.21 provided

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[1] Elephants appear to know the boundaries between hunting zones and protected areas, having been observed to dash to and from watering holes located in the hunting zone and visibly relaxing again once inside the park boundary (Scully 2002, p.87).

[2] Fischer quotes data from Roth and Douglas-Hamilton (1991) and Barnes (1999) among others.

[3] These are likely an update of the 1987 values. Interestingly, funding for this research was provided primarily by the U.S. Fish and Wildlife Service.

for the systematic re-listing of species from Appendix I to II in cases where countries of origin could agree on a quota system that would enable countries to manage species sustainably so that populations would not become endangered. There was no provision for external (third-party) verification/control as quota was to be determined solely by participating states. At the same time, under Resolution 5.12, a Management Quota System (MQS) was created for the African elephant. The MQS relied solely on management decisions taken by the producing countries, with consuming (second-party) states agreeing to prohibit imports of ivory (and other elephant products) from these countries unless accompanied by an MQS permit. There were no externally enforced incentives for sustainable use, with most states basing their quotas on expected confiscations of poached ivory. Since consumer states could obtain ivory from non-MSQ states without question, and due to lack of border controls on illegal ivory, public confidence in the MQS failed and, in 1989, the elephant was moved to Appendix I status despite a population of around 600,000 elephants (Table 1), well above what might be considered a minimum viable population for survival of the species.[4]

Five southern African elephant range states – Zimbabwe, Namibia, Botswana, Malawi and South Africa – have generally opposed the Appendix I listing, because they have relatively large elephant stocks. These countries lobbied unsuccessfully in 1990 and 1994 to down-list their populations and re-open (limited) trade in ivory and other elephant products. While lifting the restrictions on trade is unlikely to happen in the short run, lobbying by the five southern African countries resulted in a decision in June 1997 (based on Resolutions 3.15 and 5.21), to permit Botswana, Namibia and Zimbabwe to sell off nearly 50 tons of stockpiled ivory on a one-time basis. This constituted less than 60% of the ivory that these countries 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 per kg. At COP12, in 2002, another one-off sale by Botswana, Namibia and South Africa was approved, but that sale had not yet been completed by the end of 2004. These one-off sales have re-opened debates about how the African elephant is to be sustainably managed, and what role trade will play.

Population data presented in Table 1 suggest that the ivory trade ban has had at least some success. The rapid decline in elephant abundance that is thought to have occurred during the 1980s and before appears to have been halted, and indeed may even have been reversed. However, 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, and even those in Table 1 are categorized according to whether estimates are 'definite', 'probable', 'possible' or 'speculative'. Further, the area surveyed in each of the four years reported varied, being lowest for the 1998 population estimates. Thus, the population trends are indicative at best.

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[4] Soulé (1987) suggests that 2000 animals are adequate to ensure survival of a large mammal species (although with great expense a species can recover even from small populations), while Kontoleon and Swanson (2003) use a minimum viable population of 500 for the Giant Panda.

The ivory trade ban remains controversial. Critics of the ban allege that endangered species might be placed at risk by the perverse incentives that a trade ban generates. Banning trade makes elephant conservation a less attractive activity, inadvertently promoting conversion of elephant habitat to other uses. In addition, by reducing or entirely eliminating revenues from elephant management and exploitation, a trade ban might undermine the incentive to manage the stock carefully and enforce property rights to elephants and/or their habitat (see Bulte, van Kooten and Swanson 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, trade may stimulate illegal harvesting. In addition, it is suggested that the legal trade may facilitate the laundering of illegal ivory products.

The purpose in this paper is to investigate the effects of the ivory trade ban on elephant stocks compared to the situation where trade is permitted. As long as rents from elephant exploitation remain in place (so the marginal benefits of harvesting elephants and marketing ivory exceed the marginal costs), a trade ban is unable to prevent some harvest of elephants and the sale of ivory in international markets. International poaching gangs will be able to capture some of the rent and market ivory through a variety of channels. However, the marginal costs of providing ivory will likely be higher under a trade ban than under legal trade, while demand will be reduced because some potential buyers will have a stigma against purchases of ivory (Fischer 2004). Under legal trade, the marginal costs of providing ivory will be lower, while the stigma factor will no longer apply as buyers assume elephant populations are being managed sustainably.

A bioeconomic mathematical programming approach is used in this paper to study the impacts of various institutional arrangements on economic well being and elephant numbers. In particular, if property rights to elephants can be clearly defined, there may be alternative institutional arrangements that lead to larger elephant numbers and a lower chance that the African elephant becomes extinct. One possibility is a quota regime, such as the MQS, but with stronger enforcement. A regime that permits sales of ivory but also pays elephant 'owners' according to the actual size of the elephant stock in a country may lead to greater holdings of elephants while providing 'owners' with revenues to police elephant herds against poachers. Different regimes are investigated here to determine whether the trade ban is indeed the 'best' means to protect elephants. Results indicate that neither free trade nor a quota system can effectively protect the elephant unless it is accompanied by side payments. At this time, a trade ban appears to be the most effective policy.

An ivory trade model is presented in the next section, while the mathematical programming formulations of various ivory trade models are described in section III. How the models are parameterized is the subject of section IV, while results of alternative policy options and views about the effect of trade on demand and (legal and illegal) supply are provided in section V. The conclusions ensue.

II. IVORY TRADE MODEL

We begin by postulating a simple partial equilibrium ivory trade model. The model is described with the aid of Figure 1 – the international market for ivory. The African continent is the international source of ivory, as products from Asian elephants (*Elephas maximus*) are assumed to be sold only in the Asian market and usually within the country in which they are found and (illegally) harvested. Since the domestic African market for ivory is small with any ivory worked in Africa simply sold abroad (or sold domestically and smuggled abroad), ivory trade is assumed take place between Africa as the excess supplier and the rest of the world. The African excess supply function is denoted p^S in Figure 1, while the international excess demand for ivory (denoted p^D) is the demand left over after local ivory supply (from Asian elephants) is taken into account.

The excess supply function under free trade equals the horizontal sum of the legal and illegal excess supply functions. Under free trade, an amount q^* is traded at price P^*. As a result of poached ivory, market equilibrium occurs at point *v* rather than point *z* (Figure 1), with $q^*–q^L$ amount of illegal African ivory sold internationally. (An indicator variable *I* is used to denote the effect of the trade ban on supply and demand, with I=0 indicating free trade and I=1 a trade ban.) The global benefits of ivory trade (ignoring elephants) is given by the sum of the consumer and producer surpluses – area kvP^* under the demand function $p^D(I=0)$, plus area xzP^* above the $p^S(I=0)_{legal}$ function. Assuming open access, the poachers' supply curve, $p^S(I=0)_{illegal}$, is not equivalent to a marginal cost function; hence, poachers receive no rents. (An alternative assumption is considered in the trade ban situation.)

Illegal (poached) ivory masquerades as legal ivory when there is free trade. But an ivory trade ban does not halt all trade in ivory, although it does have two effects: First, the poachers' supply function shifts upwards as the transaction costs of marketing ivory increase. While poachers always incur costs associated with illegal activities (e.g., avoiding anti-poaching patrols), costs of illegal activities increase as African states step up local monitoring and enforcement when a ban is in place (perhaps because of pressure from environmental groups), and costs of finding buyers and avoiding ban-imposed custom controls rise. Second, a trade ban shifts the (excess) demand function inwards because the 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 added marketing costs for poachers. What worries many environmental groups is that removal of trade restrictions will reduce the stigma of buying and owning ivory, implying greater numbers of elephants being harvested (at equilibrium *v* rather than *w*).

An alternative to a trade ban is a quota. As already noted, a quota was in place prior to the ivory trade ban, but it was not controlled in any sense by the parties themselves or by outside parties. The quota can be illustrated with the aid of Figure 2. In the absence of poaching, an effective quota reduces ivory sales to the quota level *Q*, but poached ivory increases sales from *Q* to *Q*+, reducing the market price to P^{Q+} from P^Q. The illegal sales reduce the (scarcity or quota) rents earned by African elephant states by $P^{Q+}nrP^{Q}$ (from area $cdrP^{Q}$ to $cdnP^{Q+}$). Nonetheless, the quota results in lower harvests of elephants compared with competitive free trade and may even lead to lower levels of elephant harvest than under the trade ban if quota revenue is used to police illegal harvest. If policing increases the costs to poachers so that $p^{S}(I=0)_{\text{Illegal}}$ is shifted upward so that intercept *s* lies above P^{Q}, no illegal ivory will reach the market, effectively halting poaching.

