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Measuring The Impact Of United Nations Trade Policies On Kenyan Elephant Populations Using Bioeconometrics

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Abstract: *Every day species are driven toward extinction and none draws more attention than the African elephant. In an effort to save dwindling elephant populations, a worldwide commercial ivory trade ban was adopted in 1989. This paper combines an ecological logistic population growth model based on habitat carrying capacity with econometric supply and demand curves to statistically demonstrate the 1989 ban reduced elephant poaching deaths in Kenya by nearly 15,000 per year and was crucial in saving the Kenyan elephant from extirpation. Thisbioeconometric model builds on the observation that worldwide behavior defines ivory demand while local attitudes control supply. Since the 1989 ban was enacted, the U.N. has experimented with limited exceptions to the ban; accordingly, this paper investigates the impact of these actions, too.*

Keywords:*Bioeconometrics, ivory trade, elephant poaching, U.N. ban*
JEL Classification C4 F1 K4 Q5 R1

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I. Introduction

"Never in all my years as a forester have I seen such a massacre." said OkoRufin Antoine of the ministry of water and forests about the discovery of 200 slaughtered elephants whose tusks had been sheared off (Associated Press. 5 September 1996). Often using assault rifles from helicopters, poachers killed nearly 675,000 African elephants during the 1980s (Sands and Bedecarre 1990). "In ten years, the elephant population in Kenya declined from around 70,000 to 18,000," claimed Richard Leakey, Director of Kenya Wildlife Services (Wainaina 1990).

The largest of land animals, the African elephant (*Loxodonta Africana*) totters on the edge of extinction. The animal's prominent tusk are actually elongated incisor teeth, and the word "elephant" is from the Greek word *elephas,* which means ivory.Numbering nearly 1.5 million in 1978, only 600,000 remained left in the wild by 1995. However,the adult elephant has no natural predator . . . except humans. So being, the immediatethreat to African elephant survival is poaching although habit destruction andfragmentation also threaten them. To further complicate matters, limited financialresources and local political instability are major factors that must be considered in anyconservation program. To protect African elephants from extinction, the UnitedNations placed a ban on trading any raw elephant products by listing them on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITIES) Appendix I effective 18 January 1990.

All trade was banned by the 120 CITES signature countries (Heimert 1995) although the Vatican is not one of the signatories. However, in 1997 some geographic populations were moved back to the less restrictive Appendix II (United States Fish & Wildlife Service.November 2013). The largest numbers of elephants are found in Kenya, Zimbabwe, and SouthAfrica, and through great efforts and huge international cash contributions, the overall African elephant population has recently stabilized and has actually rebounded. However, as donor funds to protect elephants dry up (apparently the feeling is the porous ban is enough), new approaches to wildlife conservation are needed because of the expense of protecting elephants and maintaining their habitat. Estimates of protecting elephant in 1995 ranged from $1 billion annually to protect all African elephants to $200 million for just those in protected regions (Kelso 1995).

While both eastern and southern Africa plead for more international funding, led by cash-poor Kenya, the so-called Eastern Approach is simply to continue the ban of all international trade in elephant products thereby lowering the profit associated with killing elephants to the point where poaching will no longer threaten the overall population. On the other hand, the so-called Southern Approach calling for a lift of the international ban is also controversial; its gist is to treat the elephant like livestock letting the elephant pay its own way. It would, in essence, raise the profit in killing elephants to a point where only a relatively few elephant deaths would provide enough funds for saving the rest. These controlled kills—a harvest in others words—would in no way threaten the overall health of the elephant population; instead, they would insure the safety of it.

Which is the best policy for preserving African elephant populations? This paper argues that a well-constructed bioeconomic model will help provide insights and answers by combining generally accepted ecological theory with generally accepted economic theory to build a mechanistic model explaining how biology, public policy, market economics, and other factors combine to impact African elephant populations in Kenya. The paper postulates that African people have little desire to kill their elephants other than to sell the ivory to purchasers outside Africa. Thus, demand reflects global values while local values determine supply. Because of the potential predictive power of this proposed model, a successful study presents a new systematic methodology for investigating public policy considerations where endangered species are involved—especially those with no significant natural predator other than humans. This study produces an *ex-post facto* dynamic two-stage bioeconomic model, and the standard for judging this model should be by how well it brings order to disjointed data and in its originality of perception in identifying and relating variables affecting endangered species.

II. Review Of Literature

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, 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 (van Kooten 2008)

Kenya elephants live in both savannahs and forests, and according to the Kenya Wildlife Service, there are five reasons why the elephant is of critical importance to the Kenyan government. First, the population of Kenyan elephant has dramatically declined. Second, as a flagship species elephants can serve a rally point for conservation. Third, as an umbrella species elephants conservation depends on the protection of large ecosystems. Fourth,as a keystonespecies elephants serve a significant role in preserving biodiversity. Fifth, outside of protected areas human-elephant conflict is intense because of expanding human settlement and conversion of rangeland to agriculture (Litoroh et al. est. 2011). Besides, rapid agricultural expansion and the growth of agribusiness, other developments reducing suitable habitat include increasing impact of extractive industries, infrastructure development, climate change, rapid urbanization, and growing human populations (Dublin. 6 April 2016).