One obstacle to implementing a quota system is that African states must form an effective ivory trade cartel, somehow allocating quota among member states. Logically, this is best accomplished by allocating quota on the basis of existing elephant numbers. Quota trading will ensure that harvests are allocated in the most efficient fashion. The allocation mechanism will determine the distribution of rents and will need to be accepted by all parties to prevent cheating. Further, it is necessary to have in place institutions to enable a quota scheme to operate, namely, assignment and protection of property rights to elephants and their habitat, and monitoring and enforcement of elephant harvesting and ivory sales. It also requires policing of poaching throughout all range states. It is unlikely that proper monitoring and enforcement will be in place, but perhaps a portion of the revenues generated by the quota could be used to finance these aspects of the scheme.

The international community is clearly interested in protecting elephants, which is one reason for the ban on ivory trade. It is important, therefore, that payments be made to African states on the basis of the numbers of elephants that are retained *in situ*. These payments need to be made to those with property rights to elephants and/or habitat so as to encourage them to protect elephants. It is the owners, whether states, individuals or communities, that need to have appropriate incentives to harvest or protect elephants. Payments to protect elephants could perhaps increase numbers beyond what they are currently, or at least prevent elephants from being added to the list of endangered species.

The discussion has thus far ignored storage – ivory is a non-perishable commodity that can be stored from one period to the next. This means that tusks confiscated from poachers, ivory from animals that died of natural causes and tusks of culled animals enter storage. Given that ivory has value and that there are costs to wildlife programs, states with significant quantities of stored ivory, such as range states in southern Africa, will lobby to permit them to sell stocks, which is why CITES has permitted some one-off sales. The existence of stocks complicates the models discussed in Figures 1 and 2. Along with the fact that elephants grow and reproduce, an analysis that includes ivory stocks is necessarily dynamic. Hence, a dynamic mathematical programming approach is used.

III. MATHEMATICAL PROGRAMMING FORMULATIONS

Consider first an idealized dynamic bioeconomic model in which the global net benefits from ivory trade and elephant conservation are maximized over time. There is one net consuming region and several regions that have elephant populations (range states) and produce and market ivory. Initially there is no poaching, and institutions are such that payments from rich countries to range states for elephant conservation have the desired conservation effect. The model is modified to include poaching and then expanded to examine the failure of conservation payments, the potential of a quota regime, and the costs and benefits of an ivory trade ban. Compared to Fischer (2004), the advantage of the current approach is that it permits richer detail, although many of her results are confirmed.

The objective is to maximize the discounted net global benefits of selling ivory and conserving elephants over some planning horizon. It is given by the sum of consumer and producer surpluses, the spillover costs elephants impose on landowners, and the off-site preservation benefits of keeping elephants *in situ*:

$$(1)\quad \underset{q_{j,t},\, h_{j,t}}{Max} \sum_{t=1}^{T} \beta^t \left[\int_0^{\Sigma q_{j,t}} p^d(I,q)dq - \sum_{j=1}^{N} \int_0^{q_{j,t}} c(I,a)da - k(I)\sum_{j=1}^{N} h_{j,t} - s\sum_{j=1}^{N} S_{j,t} - D(x_t) + (1-I)B(x_t) \right],$$

where $p^d(I, q)$ is the inverse (excess) demand function for ivory; $q_{j,t}$ is the quantity of ivory at time t made available for sale on the international market by region j (of which there are N); 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) are the consumer surplus plus the quasi-rent accruing to ivory sellers but not elephant 'producers'. Note that the marginal cost function is not quite the same as the supply function, $p^S(I)$ in Figure 1, because it does not include elephant harvesting and opportunity costs that are taken into account by the other terms in (1). In expression (1), $k(I)$ is the per unit cost of harvesting animals, s is a fixed cost of holding ivory stocks (S), $D(x_t)$ is a measure of the damage elephants impose on the ecosystem, and $B(x_t)$ is non-market or *in situ* benefits that elephants provide at time t. The cost of harvesting elephants is not density dependent as elephants are quite large and can be easily tracked (e.g., using scat), but the cost is higher when trade is banned and poaching occurs. The factor $\beta=1/(1+\delta)$, where δ is the social rate of discount, is used to discount future returns.

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 from elephant 'harvests' minus any sales of ivory. For convenience, it is assumed that no stocks of ivory are held outside of the elephant range states. Elephant harvests may be the result of decisions to eliminate troublesome animals, cull animals because there are too many for the particular ecosystem, or simply harvest animals for sale of ivory, as well as incidental take due to natural mortality or confiscations of illegal ivory. The stock equation is given by:

$$(2)\quad S_{j,t+1} = S_{j,t} + \gamma h_{j,t} - q_{j,t},\quad \forall j,\ t=1, ..., T-1 \qquad \text{(Ivory stock holding constraint)}$$

where γ is a parameter that converts elephants to ivory. Countries can sell ivory or hold it until a later period, but sales of ivory cannot exceed available stocks in any period:

(3) $q_{j,t} \leq S_{j,t}, \ \forall j,t$. (Sales of ivory cannot exceed available stock)

In addition to a stock constraint, an equation is needed to describe the growth and harvest of elephant populations:

(4) $x_{j,t+1} - x_{j,t} = g(x_{j,t}) - h_{j,t}, \ \forall j$, t=1, ..., T–1 (Elephant growth constraint)

where $g(x_{j,t})$ is the elephant growth function that might exhibit logistic or depensational growth (van Kooten and Bulte 2000, pp.184-189). It is discussed in greater detail below.

For each region, initial (opening) stocks of ivory and elephants need to be identified:

(5) $S_{j,0} = \bar{S}_j$, $x_{j,0} = \bar{x}_j , \forall j$. (Initial conditions)

In addition, non-negativity constraints need to be imposed:

(6) $q_{j,t}, S_{j,t}, x_{j,t}, h_{j,t} \geq 0, \ \forall j,t$. (Non-negativity)

Lastly, it is possible to specify optional sustainability conditions. Sustainability can be specified, for example, as an endpoint constraint on elephant stocks in each region, or as a requirement that elephant numbers remain at or above some minimum viable population level ($\bar{m}$):

(7) $x_{j,T} \geq \hat{x}_j , \ \forall j$ or $x_{j,t} \geq \bar{m} , \ \forall j,t$. (Sustainability criterion)

The sustainability constraint is meant primarily to satisfy international demands that elephant stocks be maintained. Less restrictive versions of (7) might require that the total of elephant stocks across all range states exceed some specified value at t=T, or that this total exceed some minimum value in each period t. We investigate several sustainability conditions, but also the possibility that the African elephant is allowed to go extinct.

The forgoing expressions form the basis of several models that can be used to investigate the effects of poaching and different institutional arrangements on wellbeing and elephant conservation. They can be used to determine which policies and perspectives are likely to be the most effective in protecting elephants.

Global Wellbeing with No Poaching

The first question of interest is: What are the consequences of free trade when there is no poaching? The following mathematical program is used to examine the consequences for elephant conservation of maximizing global welfare in this case:

P1:

$$\underset{q_{j,t},h_{j,t}}{Max} \sum_{t=1}^{T} \beta^t \left[\int_0^{\Sigma q_{j,t}} p^d(0,q)dq - \sum_{j=1}^{N} \int_0^{q_{j,t}} c_j(0,a)da - k(0)\sum_{j=1}^{N} h_{j,t} - s\sum_{j=1}^{N} S_{j,t} - D(x_t) + B(x_t) \right]$$

Subject to: (2), (3), (4), (5), and (6). A sustainability constraint, such as (7), is optional.