Kenya has one of the fastest growing populations worldwide leading to increasing conflict with elephants. To reduce this widespread conflict, elephants are legally killed by wildlife authorities and illegally killed by locals in response to crop destruction and attacks on livestock. In Kenya, 130 elephants were killed due to human-elephant conflict (HEC) between 1990 and 1993 whereas during the same period elephants killed 108 humans(Kiokl et al. 2008). Most HEC incidents involved elephants consuming or destroying food crops and injuring or killing people trying to protect their fields (Smith and Kasiki.January 2000). While the HEC is often assessed principally on the harm inflicted on people and property, local communities are known to retaliate with elephant injuries and sometimes elephant deaths (Mijele et al. 2013). As humans continue to encroach on elephant habitat, there are hidden costs, too. These hidden costs for humans include increased night duties, decreased mental wellbeing, and increases in sociopolitical inequities. Humans new to the HEC have trouble adapting to dangers and challenges of sharing their space with elephants (Bond 2015). According to Duffy et al (2015), the links between poverty and illegal wildlife hunting reveal a "limited understanding and that conservationist need to take a more expansive view of what constitutes illegal wildlife hunting . . . some communities could regard laws that criminalize their continued use of wildlife as unjust precisely because these laws were instituted by colonial regimes or post-independence states that communities may regard as oppressive rather than representative."

While all African elephants were moved to CITES Appendix I in 1989, the elephant populations of Namibia, South Africa and Zimbabwe returned to Appendix II allowing them to sell raw ivory under strict conditions. In 1997 Botswana, Namibia, and Zimbabwe agreed to sell and in June 1999 they delivered 22,500 pounds of ivory to Japan. In October/November 2008 a second sale involved Botswana, Namibia, South Africa, and Zimbabwe selling 49,000 pounds of ivory to China and Japan. However, since 2007 there has been an alarming trend in African elephant poaching; illegal ivory trade has doubled and is now three times greater than in 1998. Seizures of ivory shipments hit a high in 2011 indicating a growing and well-organized illegal ivory trade between Africa and Asia. Poaching is spreading due to rising ivory demand in Asia (particularly China and Thailand) and weak governance and collusive corruption, at all levels. Poverty aids the recruitment (by bribery or threats) of underpaid police, military personnel, and wildlife rangers by organized criminals (UNEP et al. 2013). Previous studies show correlations between elephant population trends and corruption, and have documented corruption in the illegal killings of elephants for ivory and meat (Smith 2015). And while Bryan

Christy firmly believes poaching is a significant financial resource for terrorists in Africa (Christy.12 August 2015), Tristan McConnell argues just as strongly the “real killers of African elephants are criminal enterprises with the ability to establish and maintain supply chains stretching from the forest of Africa to the markets of Asia, greasing palms and paying off corrupt official every step of the way”; she believes to stop poaching, you must target “corruption, criminals, and the buyers of illegal ivory” (McConnell. 29 October 2015).

Often overlooked is the impact of ivory poaching on elephant genetics and group dynamics. Because they carry the largest tusks, poaching selectively removes the large breeding male elephants and social group matriarch thereby negatively impacting demographic processes and social organization. Moreover, while genetic evidence of the recent effects of poaching has been detected, allelic diversity was not detectably affected on account of the short duration of the poaching epidemic thus far(Ohman 2015).

While Messer (2000) modeled the ivory price vs. elephant populations as a Poacher’s Dilemma balancing marginal costs against marginal benefits, perhaps the simplest way to estimate the impact of U.N trade policies on elephant poaching is a parsimonious bioeconometric model with two endogenous variables and two exogenous variables. It seems the first bioeconometric model published was by Barbier (2003) when he used regression analysis to model the supply and demand (including a shift in demand rather than a change in slope) curves associated with mangrove loss and long-run equilibrium of an open-access fishery. However, Smith (2008) seemingly coined the name bioeconometrics and defined it as: “A bioeconometric model is a structural model that econometrically estimates one or more parameters of a bioeconomic system.” An interesting approach, in designing her Dual Markets Model, Fisher (2004) thought of elephant stock as exogenous and used equilibrium poaching from her static model to feed back into the elephant stock. Equally interesting was Gren et al (2016) using a logistic function to model wildlife populations in a hunting model. However, the literature review found no attempt to econometrically measure the impact of any governmental policy changes on wildlife including the impact of U.N. trade policies on elephant populations.

III. Model Development

Since all models are wrong the scientist cannot obtain a "correct" one by excessive elaboration. On the contrary following William of Occam he should seek an economical description of natural phenomena. Just as the ability to devise simple but evocative models is the signature of the great scientist so overelaboration and overparameterization is often the mark of mediocrity—George Box 1976

In any bounded environment there is a finite amount of resources, and all life forms require certain—whatever they may be—resources to live. Obviously then, the more identical the needs of two life forms are the more they will have to compete with each other if there is not enough of the required resource. So, if all others things remain constant, each environmental space has a limited biological “carrying capacity” for each species. Accordingly, as a species population approaches its carrying capacity, birth rates fall and death rates increase, and past studies indicate that logistic equations are useful in modeling elephant populations (Laws 1975). Thus, the following logistic equation is forwarded to model this phenomenon for African elephants:

$$dN/dt = rN(1-N/K) \tag{1}$$

where

dN/dt is the African elephant population growth rate,
r is the intrinsic dt net growth rate for African elephants,
N is the African elephant population size, and
K is the geographic carrying capacity of African elephants.

This is a very functional equation because by varying K. it is possible to model environmental impacts on speciespopulations. This model represents the first stage, and the results of this model feed into the second stage model.

Humans relate to elephants on two distinct bases: as competitors and as predators. As biological competitors, humans compete with elephants for land-based resources. Unlike elephants, humans have the technological ability to reduce their dependence on the immediate surrounding land. In addition, while the relationship may vary from place to place; still, human presence typically reduces the biological carrying capacity of elephants.