Global Wellbeing with Poaching

Next, consider the real-world case where elephant poaching and illegal ivory marketing occur. It is assumed that the decision maker maximizes benefits as before, taking into account the supply function of poachers, although it can affect this supply through anti-poaching effort (Bulte and van Kooten 1999). The supply of illegal ivory from region *j* at time *t* is assumed to be a function of the international price p^d and anti-poaching effort *E*: $q^p_{j,t}=f_j(E, p^d)$, where superscript *p* is used to denote poaching. While *E* is a potential decision variable (a subject for further research), simulation could also be used to examine the role of enforcement. The mathematical bioeconomic modeling program can now be written as:

P2:

$$\underset{q_{j,t},h_{j,t}}{Max} \sum_{t=1}^{T} \beta^t \left[\int_0^{Q_t} p^d(0,q)dq - \sum_{j=1}^{N} \int_0^{q_{j,t}} c_j(0,a)da - k(0)\sum_{j=1}^{N} h_{j,t} - s\sum_{j=1}^{N} S_{j,t} - D(x_t) + B(x_t) \right]$$

Subject to: (2), (3) and (5), plus:

(6′) $q_{j,t}, S_{j,t}, x_{j,t}, h_{j,t}, q^p_{j,t}, h^p_{j,t} \geq 0, \ \forall j,t$ — Non-negativity

(8) $q^p_{j,t} \leq \gamma h^p_{j,t}, \ \forall j,t$ — Sales of poached ivory cannot exceed ivory from poached elephant harvests

(9) $Q_t = \sum_{j=1}^{N}\left(q_{j,t} + q^p_{j,t}\right), \ \forall t$ — Adding up constraint

(10) $q^p_{j,t} = f_j\left(E, p^d(0,Q_t)\right), \ \forall j, t$ — Supply of illegal ivory from each region

(4′) $x_{j,t+1} - x_{j,t} = g(x_{j,t}) - h_{j,t} - \dfrac{q^p_{j,t}}{\gamma}, \ \forall j, \ t=1, ..., T-1$ — Elephant growth constraint

Constraint (8) is required so that sales of illegal ivory cannot exceed ivory available from poached elephants; it is assumed that illegal ivory is sold in the same period the poached elephants are killed and that poachers do not stockpile ivory. Constraints (9) and (10) are required to determine the global price of ivory and the amounts illegal ivory sold from each region.[5] The last term in (4′) indicates the number of elephants that poachers

[5] Given the assumption underlying constraint (8), this implies that illegal sellers have some notion or forecast of the price. Further research is required into alternative formulations, perhaps ones that involve holding of illegal stocks.

would harvest. It is also assumed that poachers do not hold ivory stocks and that no confiscated ivory enters stocks. Relaxation of these assumptions is a topic for future research. Finally, a sustainability constraint can also be imposed.

African Welfare with Competitive Selling and Poaching

Now consider the case where only the wellbeing of African elephant range states is important. In that case, we eliminate as a consideration the wellbeing of ivory buyers and, since actual payments are never made and certainly not on the basis of the actual number of elephants held *in situ*, the preservation benefits that accrue mainly to those in rich countries. The modified program is:

P3:

$$\underset{q_{j,t},h_{j,t}}{Max} \sum_{t=1}^{T} \beta^t \left[\sum_{j=1}^{N} \left\{ q_{j,t}\, p^d(0,Q_t) - \int_0^{q_{j,t}} c(0,a)da - k(0)h_{j,t} \right\} - s\sum_{j=1}^{N} S_{j,t} - D(x_t) \right]$$

Subject to the same constraints as in **P2**.

An Ivory Cartel with Poaching

Suppose that the 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 additional efficiency condition requires that marginal costs of harvesting elephants and marketing ivory are the same in each region and equal to marginal revenue. Damage from elephants is ignored in this marginality condition, but not the marginal cost of harvesting elephants for their ivory. 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 are to be harvested in each region for their ivory. The optimization program is:

P4:

$$\underset{q_{j,t},h_{j,t}}{Max} \sum_{t=1}^{T} \beta^t \left[\sum_{j=1}^{N} \left\{ q_{j,t}\, p^d(0,Q_t) - \int_0^{q_{j,t}} c(0,a)da - k(0)h_{j,t} \right\} - s\sum_{j=1}^{N} S_{j,t} - D(x_t) \right]$$

Subject to the same constraints as in **P2** plus:

(11) $$c(0,q_{j,t}) + \frac{k(0)}{\gamma} \geq Q_t \frac{\partial p^d(0,Q_t)}{\partial Q_t} + p^d(0,Q),\ \ \forall\, j,t$$ Marginality condition: $MC_j \geq MR$

Ivory Trade Ban with Poaching

Finally, 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 take the perspective of the criminal gangs that sell ivory illegally in international markets. It is assumed that they maximize quasi-rents (producer surplus) from marketing ivory, but that they cannot form a cartel. If they were somehow able to exert market power, then less ivory will be sold than under the assumptions of program **P5** and less elephants will be killed. Hence, the trade ban case considered here might be regarded as a worse-case, trade-ban scenario. Any sustainability constraint that might be imposed also falls away since poachers are not concerned about maintaining elephants over time.

P5:

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

Subject to: (4) plus

(9′) $Q = \sum_{j=1}^{N} q^p_{j,t} \;\; \forall t$	Modified adding up constraint
(3′) $q_{j,t} \le \gamma h_{j,t}, \;\; \forall j,t$	Sales of ivory cannot exceed ivory from elephant harvest
(4″) $x_{j,t+1} - x_{j,t} = g(x_{j,t}) - h^p_{j,t} \;\; \forall j,\ t=1, ..., T-1$	Modified elephant growth constraint
(5′) $x_{j,0} = \bar{x}_j, \forall j$	Initial condition on elephant numbers only
(6″) $q^p_{j,t},\ x_{j,t},\ h^p_{j,t} \ge 0, \;\; \forall j,t$	Modified non-negativity

Model **P5** implies that elephants are not truly an open access resource, but a derived demand. Illegal killing of elephants may still occur under open access, however, if tusks are illegally stockpiled, elephants are killed for bush meat and/or hides, or illegal killing is done by peasants simply to get rid of troublesome animals. While stocks of ivory are considered immaterial in **P5,** since only governments are assumed to stockpile 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.

IV. DATA AND MODEL PARAMETERIZATION

A major problem in implementing the forgoing models concerns the availability of data. Few data are available and much of that is based on local observations in range states (e.g., Menon 2002). The IUCN Species Survival Commission has tracked elephant numbers for the past decade and a half (ITGR 1989; Said et al. 1995; Barnes et al. 1999; Blanc et al. 2003), while the international community has implemented Monitoring the Illegal Kill of Elephants (MIKE) and the Elephant Trade Information System (ETIS) to keep an eye on illegal activities exacerbated by the trade ban. MIKE started in October 2001 and is managed by the CITES Secretariat through a Central Coordinating Unit headed by a Director based in Nairobi, while ETIS is managed by TRAFFIC – a joint program of the World Wildlife Fund and the World Conservation Union (IUCN) (http://www.traffic.org/). MIKE represents an effort to monitor illegal elephant killing in elephant states by developing the capacity of wildlife agencies to use their anti-poaching patrols and other methods for detecting carcasses, recording what they find and entering information into a standardized database. The agencies also undertake to conduct population surveys on a two to three year cycle. ETIS is an international monitoring system to track illegal trade in elephant products (mainly ivory), but it relies on individual countries to report seizures. While ETIS has published time series of seizure data by country that could provide a starting point for an analysis of the impact of species' listing and trade on seizures (see Figure 3) (Milliken et al. 2004), progress on MIKE has been more limited because it is taking time to get the system up and running (Hunter, Martin and Milliken 2004).

We employ data from various sources on prices and quantities traded in the pre-trade ban period (1960-1989) to construct the excess demand function $p^d(0, q)$. This information is provided in Table 2. Although many data points are missing, seven observations are complete. Upon regressing deflated prices (2000 US$ per kilogram) on quantity (kilograms of ivory) and time (with 1960=1 and 1989=29), we obtain the following estimates:

$$(12) \qquad P = \underset{(1.83)}{220.025} - \underset{(-2.37)^{*}}{0.00046\, q} + \underset{(3.73)^{**}}{16.581\, t}, \quad R^2 = 0.883 \quad F=7.059^*$$

where the t-statistics are provided in parentheses, ** indicates statistical significance at the 1% level or better and * indicates significance at the 5% level. Taking t=30 and assuming that (12) represents the excess demand function,[6] it is possible to write the demand function in Figure 1 approximately as:

$$(13) \qquad p^d(I=0) = 720 - 0.0005\, q.$$

Fischer (2004) reports that ivory was trading for about \$150 per kg in the pre-ban period (or about \$230/kg in real 2000 dollars), with price peaking at over \$1,200 per kg shortly after the ban's imposition and then settling at some \$450/kg thereafter. According to (13), at a real pre-ban price of \$230/kg, some 980 tonnes of ivory would be traded. What would be sold under a trade ban assuming the demand curve changes due to a stigma effect?

The demand for ivory in the post-ban period (as in the pre-ban period) is unknown. The only information that is available pertains to reported seizures of elephant products. The first year for which these are reported is 1989, the year of the trade ban. From Table 3, the average number of annual seizures of illegal elephant products (as they crossed international borders) increased by 120% after 1989, although, as indicated in Figure 3, there is no real discernable trend in the amount of illegal ivory sold in the years following the trade ban, at least based on reported seizures.

It appears that illegal activity continues unabated. Hunter, Martin and Milliken

[6] The estimation is crude and the identification problem is ignored. Given a dearth of data, there is no other way to derive (as opposed to assuming) an excess demand function, although assuming excess demand takes the form of (13) would also suffice.

(2004) use observations on ivory carvers in various regions of Africa and Asia to estimate that between 6,433 and 16,185 African elephants (and 123 to 349 Asian elephants) are still supplied illegally to the market each year (Table 3). This implies that between 44.4 and 111.7 tonnes 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. If the pre-ban demand function (13) continued to describe the situation, the market price of the ivory would be \$664-\$698 per kg. As noted, however, it is reported to be nearer \$450 per kg. We assume that the intercept on the post-ban excess demand curve has shifted down by this difference, or by about \$230 (=\$670 – \$450), so that the no-trade excess demand function can be described by:

(14) $p^d(I=1) = 500 - 0.0005\, q.$

At a price of \$450 per kg, only 100 tonnes of African ivory would be sold internationally, well within the range estimated above.[7]

On the supply side, the African continent is divided into four regions that represent different elephant subspecies – the savanna elephant (*Laxodonta africana africana*) and the forest elephant (*Laxodonta africana cyclotis*) – and elephant economics. The forest elephant is difficult to view and is found primarily in West and Central Africa, with populations in West Africa rather small and insignificant in continental terms (Table 1). The savanna elephant is an important flagship species for the tourism industry. While important in all states of East and Southern Africa, populations in the latter region have threatened the ecosystem carrying capacity, so elephants have been culled and ivory stockpiled. Thus, while Kenya is concerned about the adverse impacts of ivory trade, states in Southern Africa have lobbied to sell ivory.

It is assumed that, in addition to the costs of harvesting elephants (see equation (1)), there is a fixed cost plus a per unit cost of taking ivory out of stocks and bringing it to market. The fixed cost represents the transportation and search costs (finding markets). Both fixed and per unit costs are higher when a trade ban is in place as transactions are illegal. To determine the supply functions in each region, we begin by assuming that under a trade ban, 100,000 kg of ivory would sell for \$450/kg. To determine the regional illegal supply functions, we further assume that 60% of the illegal supply (or 60,000 kg) comes from Central Africa, since Hunter, Martin and Milliken (2004) argue that much of the illegal supply originates in this region. The amounts coming from the other regions are indicated in Table 4. If we assume linear supply functions and arbitrary intercepts, it is then possible to determine the slopes of the supply curves based on the share of the total quantity of illegal ivory that each region contributes to the market. The intercept and slope parameters for the illegal supply (marginal cost) functions under a trade ban are provided in Table 4.

In order to construct the legal and illegal supply functions, a number of assumptions

[7] Based on the calculations provided here, the price paid by Japan in 1999 (\$103/kg) is likely low.

need to be made. Under free-trade, 980 tonnes of ivory are traded at a price of \$230/kg. At that price, regions are assumed to supply legal ivory to the market according the proportions indicated in Table 4 (roughly based on the proportions in Table 1). However, not all of the ivory sold is from legal stocks. Under a ban, 100 tonnes of ivory are assumed to be supplied illegally (as noted above); with free trade, we assume that 200 tonnes are provided illegally with the proportion of the illegal supply from each region the same as under the ban. Thus, 780 tonnes per annum are supplied legally. We assume that the illegal supply functions are flatter and have shifted down compared to the trade-ban case, because trade reduces anti-poaching effort and makes it easier to launder poached ivory. The legal supply functions are assumed to have a lower ordinate intercept and to be flatter than the illegal supply curves, as marginal costs of supplying ivory to the international market must be lower for legal suppliers than illegal ones. The intercept and slope parameters for the illegal and legal supply functions in the case of trade are also provided in Table 4.

Anti-poaching effort can affect the supply of illegal ivory. Unfortunately, there is little information about the effect that law enforcement has on the illegal supply of ivory. Milliken et al. (2004) provide two measures of law enforcement effort – the Corruption Perception Index score (which for a region would be the average of the country scores) and an index of enforcement given by "the total number of in-country seizures divided by the total number of seizures" (p.23). Arguably, the World Bank's (2005) Governance and Anti-corruption indicators are a better indicator of enforcement ability than the Corruption Perception Index. Thus, rather than a single index, four indexes are provided for each of the regions in the model (see Table 5). Further, Milliken et al.'s index of enforcement, but then adjusted for elephant populations and normalized for Africa, is also provided in Table 5 for each region. West and Central Africa have the worst scores, respectively, in terms of enforcing the ivory trade ban, and these low scores accord with the World Bank's low measures of performance related to government effectiveness, rule of law and corruption. East Africa performs just as poorly on the World Bank's indicators, but does relatively better in the enforcement of the ivory trade ban, perhaps because of the perceived or real importance of the elephant to the economy of East African states. States in Southern Africa are more prone to enforce ivory trade laws and are generally better performers on other measures as well, but all states in Africa lag well behind states in Asia that purchase elephants and countries of Europe and North America (see Bulte, van Kooten and Swanson 2004). As part of the analysis, it is assumed that African range states can do better in the enforcement of illegal killing of elephants and trade in elephant parts.

To describe the fecundity, mortality and growth characteristics of elephants, we specify the following simple linear function:[8]

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[8] An alternative is to employ the standard logistics growth function: $x_{t+1} - x_t = r\, x_t\, (1 - x_t/K)$, where r is the intrinsic growth rate in elephant stocks and K is the ecosystem's elephant carrying capacity. However, for this discrete form and the parameters used in this model, it leads to an immediate reduction in elephant numbers by half even outside the current model (i.e., without harvests).

(15) $x_{t+1} = (1+r)\, x_{j,t}$, with $x_{j,t} \le K_j \quad \forall j, t$,

where r is the growth rate in elephant stocks and K_j is the elephant carrying capacity for ecosystems in region j. Set r=0.067 (Milner-Gulland and Leader-Williams 1992) and initial elephant populations equal to the elephant totals for each region in 2002 (Table 1). The carrying capacity of each region is determined from information about elephant range and the proportion of elephant range that is protected. For the forest elephant, it is assumed that unprotected elephant range has a carrying capacity of 0.15 elephants per km^2, while it is 0.25 elephants per km^2 for protected range. The carrying capacity of open range is higher, so it is assumed to be 0.20 per km^2 for unprotected and 0.35 for protected range in the case of the savanna elephant. Background information and carrying capacities are provided in Table 6. The estimated continental carrying capacity of about 974,000 elephants is lower than numbers existing in the early 1970s (some 1.2 million), but elephant range has decreased significantly since then due to rising human populations and encroachment.

Ivory stocks are largely unknown, although Milliken (1997) estimates that there are some 462.5 tonnes of verifiable and legitimately held stocks of ivory in Africa, and another 243 tonnes of undeclared (perhaps illegal) ivory, or a total of 705.5 tonnes. This amount is allocated across regions in proportion to each region's number of elephants. One estimate of extant stocks is to add to these estimates the increase in stockpiled ivory over the period 1997-2004 relying on information reported by Milliken et al. (2004). Average seizures by region are provided in Table 3 for the period 1990-2003, while the raw ivory equivalent weight of an average seizure over the period 1989-2004 was 0.498 kg. Assume that seized ivory accounted for half of the increase in ivory stocks, with the remainder coming from culling, killings of troublesome animals, and, in some regions, legal hunting for monetary gain. Using this information to determine the increase in stocks since 1996 gives the estimates provided in the next to last row of Table 6. One could also argue that, using Milliken's (1997) estimate of 1996 stocks, an average of 88.2 tonnes of ivory were added to stocks each year. If this continued up to 2004, there would be some 1300 tonnes of stockpiled ivory. As the exact number is unknown, we assume 900 tonnes of stocks allocated as indicated in the last row of Table 6.