The second way humans relate to elephants is as predators. However, unlike other animal predator-prey relationships, in this one economics rather than biology governs. The law of supply and demand for ivory governs nearly all the elephant killings each year. A supply curve relates the number of dead elephants that a local population will provide for a given price and is based upon how much the locals value live elephants along with local concerns about killing elephants—legal or not. As the elephant population drops, if all other things remain the same, the supply curve should shift to the left reflecting an increasing value due to increasing scarcity of the remaining herds. A demand curve relates the number of dead elephants the world purchases from the locals at a given price. Whether they are legal kills or not, aggregate worldwide demand shapes it. As the most valued part of a dead elephant, the market value of raw ivory should reflect this aggregate demand accurately. Accordingly, the U.N. ban should have shifted the demand curve to the left relative to ivory reflecting a reduced worldwide demand. Where the supply and demand curves cross determines how many elephants are killed at a given ivory price. This intersection is the second stage model. In summary, while the primary purpose of this study is to measure the shift of the demand curve brought on by changing U.N. trade policies, it will also measure the protective attitudes of the local people relative to changing elephant population numbers.

The following exactly identified structural equations are designed to model supply and demand:

$$Q_s = \alpha_1 P + \beta_1 S + C_1 \qquad (2)$$

$$Q_d = \alpha_2 P + \beta_2 U + C_2 \qquad (3)$$

where Q is the number of Kenyan elephant poaching deaths,
P is the global price of ivory per pound,
S is the Kenyan elephant population,
U is a dummy variable representing U.N. trade policy, and
C is the intercept.

IV. Data And Methodology

While comprehensive detailed data are not available, there are enough data point sources to interpolate enough for modeling. The study period is from 1980 through 2015 and the literature review provides the initial figures shown in Appendix Table A.1.

The U.N. ban went into effect in 1990 and the first post-ban one-time U.N. approved sale took place in 1999. In their review of the literature, Milner-Gulland and Beddington (1993) cited two studies that listed the recruitment rate at 7% per year for African elephants, and suggested the African elephant population was only 8% of the carrying capacity in 1987. For model purposes, the intrinsic growth rate is determined using logistic equation (1), and elephant population numbers are estimated based on interpolation of sourced data. Based on Ohman (2015) observation that agricultural lands in Kenya increased by 7.5% between 1977 and 2012, for modeling purposes carrying capacity is decreased by 1% annually without regard to the impact cyclical droughts have on carrying capacity and thus small oscillations in intrinsic growth, nor is elephant migration in and out of Kenya, adjusted for. I do not attempt to identify authorized killings either. In the first-stage ecology model prior population plus intrinsic growth minus current population equals premature deaths, i.e. poaching. For the stage-two econometric model, ivory prices are interpolated based on sourced data and adjusted for inflation using the United States Consumer Price Index (Consumer Price Index Data from 1913 to 2016, 2016). I use the resulting figures in Appendix Table A.2 to fit the econometric structured equations.

Because at equilibrium supply must equal demand, the following identity is used:

$$Q_s = Q_d \qquad (4)$$

and so the two structural equations, (2) and (3), are first converted to the following reduced forms

$$P = \pi_{11} U + \pi_{12} S + \varepsilon_1 \qquad (5)$$

$$Q = \pi_{21} U + \pi_{22} S + \varepsilon_2 \ (6)$$

where $\pi_{11} = \frac{\beta_2}{\alpha_1 - \alpha_2} \pi_{12} = \frac{-\beta_1}{\alpha_1 - \alpha_2} \pi_{21} = \frac{\alpha_1 \beta_2}{\alpha_1 - \alpha_2} \pi_{22} = \frac{-\alpha_2 \beta_1}{\alpha_1 - \alpha_2}$ (7)

and then regressed using Ordinary Least-Squares (OLS) on the data in Appendix Table A.2.

5. RESULTS AND DISCUSSION

I first use these price and quantity regressions to measure the impact of the U.N. ban covering the period 1980 – 1998. As shown in Appendix Tables 3 and 4, the results of the regression are as follows:

$$\pi_{11} = -179.0636 \pi_{12} = -0.003308 \pi_{21} = -4{,}194.304 \pi_{22} = 0.1984832 (8)$$

Therefore, for the period 1980 – 1998,

$$Q_s = -6{,}844 + 23.42P + 0.276S + \varepsilon \qquad (9)$$

and

$$Q_d = 17{,}729 - 59.96P - 14{,}932U + \varepsilon \qquad (10)$$

Together they produce Figure 1.

As shown in Appendix Tables A.5 and A.6, the residuals appear to be random and the F value (59.2) for the supply curve indicates there is well under a 1% chance of Type I error in its usage. However, the demand curve is the primary concern of this study and again the F value (38.9) is more than enough to reduce the chance of Type I error to below 1%. The standard error of the demand coefficients is 5.4 for price and 921.3 for the ban. For beta two (the coefficient representing the demand curve shift caused by the U.N. ban) the probability of it not being statistically different from zero is less than one percent. Therefore, statistically speaking, I infer from the data modeled here the ban on ivory trading had a significant impact in reducing poaching in Kenya. A change in global trade policy changed the supply and demand equilibrium. This model indicates that an average reduction of 14,932 elephant deaths per year in Kenya coincides with the placement of elephants on CITES Appendix I.