Milner-Gulland and Leader-Williams (1992) estimate poaching costs to be about \$180 per elephant. With inflation, these rise to about $c(I=1)$=\$225; arbitrarily choose one-third of this amount to be legal harvesting costs, $c(I=0)$=\$75. While Kenya and Mozambique, for example, do not permit hunting of elephants, hunting is allowed in some states. Nonetheless, Scully (2002, pp.47,86,122) reports that, in 1999, Safari Club International members could pay some \$10,000 for the 'privilege' of hunting an elephant (likely in southern Africa and specifically Zimbabwe). Although left to future research, for southern Africa at least, we could consider elephant harvests yielding a benefit of \$10,000.

The cost of holding ivory stocks is assumed to be small, s=\$0.50/kg each period. Hunter, Martin and Milliken (2004) report that, based on 7800 ivory seizures, the average tusk weighs 3.68 kg. Both male and female African elephants grow tusks (while only male Asian elephants have tusks), but for whatever reason the average number of tusks per African elephant is 1.88. Thus, $\gamma \approx 7$ kg of ivory per elephant.[9]

Bulte and van Kooten (1996) assume a linear damage function, $D(x)=vx$, with the constant cost imposed by elephants on the ecosystem, v, determined by the amount of forage that an elephant consumes annually (which is equivalent to the consumption of 4.7 cows or about 36,500 kg of dry matter). This forage is valued at v=\$165.[10]

Lastly, it is necessary to determine the benefits that accrue as a result of holding elephants *in situ*. These benefits accrue primarily to people in developed countries and represent their annual willingness to pay (WTP) to preserve elephant populations in Africa. Assume there are 200 million households in Europe and North America and each is WTP some amount annually to preserve 700,000 elephants. Assume that the marginal benefit (marginal WTP) function is linear: $B'(x)=a-bx$, and, as a base case, that a=1800 and b=0.002. Then $B(x$=700,000)=\$770 million with each household contributing \$3.85/year. Given the importance of *in situ* payments to elephant conservation, we also assume a=3600, b=0.003 ('Hi' scenario), so that $B(x$=700,000)=\$1785 million with each household paying about \$9 per year; and a=900, b=0.001 ('Lo' scenario), so that $B(x$=700,000)=\$385 million with each household paying nearly \$2 per year.

V. RESULTS

The outcomes of different strategies are examined using a series of mathematical programs coded in GAMS and solved using the CONOPT3 nonlinear solver (Brooke et al. 2004). The simulations are for 100 years, although data is reported only for 50 periods. 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 ('salvage') value beyond the end of the planning

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[9] From Table 2, it appears that 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, pp.69-71) reports that, after making 'donations' to several local Mozambique causes (including a hospital), three members of the Safari Club International killed, among other animals, three elephants in July 1998, despite an unambiguous 1990 law prohibiting elephant hunting in Mozambique. The largest of the elephants had tusks weighing an incredible 92 lbs (41.8 kg) each! Quoting David Chadwick, Scully also points out that it took 55 elephants to obtain 1 tonne of ivory in 1979, compared to 113 elephants around 1990 (p.123). Not only is tusk size (and the age of elephants) declining, but more are born without tusks (p.123). Yacob et al. (2004) measured 31 tusks of elephants in Eritrea and found an average tusk weight of 8.7 kg.

[10] In a very recent issue of *Pachyderm* (vol. 38, http://www.iucn.org/themes/ssc/sgs/afesg/pachy/), several articles report on human-elephant encounters and crop damage. These suggest that overall damages are small (except perhaps for the few farmers whose crop are affected) and a function of the land's nearness to an elephant conservation area. As noted earlier, elephants appear to avoid leaving protected areas except to raid when the need arises.

horizon. All animals will be harvested unless they have no value – the (marginal) cost of harvesting the next animal is less than the marginal benefit.

Given the richness of the model, it is possible to explore only a limited number of scenarios and variables. Since a major concern of animal welfare groups is the conservation of elephants in the wild, only the effects of various scenarios on animal numbers are examined. The most surprising result of the analysis relates to conservation payments – annual payments from rich countries to range states on the basis of the number of elephants maintained in their herds.

Consider first the case of free trade. If countries receive payments for preserving elephants *in situ*, the effect of poaching on elephant numbers is nearly insignificant, although the magnitude of the payments does have an important effect on the eventual stock of African elephants that range states should optimally maintain. The simulation results are indicated in Figure 4 for two marginal non-market benefit functions: $B'(x)$=1800–0.002x (base case) and $B'(x)$=3600–0.003x ('Hi'), or approximate annual payments of \$4 and \$9 per household, respectively. Under high annual payments, optimal elephant stocks are almost 150,000 higher than under base payments. Poaching seems to have little impact: in the absence of poaching, optimal elephant numbers will be only very slightly higher than when poachers are present. Because earnings from conservation payments are significant, range states simply reduce their own sales of legal ivory, making room for poachers to kill elephants and sell their ivory. In many years, no legal ivory is sold whatsoever as range states participate in the market only to sell off any ivory stocks they may have accumulated, and occasionally kill elephants for that purpose. Almost all ivory that is sold comes from illegal harvests. Thus, when comparing the trade case with and without poaching, range states only lose to poachers the surplus associated with the sale of ivory, but they make up for it through conservation payments from developed countries.

The further impact that conservation payments have on elephant conservation is illustrated with the aid of Figure 5. Scenarios in which conservation payments are made are denoted 'Extra'. Under free trade and in the absence of conservation payments ('No Extra' scenarios), there is a 'race to the bottom' as it is optimal to drive the elephant to extinction. The rate of decline in elephant populations is determined by the (social) discount rate. As indicated in the figure, at a discount rate of 4%, it takes more than 40 years for the elephant to disappear, but it takes only 10 years if the discount rate is 20%. 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.

Conservation payments arrest the decline of elephant numbers. For the scenarios in Figure 5 labeled 'Extra', each rich country household is assumed to be willing to pay approximately \$2 per year (labeled 'Lo'), \$4 per year (not labeled), and \$9 per year ('Hi'), and payments are made to range states according to the schedules indicated in the previous section. Appropriate institutions are assumed to be in place and the amount that rich countries do pay depends on the choices elephant owners make, presumably the range state governments. For both 4% and 20% discount rates, the African elephant is driven to extinction if no conservation payments are made. If the discount rate is 20%, the elephant population declines below 40,000 if *in situ* payments are too low, and there exists the real possibility that the African elephant could go extinct. Indeed, for two African regions, the Central and West, the elephant does go extinct in this scenario, while it almost goes extinct in Southern Africa (Figure 6). The good news is that extinction can be avoided even when the future is heavily discounted if conservation payments are sufficiently large. Sufficiently large in this case implies a payment between $5 and $10 per European and North American household; indeed, if the payment falls in the upper end of that range, elephant population could stabilize at more than 400,000 animals, sufficient to ensure their long-term survival.

These results support observations initially made by Bulte and van Kooten (1996), who point out that, even if conservation payments are made, high discount rates in some regions could result in much lower population levels, with the result that a trade ban is preferred. However, the researchers did not demonstrate that elephants could go extinct in the absence of a trade ban. The current results unambiguously indicate that, under free trade and even with conservation payments, the optimally desirable policy (whether overt or inadvertent) could be one the leads to the demise of the elephant, at least in some regions where they now appear to be plentiful (above the minimum viable population). Can a trade ban mitigate the species' demise?

The simulation results indicate that a trade ban on ivory may indeed be successful in conserving the African elephant. The results are robust with respect to interest rates of 4% and 20%. They indicate that the optimal strategy of poachers is to kill a large number of elephants quickly to get onto the optimal exploitation path, which then leads to a rising number of elephants over time (Figure 7). Indeed, elephants will grow in numbers to fill the ecosystem capacities of each of the regions, which occurs for all regions by the twentieth year. The price over the entire period is $450 per kg of ivory, with 100 tonnes of ivory sold annually. The results, therefore, are driven by the illegal supply functions and the stigma-impacted demand function. To the extent that these functions continue into the indefinite future, animal welfare groups can be content in their argument that a trade ban is necessary to protect the elephant. Indeed, the results in Figure 7 appear to be supported by the data in Table 1 that suggest the trade ban has been a success. However, if range states and international organizations do not remain vigilant in monitoring and enforcing the trade ban, it is possible that the underlying parameters describing the international demand for ivory and illegal supply functions (and killing of elephants) might change so that, once again, elephant populations become endangered.