Next, I use price and quantity regressions to measure the impact of the exemption from the U.N. trade ban covering the period 1990 – 2015. As shown in Appendix Tables A.7 and A.8, the results of the regression are as follows:

$$\pi_{11} = -344.87806\pi_{12} = 0.06401719\pi_{21} = 1{,}021.1468\pi_{22} = 0.036655(11)$$

Therefore, for the period 1990 – 2015,

$$Q_s = -4{,}586 - 2.96P + 0.226S + \varepsilon \qquad (12)$$

and

$$Q_d = 67 + 0.573P + 1{,}219U + \varepsilon \qquad (13)$$

Together they produce Figure 2.

As shown in Appendix Tables A.9 and A.10, the residuals of the demand curve appear to be random and the F value (38.9) for the demand curve indicates there is well under a 1% chance of Type I error in its usage. However, the supply curve suffers two problems. First, the error terms do not seem random and, second, the F value (1.09) is too low to be statistically significant. While theoretically OLS yields the Best Unbiased Linear Estimator, it requires random distribution of error terms to insure the data is correctly modeled. Nevertheless, the demand curve is the primary concern of this study and again its F value (113.5) is more than enough to reduce the chance of Type I error to below 1%. The standard error of the demand coefficients is 0.1448 for price and 91.3 for periods including and following the ban-exempt sales. For beta two (the coefficient representing the demand curve shift caused by the U.N. exempt sales) the probability of it not being statistically different from zero is less than one percent. Therefore, statistically speaking, I infer from the data modeled here that the allowance of exempt sales on ivory trading had a significant impact in increasing poaching in Kenya. Again, a change in global trade policies shifted the equilibrium. This model indicates that an average increase of 1,219 elephant deaths per year in Kenya coincides with the allowance of exempt sales. In other words, the so-called one-time exempt sales coincide with a continuing annual increase of 1,219 elephant deaths in Kenya since the first exempt sales in 1999.

While the supply and demand curves of the period 1980 to 1998 follow the traditional pattern of an upward sloping supply curve and a downward sloping demand curve, things turn nontraditional for measurements made for the period 1990 to 2015. Here, violating the "law of demand," the demand curve slopes upwards like modeling for a Giffen Good. This rare phenomenon is consistent with a demand bubble where demand chases demand seeking the "bigger fool." A contributing factor could be the popular prediction that a major purchaser of ivory (the people of China) could face national ivory restrictions. Regardless, the international price of ivory saw a major drop in 2016 perhaps indicating a market correction for the upward sloping demand curve.

Although the supply curve for the period 1990 to 2015 failed the statistical test for inference, still a few observations are possible. The residual pattern indicates a linear model does not fit the data for this extended period. While a regional resource-dependent economy might increase supply to maintain revenues providing a downward sloping supply, there is just not enough evidence that this phenomenon is what occurred in Kenya. Perhaps dividing the data into smaller time segments might make it easier to fit the data into a linear model. Regardless, the graph of an upward demand curve crossing a downward sloping supply curve is indeed a rare sight. Clearly, data that are more reliable would provide additional assurance, but the findings seem reasonable considering the economic environment. With demand being determined in one part of the world while demand restriction being attempted though fluctuating global regulation and a resource-dependent economy suffering the ambitions of cash-hungry terrorists and impoverished farmers controlling the supply in a separate geography, it should come as no surprise that modeling the economics of poaching might turn strange.

Using just four variables, this study establishes that dynamic bioeconometric equilibrium modeling is useful for determining the impact of changing global regulation on an endangered species. The relatively simple second-stage bioeconometric model merely requires data for species population, poaching numbers, prices, and the dates of policy changes for a period under review. The endogenous regression variables are market prices along with quantity of deaths and the exogenous variables are species population along with before/after policy change date. This endangered-species model is premised on demand being determined globally while supply is determined locally. In this case, because of data limitations a first-stage ecological model is used to provide poaching numbers based on estimated habitat carrying capacity, species intrinsic growth rate, and species population data.

V. Conclusions

According to the models produced, the United Nations ban reduced the amount of elephant poaching each year by 14,932 in Kenya, and this reduction was crucial in saving Kenya's elephant population. These models also reveal that during the period 1980 – 1998, the local population allowed poaching of 27.6% of theexisting Kenyan elephant populationeach year plus nearly 24 more elephants for every U.S. dollar per pound increase in global ivory prices, *ceteris paribus*. With an intrinsic growth rate of only 7%, clearly, there is local collective willingness (obviously not all locals feel this way) that would have led to the extirpation of elephants in Kenya without the global stigma (again, not all individuals feel this way) associated with a U.N. ban. These models further reveal that for the period 1980—1998 yearly global demand dropped by 60 elephants for every U.S. dollar the global price per pound increased. These models also show the number of yearly poaching deaths in Kenya increased by 1,219 following the allowance of so-called one-time sales.

While more and better empirical data would obviously make for better models, this parameter-limited methodology works. Do these models answer all questions about African elephant management practices? Of course not! To begin with, I need better ways to identify and estimate the factors affecting regional carrying capacities. This study makes no attempt to measure the short-run impact of droughts on net growth rates, nor does it allow for migration in and out of the study zone. These are thought to balance out. Also, by not attempting to distinguish non-poaching kills this study uses estimated premature deaths as an instrumental variable for poaching numbers. However, I believe the study format sufficiently robust to overcome these shortcomings in addressing the essences of the big questions. Even if the demand shift were overstated quantitatively, the direction of the shift made by U.N. policy changes is undeniable. Additionally, this investigation is limited to Kenya. For African elephant answers as a whole, more regional studies have to be performed and compiled because saving the elephant requires regional cooperation. While this paper is not a perfect empirical investigation, it does seem to be the first to bioeconometrically measure the impact of changing trade policies on wildlife populations. Moreover, in this case the parsimonious methodology demonstrates how to approximate the bioeconomic reasons for the near extinction of a species thought by many to be worth more dead than alive. Besides modeling wildlife and fisheries, this approach also has potential for use in other areas, e.g. illegal drug trade.