The analysis of a trade ban does not take into account the possibility of increasing stockpiles of ivory that accrue as a result of anti-poaching enforcement and culling of animals. (Explicit modeling of this effect is left to future research.) As a result, some range states will continue to agitate for continued sales of ivory. To investigate this further, consider the possibility of an 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 well being, conservation payments from developed countries for *in situ* elephants are ignored. Under these assumptions, unfortunately, an ivory cartel does not ensure the elephant's survival. Indeed, as indicated in Figure 8, for a 4% rate of discount a cartel only slows down the rate of decline in elephant numbers marginally compared to unrestricted free trade in elephant products; in either case, the optimal policy of range states is to drive elephant numbers to endangerment within forty years. At a 20% rate of discount, the elephant is endangered in less than 20 years.

VI. DISCUSSION AND CONCLUSIONS

The analysis of this study provides one very important conclusion: Unless elephants have preservation value as expressed by people's willingness to prevent them from going extinct, the elephant is most likely to remain a species under threat of extinction. This willingness is represented in the current model by actual payments from those in developed countries to those capable of preventing the harvest of elephants, or by the combination of a stigma effect on the demand side and high costs of poaching on the supply side. While the stigma and supply-side effects of a trade ban are important, their existence is essentially 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. The conclusion in that case is that intervention by rich countries is required in the form of preservation benefit payments that are tied to the numbers of elephants that range states conserve. As indicated in Figures 4 and 5, the payment schedule will have a large impact on range states' optimal elephant numbers, and the subsequent effort that range states make in policing herds.

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 in general lack the institutions and governance structures that characterize developed countries (see Table 5; Bulte, van Kooten and Swanson 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. The reason is that, 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 production than it was producing bison, even if these could somehow be domesticated (see Anderson and Hill 2004, pp.94-102). Likewise, without conservation payments made to those with a stake in the land, elephants are less valuable than agricultural crops, and unable to compete for land.

The results of the model presented here 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, but it should perhaps be modeled as a function of time. It is not clear, however, 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., bush meat). Further, it is necessary to consider the relationship between the legal and illegal takings of elephants. The effect of monitoring and enforcement needs to be explicitly taken into account; the supply of illegal ivory needs to be modeled as a function of anti-poaching expenditures and of the supply of legal ivory. At the same time, it is necessary to take into account the reactions of the state to supplies of illegal ivory when free trade is permitted, or when states act to form an ivory cartel. Currently, illegal marketing of ivory is taken as given, while, in the case of the cartel, it was simply assumed that poachers were driven out of the market, which may simply be too expensive a proposition. These interactions certainly warrant further investigation.

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Table 1: African Elephant Stocks and Elephant Range by Region

Year & Category	Central Africa	East Africa	Southern Africa	West Africa	**TOTAL**
1989	**275,600**	**110,650**	**203,300**	**18,380**	**609,919**
1995					
Definite	7,320	90,482	170,837	2,760	286,234
Probable	81,657	16,707	16,402	1,376	101,297
Possible	128,648	19,999	18,983	5,035	155,944
Speculative	7,594	1,084	21,825	5,554	36,057
Total	**225,219**	**128,272**	**228,047**	**14,725**	**617,264**
1998					
Definite	7,322	83,770	196,845	2,489	301,773
Probable	27,104	22,698	17,057	644	56,196
Possible	27,613	17,216	22,623	6,228	60,780
Speculative	63,469	1,495	190	3,442	68,596
Total	**125,508**	**125,179**	**236,715**	**12,803**	**521,809**
2002					
Definite	16,450	117,716	246,592	5,458	402,067
Probable	32,263	17,702	23,722	1,188	59,024
Possible	64,477	22,511	26,098	3,039	99,813
Speculative	82,563	5,738	7,508	3,498	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.

Table 2: Evidence of Traded Quantities and Prices in Pre-Ivory Trade Ban Period, Selected Years before 1990

Year	Average weight per tusk (kg)	Raw ivory price (US$/kg)	US CPI (2000=1.000)	Ivory trade (tones)	Elephants Killed	Ivory-based elephant value (US$ 2000)
1960	5.2	7.5	0.172	412	42,000	426
1970	5.2	n.a.	0.225	564	57,500	n.a.
1971	5.2	n.a.	0.235	n.a.	n.a.	n.a.
1972	5.2	30	0.243	n.a.	n.a.	1,207
1973	5.2	n.a.	0.258	n.a.	n.a.	n.a.
1974	5.2	n.a.	0.286	n.a.	n.a.	n.a.
1975	5.2	110	0.312	n.a.	n.a.	3,447
1976	5.2	n.a.	0.330	n.a.	n.a.	n.a.
1977	5.2	n.a.	0.352	n.a.	n.a.	n.a.
1978	5.2	75	0.379	n.a.	n.a.	1,935
1979	5.2	66	0.422	879	89,700	1,529
1980	4.9	60	0.479	966	105,000	1,154
1981	4.6	59	0.528	1034	120,200	966
1982	4.3	67	0.560	925	115,600	967
1983	3.9	n.a.	0.578	n.a.	n.a.	n.a.
1984	3.6	n.a.	0.603	n.a.	n.a.	n.a.
1985	3.7	n.a.	0.625	n.a.	n.a.	n.a.
1986	3.8	100	0.636	847	118,600	1,123
1987	3.8	150	0.660	n.a.	n.a.	1,624
1988	3.8	275	0.687	n.a.	n.a.	2,860
1989	3.8	300	0.720	770	107,500	2,977

Notes:

The data on ivory prices, quantity of ivory traded and elephant killed come from various CITES sources and were collected over a period of 10 years; n.a. means the data was not available. Tusk weight and elephant value are based on the assumption that an average African elephant yields 1.88 tusks.

Table 3: 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**	**4,648**	**11,710**
Central Africa	0	2.0	198	1,770	4,453
East Africa	34	36.4	35	216	545
Southern Africa	70	98.9	132	841	2,122
West Africa	8	1.0	152	1,119	2,821
Asia[d]	**6**	**59.5**	**379 (655)**	**1,785 (123)**	**4,475 (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.**

Notes:

[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 is omitted because not all information is yet available.

[c] Source: Hunter, Martin and Milliken (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 4: Postulated Regional Ivory Supply Functions: Legal and Illegal

	With Ivory Trade						Under Trade Ban		
	Legal supply			Illegal supply			Illegal supply		
Region	% of market	Intercept	Slope	% of market	Intercept	Slope	% of market	Intercept	Slope
Central	25%	30	0.00103	60%	40	0.00158	60%	80	0.00617
East	20%	10	0.00141	15%	50	0.00600	15%	60	0.02600
Southern	50%	50	0.00046	20%	75	0.00388	20%	100	0.01750
West	5%	20	0.00538	5%	35	0.01950	5%	50	0.08000

Table 5: Summary Indicators of Governance and an Index of Law Enforcement

Item	Central Africa	East Africa	Southern Africa	West Africa
Government effectiveness[a]	-1.07	-0.88	-0.32	-0.88
Regulatory quality[a]	-1.02	-0.92	-0.35	-0.70
Rule of law[a]	-1.08	-0.97	-0.41	-0.79
Control of corruption[a]	-1.13	-0.77	-0.46	-0.66
Index of law enforcement[b]	0.0102	0.1668	0.8225	0.0006

Notes:

[a] Source: World Bank (2005). Each index lies between -2.5 and +2.5, with lower values indicating poorer performance. (As an example, for each of the indexes in descending order in the left-hand column, Finland scores 2.01, 1.93, 1.99 and 2.39, respectively.)

[b] Total number of in-region seizures divided by total seizures in Africa, and normalized for the number of elephants in the region.

Table 6: 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	**1,106**
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 – 11: calculation. Values in row 7 assume that for forest elephants (Central and West Africa) carrying capacity is 0.15 elephants per km^2 in unprotected range and 0.25 per 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 per 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.