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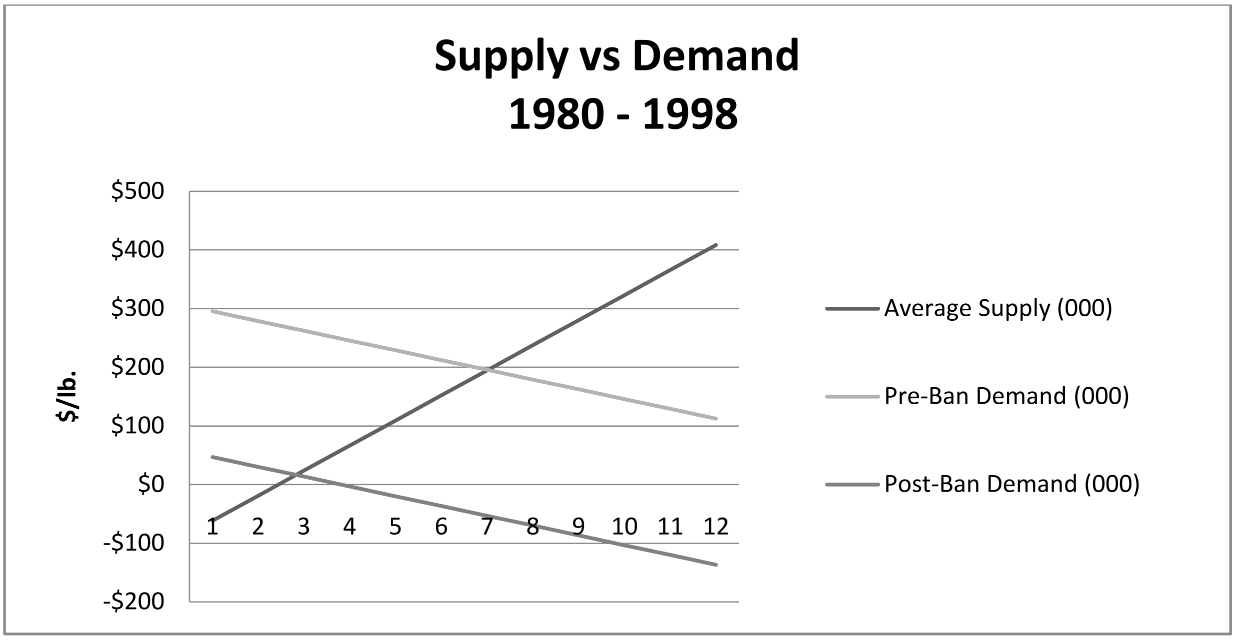

Figure 1

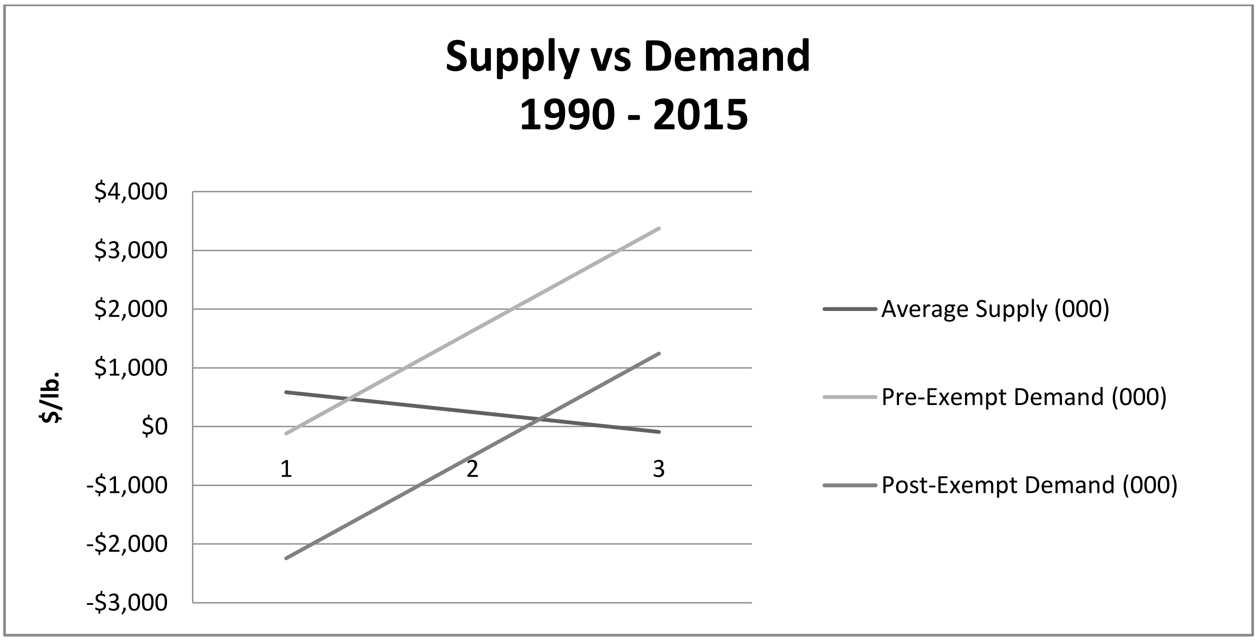

Figure 2

8. APPENDIX

Table A.1

Sourced Data

Year	Source	Kenyan Elephant Population	Source	Kenyan Ivory Prices $/lb.	Source	Global Ivory Prices $/lb.
1980	Wainaina	70,000	Messer	35	Parker	34
1981					Parker	29
1982					Parker	26
1983					Japan	65

1984					Japan	69
1985			Messer	60	Japan	86
1986					Japan	84
1987					Japan	94
1988	Heimert	19,000			Japan	121
1989	Balzar	16,000	Messer	90	Japan	161
1990			Kenya	2		
1991						
1992						
1993						
1994	Bulte	23,797	Menon	23	Menon	74
1995	Balzar	25,000	Balzar	1	Menon	74
1996			Menon	23	Menon	74
1997					Poaching	45
1998	Barnes	25,714			Menon	205
1999					Japan	47
2000						
2001						
2002	Blanc	28,806			Straziuso	45
2003						
2004					Cowell	97
2005						
2006	Elephant	28,951			Stiles	298
2007	Lemieux	31,636	Rising	17		
2008					Poaching	64
2009						
2010			Gao	34	Price	340
2011						
2012						
2013	Elephant	34,905	Gao	86	China's	863
2014			Gao	95	Stiles	954
2015					Poaching	973
2016	Kiambi	35,149			Sharp	500

Source refer to Reference Section

Table A.2

Regression Data

Year	UN Ban n=0 y=1	Kenyan Elephant Population	Carrying Capacity	Intrinsic Growth	Premature Deaths	Inflation Adjusted Ivory Prices $/lb.	Post UN Approved Sales n=0 y=1
1980	0	70,000	294,837	3,737	12,737	102	0
1981	0	61,000	291,918	3,378	12,378	78	0
1982	0	52,000	289,028	2,985	10,985	64	0
1983	0	44,000	286,166	2,606	9,606	155	0
1984	0	37,000	283,333	2,252	8,252	158	0
1985	0	31,000	280,528	1,930	6,930	191	0
1986	0	26,000	277,750	1,650	5,650	191	0
1987	0	22,000	275,000	1,417	4,417	198	0
1988	0	19,000	272,250	1,237	3,237	244	0
1989	0	17,000	269,528	1,115	1,615	311	0
1990	1	16,500	266,832	1,084	84	18	0
1991	1	17,500	264,164	1,144	44	16	0
1992	1	18,600	261,522	1,209	9	14	0
1993	1	19,800	258,907	1,280	80	11	0
1994	1	21,000	256,318	1,350	50	96	0

1995	1	22,300	253,755	1,424	24	8	0
1996	1	23,700	251,217	1,502	2	112	0
1997	1	25,200	248,705	1,585	85	66	0
1998	1	26,700	246,218	1,666	366	67	0
1999	1	28,000	243,756	1,735	1,335	67	1
2000	1	28,400	241,318	1,754	1,354	65	1
2001	1	28,800	238,905	1,773	1,573	61	1
2002	1	29,000	236,516	1,781	1,281	59	1
2003	1	29,500	234,151	1,805	1,305	91	1
2004	1	30,000	231,809	1,828	1,328	122	1
2005	1	30,500	229,491	1,851	1,351	240	1
2006	1	31,000	227,196	1,874	1,374	351	1
2007	1	31,500	224,924	1,896	1,396	196	1
2008	1	32,000	222,675	1,918	1,918	71	1
2009	1	32,000	220,448	1,915	1,415	224	1
2010	1	32,500	218,244	1,936	1,436	367	1
2011	1	33,000	216,061	1,957	957	545	1
2012	1	34,000	213,901	2,002	1,502	709	1
2013	1	34,500	211,762	2,022	2,022	876	1
2014	1	34,500	209,644	2,018	1,518	953	1
2015	1	35,000	207,548	2,037	2,037	973	1

Interpolated and estimated data from Table 1

Table A.3

P = π11U + π12S + e

Regression Statistics	
Multiple R	0.882940154
R Square	0.779583315
Adjusted R Square	0.75203123
Standard Error	43.51292794
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	107145.6806	53572.84	28.29489	5.57129E-06
Residual	16	30293.99837	1893.375		
Total	18	137439.679			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	294.6391988	32.50876286	9.063378	1.06E-07
X Variable π11U	-179.063608	23.81222448	-7.51982	1.23E-06
X Variable π12S	-0.00330828	0.000777125	-4.25707	0.000602

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*
1980	63.05959966	39.07456486
1981	92.83411955	-14.93178621
1982	122.6086394	-58.17192682
1983	149.0748793	6.251858906
1984	172.2328392	-13.98177939
1985	192.0825192	-1.572547609
1986	208.6239191	-17.28485478
1987	221.8570391	-24.29896352
1988	231.781879	12.63080032
1989	238.398439	72.28463424
1990	60.98897114	-42.64462263
1991	57.68069115	-42.05392295
1992	54.04158317	-40.50316173
1993	50.07164718	-38.59935405
1994	46.1017112	49.8108743
1995	41.80094721	-34.02626325
1996	37.16935523	74.84047638
1997	32.20693525	33.89498178
1998	27.24451527	39.28099216