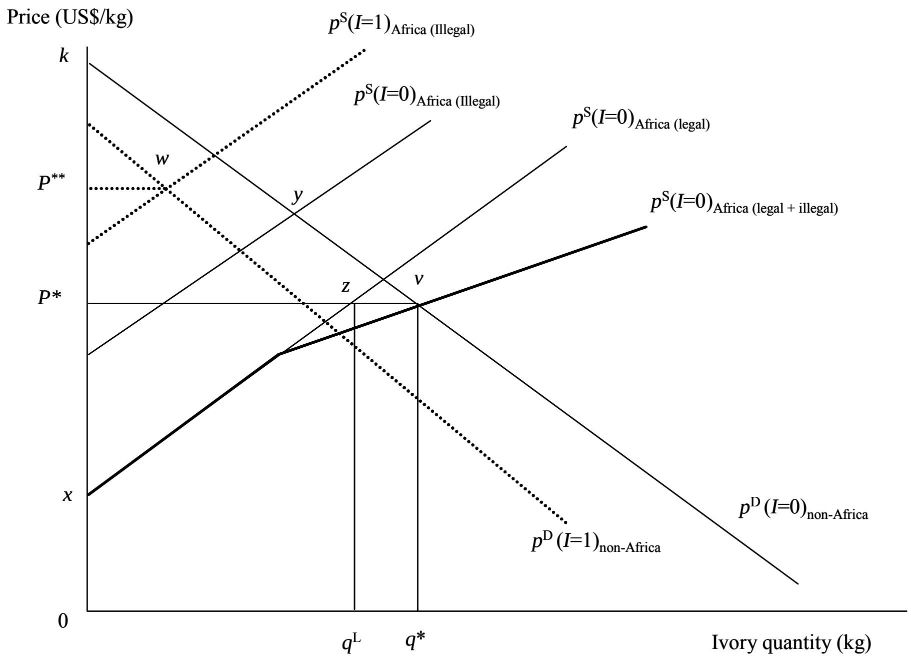

Figure 1: International Ivory Market under Free Trade and Trade Ban

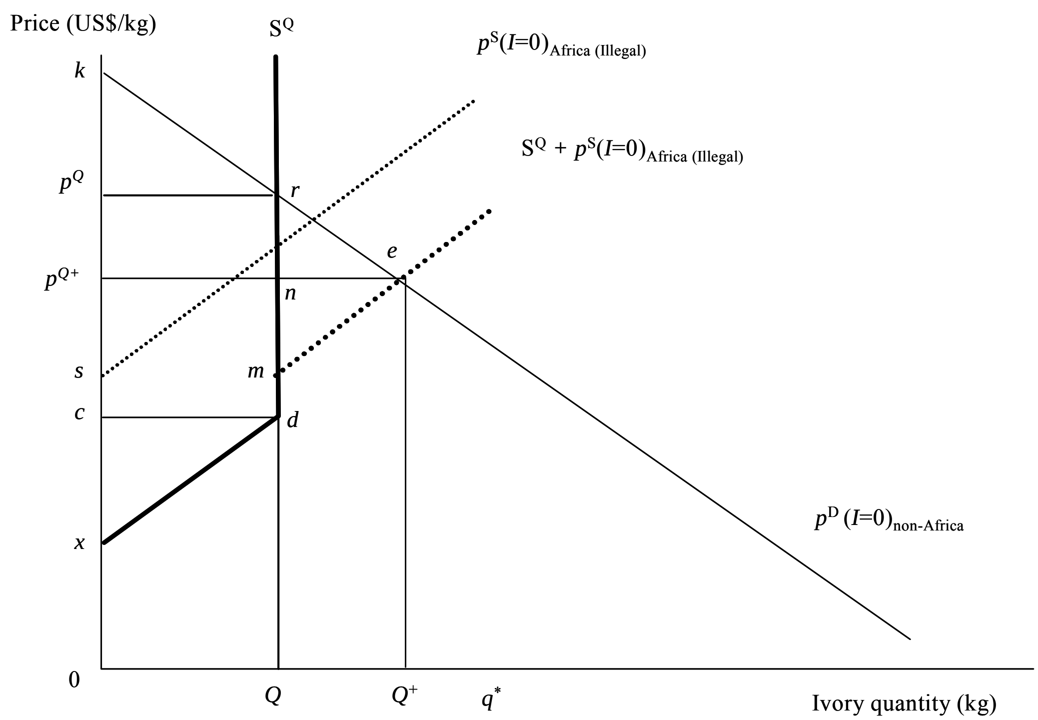

Figure 2: International Ivory Market under a Quota System

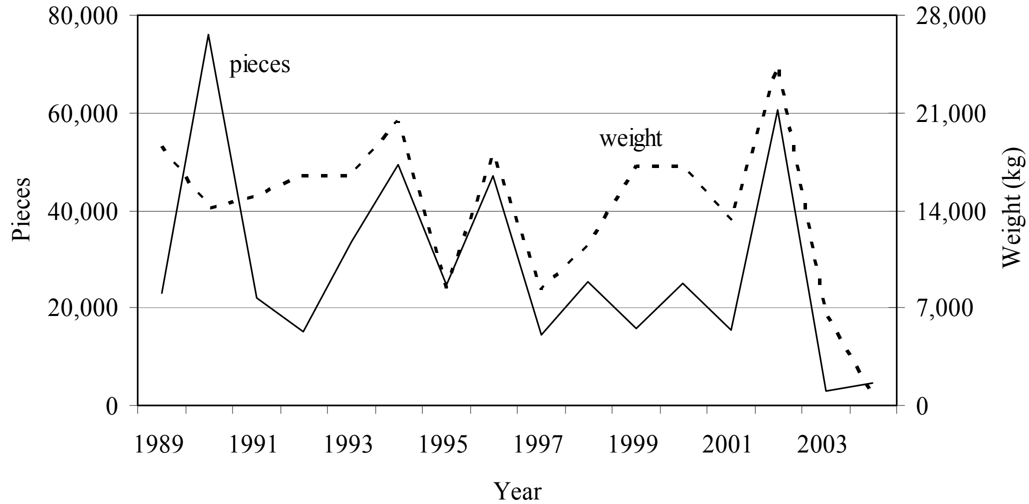

Figure 3: Estimated Amount of Ivory (in 'raw ivory equivalent') Represented by ETIS Seizure Data, 1989-2004 (as of 6 July 2004)

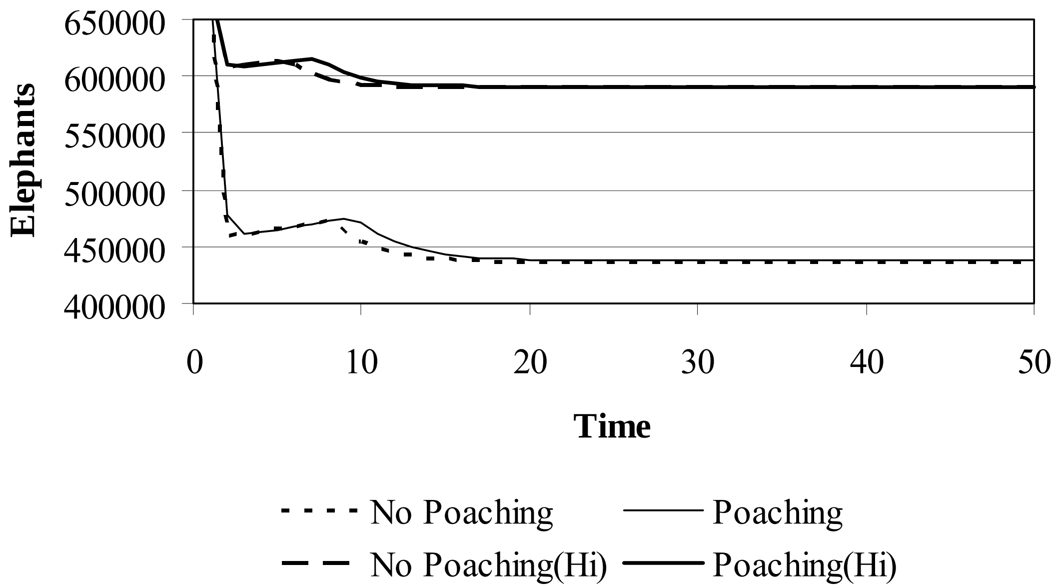

Figure 4: Optimal Elephant Populations under Trade, with and without Poaching, and for High and Low Levels of Estimated *in situ* Benefits