Table A.4

Q = π21U + π22S + e

Regression Statistics	
Multiple R	0.986248182
R Square	0.972685477
Adjusted R Square	0.969271162
Standard Error	827.1377736
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	389811375.4	1.95E+08	284.8845	3.09848E-13
Residual	16	10946510.35	684156.9		
Total	18	400757885.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	58.1332266	617.9594665	0.094073	0.926219
X Variable π21U	-4194.304224	452.6468631	-9.26617	7.85E-08
X Variable π22S	0.198483163	0.014772385	13.43609	3.94E-10

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*
1980	13951.95464	-1215.308434
1981	12165.60617	212.1228347
1982	10379.25771	605.85711
1983	8791.392402	815.036484
1984	7402.010261	849.7655434
1985	6211.111282	719.0904806
1986	5218.695467	430.9354963
1987	4424.762814	-7.962814417
1988	3829.313325	-592.1324253
1989	3432.346999	-1817.404275
1990	-861.1988069	944.7775234
1991	-662.7156438	706.5633752
1992	-444.3841645	453.7832529
1993	-206.2043688	286.2095689
1994	31.97542695	17.58822628
1995	290.003539	-266.1843972
1996	567.8799673	-565.3911188
1997	865.6047119	-780.3417191
1998	1163.329457	-797.0047116

Table A.5

Supply Curve Analysis

Year	Poaching Deaths	Q(s)	Error	SSE	SST
1980	12,737	14,868	-2,131	4,542,593	75,823,102
1981	12,378	11,816	561	315,009	69,701,276
1982	10,985	9,017	1,968	3,873,052	48,387,533
1983	9,606	8,938	669	447,128	31,107,713
1984	8,252	7,074	1,178	1,386,591	17,831,835
1985	6,930	6,174	756	572,229	8,416,972
1986	5,650	4,813	836	699,682	2,626,445
1987	4,417	3,855	562	315,833	150,389
1988	3,237	4,124	-887	786,705	626,977
1989	1,615	5,124	-3,509	12,314,870	5,827,673
1990	84	-1,860	1,944	3,778,957	15,566,349
1991	44	-1,648	1,692	2,862,420	15,881,439
1992	9	-1,393	1,403	1,967,649	16,157,191
1993	80	-1,111	1,191	1,417,348	15,594,560
1994	50	1,198	-1,149	1,319,533	15,835,914
1995	24	-507	531	281,893	16,041,474
1996	2	2,320	-2,318	5,373,038	16,212,792

1997	85	1,659	-1,574	2,477,614	15,553,062
1998	366	2,083	-1,717	2,947,755	13,415,190
Mean	4,029.0		Totals	47,679,898	400,757,886

	df	SS	MS	F ratio
Regression	2	353,077,988	176,538,993.8	59.2
Residual	16	47,679,898	2,979,993.6	
Total	18	400,757,886		

Table A.6

Demand Curve Analysis

Year	Poaching Deaths	Q(d)	Error	SSE	SST
1980	12,737	11,605	1,132	1,280,543	75,823,102
1981	12,378	13,058	-680	462,736	69,701,276
1982	10,985	13,865	-2,880	8,295,897	48,387,533
1983	9,606	8,416	1,191	1,418,053	31,107,713
1984	8,252	8,240	12	132	17,831,835
1985	6,930	6,306	624	389,600	8,416,972
1986	5,650	6,256	-607	368,059	2,626,445
1987	4,417	5,883	-1,467	2,150,968	150,389
1988	3,237	3,074	163	26,623	626,977
1989	1,615	-900	2,514	6,322,709	5,827,673
1990	84	1,697	-1,613	2,603,363	15,566,349
1991	44	1,860	-1,816	3,298,478	15,881,439
1992	9	1,985	-1,976	3,903,932	16,157,191
1993	80	2,109	-2,029	4,117,312	15,594,560
1994	50	-2,954	3,003	9,020,906	15,835,914
1995	24	2,331	-2,307	5,322,299	16,041,474
1996	2	-3,919	3,922	15,378,934	16,212,792
1997	85	-1,166	1,252	1,566,838	15,553,062
1998	366	-1,192	1,558	2,427,969	13,415,190
Mean	4,029.0		Totals	68,355,351	400,757,886

	df	SS	MS	F ratio
Regression	2	332,402,534	166,201,267.2	38.9
Residual	16	68,355,351	4,272,209.5	
Total	18	400,757,886		

$t^*_{\alpha 2} = \frac{-59.96}{5.4} = -11.1$

$t^*_{\beta 2} = \frac{-14932}{921.3} = -16.2$

Table A.7

$P = \pi11U + \pi12S + e$

Regression Statistics	
Multiple R	0.74401973
R Square	0.553565359
Adjusted R Square	0.514744956
Standard Error	213.0149395
Observations	26

ANOVA

	df	*SS*	*MS*	*F*
Regression	2	1294073.612	647036.8	14.25965
Residual	23	1043633.382	45375.36	
Total	25	2337706.994		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1315.464655	343.7060314	-3.8273	0.000863
X Variable π11U	-344.8780573	183.2767612	-1.88173	0.072588
X Variable π12S	0.064017189	0.015821357	4.046251	0.000501

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*
1990	-259.1810369	277.5253854
1991	-195.1638479	210.7906161
1992	-124.74494	138.2833614
1993	-47.92431321	59.39660634
1994	28.89631357	67.01627193
1995	112.1186593	-104.3439753
1996	201.7427238	-89.73289222
1997	297.7685073	-231.6665903
1998	393.7942908	-327.2687834
1999	132.1385792	-65.28386829
2000	157.7454548	-92.6730081
2001	183.3523304	-121.9558598
2002	196.1557682	-136.7722843
2003	228.1643627	-136.8424199
2004	260.1729572	-137.767023
2005	292.1815516	-51.97928631
2006	324.1901461	27.01855784
2007	356.1987406	-159.9033355
2008	388.2073351	-317.3534839
2009	388.2073351	-164.6204106
2010	420.2159296	-53.51012816
2011	452.2245241	93.24710238
2012	516.2417131	193.1642828
2013	548.2503076	327.5927574
2014	548.2503076	404.8973095
2015	580.2589021	392.7410979