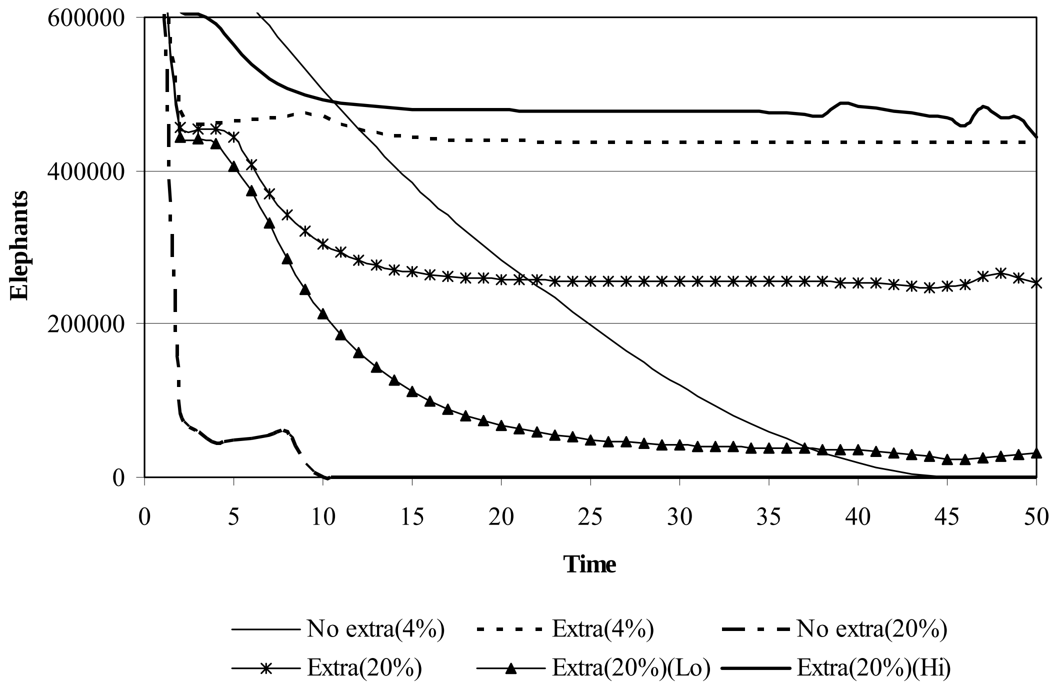

Figure 5: Race to the Bottom: Optimal Elephant Populations under Trade, with and without the Inclusion of *in situ* (extra) Benefits and Discount Rates of 4% and 20%

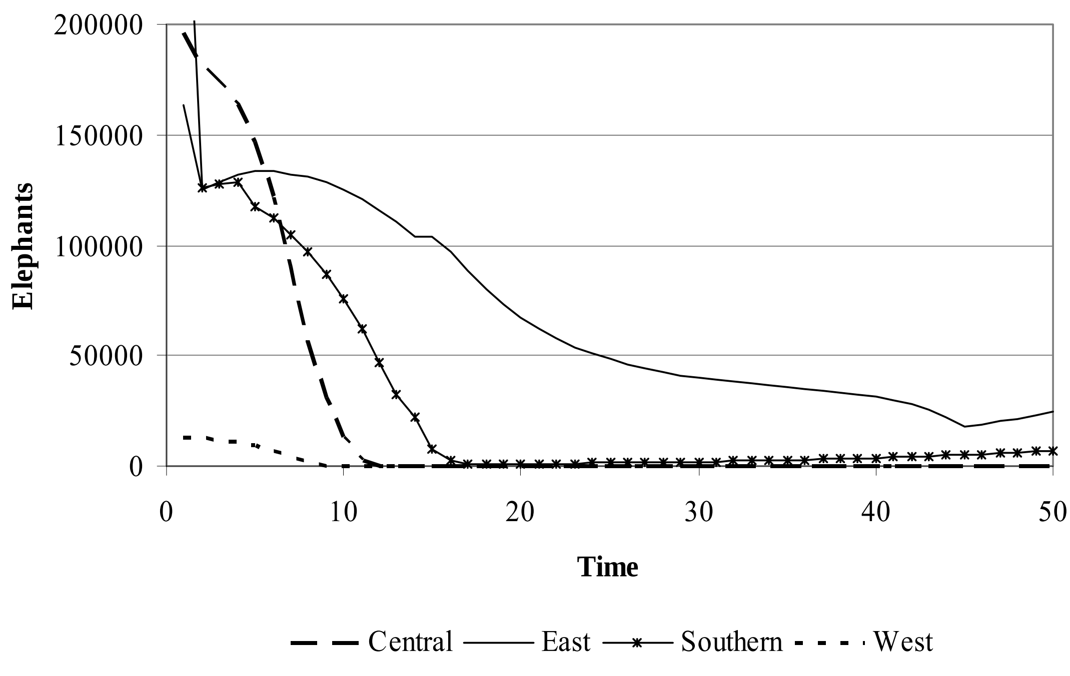

Figure 6: Race to the Bottom: Optimal Elephant Populations under Trade, with Low Conservation Payments and a Discount Rate of 20%, African Regions

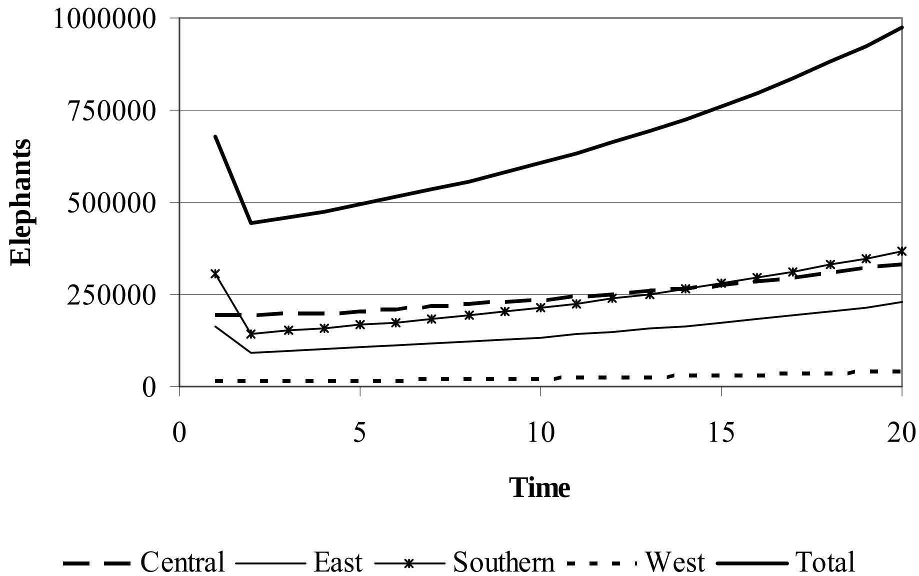

Figure 7: Optimal Elephant Numbers under an Ivory Trade Ban by Region and Africa

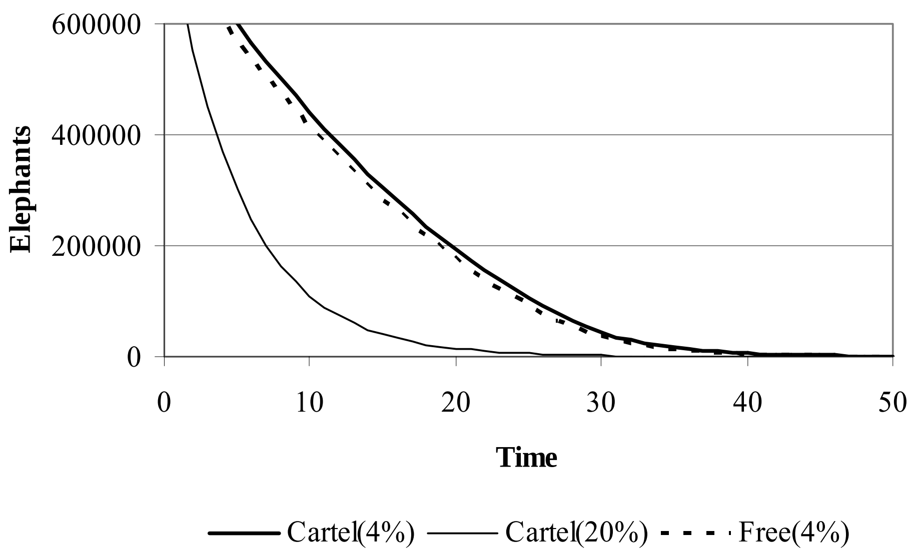

Figure 8: Optimal Elephant Numbers under an Ivory Cartel