Table A.8

$Q = \pi21U + \pi22S + e$

Regression Statistics	
Multiple R	0.955797703
R Square	0.91354925
Adjusted R Square	0.906031793
Standard Error	219.1835609
Observations	26

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	11676346.95	5838173	121.5237	5.92708E-13
Residual	23	1104952.967	48041.43		
Total	25	12781299.91			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-696.422432	353.659288	-1.96919	0.061094
X Variable $\pi21U$	1021.146824	188.5842056	5.414806	1.68E-05
X Variable $\pi22S$	0.03665495	0.016279522	2.251599	0.0342

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*
1990	-91.6157509	175.1944674
1991	-54.96080053	98.8085319
1992	-14.64035513	24.03944362
1993	29.34558531	50.65961484
1994	73.33152575	-23.76787252
1995	120.9829612	-97.16381944
1996	172.2998917	-169.8110433
1997	227.2823173	-142.0193245
1998	282.2647428	84.06000204
1999	1351.063003	-16.20632679
2000	1365.724983	-11.68653648
2001	1380.386963	192.5843181
2002	1387.717953	-106.6228398
2003	1406.045428	-101.2088672
2004	1424.372904	-96.14793046
2005	1442.700379	-91.44753786
2006	1461.027854	-87.11532896
2007	1479.355329	-83.15907637
2008	1497.682804	420.4133121
2009	1497.682804	-82.83824225
2010	1516.010279	-79.79404619
2011	1534.337755	-577.1539851
2012	1570.992705	-69.2987799
2013	1589.32018	432.2307918
2014	1589.32018	-71.74344083
2015	1607.647655	429.1945162

Table A.9

Supply Curve Analysis

Year	Poaching Deaths	Q(d)	Error	SSE	SST
1990	84	-903	987	973,338	829,049
1991	44	-669	713	508,152	902,979
1992	9	-413	422	178,421	969,636
1993	80	-135	215	46,227	835,569
1994	50	-113	163	26,427	892,149
1995	24	442	-418	174,875	941,445
1996	2	451	-449	201,162	983,293
1997	85	926	-841	706,839	825,985
1998	366	1,265	-899	807,617	394,102
1999	1,335	1,558	-223	49,793	116,115
2000	1,354	1,654	-300	89,977	129,556
2001	1,573	1,755	-182	33,134	335,092
2002	1,281	1,807	-526	276,576	82,366
2003	1,305	1,825	-520	270,570	96,557
2004	1,328	1,847	-519	269,128	111,639
2005	1,351	1,611	-260	67,469	127,558
2006	1,374	1,396	-22	488	144,258
2007	1,396	1,968	-572	326,960	161,681
2008	1,918	2,452	-534	285,053	853,769
2009	1,415	2,000	-585	342,407	177,026
2010	1,436	1,690	-254	64,406	195,467
2011	957	1,274	-317	100,373	1,363
2012	1,502	1,015	487	236,871	257,652
2013	2,022	636	1,386	1,919,751	1,055,655
2014	1,518	407	1,111	1,233,381	274,028
2015	2,037	461	1,576	2,483,279	1,087,311
Mean	994.1		Totals	11,672,672	12,781,300

	df	SS	MS	F ratio
Regression	2	1,108,627	554,313.7	1.0922277
Residual	23	11,672,672	507,507.5	
Total	25	12,781,300		

Table A.10

Demand Curve Analysis

Year	Poaching Deaths	Q(d)	Error	SSE	SST
1990	84	78	6	37	829,049
1991	44	76	-32	1,031	902,979
1992	9	75	-65	4,272	969,636
1993	80	74	6	41	835,569
1994	50	122	-72	5,241	892,149
1995	24	71	-48	2,269	941,445
1996	2	131	-129	16,562	983,293
1997	85	105	-20	385	825,985
1998	366	105	261	68,228	394,102
1999	1,335	1,324	11	111	116,115
2000	1,354	1,323	31	946	129,556
2001	1,573	1,321	252	63,399	335,092
2002	1,281	1,320	-39	1,516	82,366
2003	1,305	1,338	-33	1,122	96,557
2004	1,328	1,356	-28	779	111,639
2005	1,351	1,424	-72	5,239	127,558
2006	1,374	1,487	-113	12,844	144,258
2007	1,396	1,398	-2	5	161,681
2008	1,918	1,327	591	349,869	853,769
2009	1,415	1,414	1	1	177,026
2010	1,436	1,496	-60	3,589	195,467
2011	957	1,599	-641	411,357	1,363
2012	1,502	1,692	-191	36,403	257,652
2013	2,022	1,788	234	54,612	1,055,655
2014	1,518	1,832	-315	98,959	274,028
2015	2,037	1,844	193	37,370	1,087,311
Mean	994.1		Totals	1,176,185	12,781,300

	df	SS	MS	F ratio
Regression	2	11,605,115	5,802,557.3	113.46751
Residual	23	1,176,185	51,138.5	
Total	25	12,781,300		

$$t^*_{\alpha 2} = \frac{0.573}{0.1448} = 4t^*_{\beta 2} = \frac{1219}{91.3} = 13.4$$