Elephants and Mammoths: Can Ice Ivory Save Blood Ivory?*

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Abstract

We study both theoretically and empirically how the presence of a substitute alters the exploitation path of an open access resource. Elephants, poached for ivory, are the endangered species, and mammoth ivory is a non-renewable substitute. Our theory shows that the presence of the mammoth ivory substitute reduces both the elephant poaching rate and the minimum viable elephant population. Thus, there exist elephant population levels which are non-viable absent a substitute, but become viable with a substitute. Our empirical analysis finds that absent the eighty tonnes of Russian mammoth ivory exports per annum 2010-2012, the current poaching level of 34,000 elephants per year may have increased to as many as 85,000 elephants per year, out of a population of a half-million animals, and reduced elephant ivory prices by $100 per kilogram. Thus mammoth ivory trade may be saving elephants from extinction.

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1 Introduction

While elephants have been harvested for their ivory since antiquity, between 1979 and 1989, the slaughter caused the African Elephant (*Loxodonta africana*) population to more than halve from about 1,300,000 animals to 600,000 animals (Barbier et al. 1990). This rapid decline led to trade in African elephant ivory being declared illegal in 1989 under the Convention on International Trade in Endangered Species (CITES).[1] Yet continued poaching threatens elephants with extinction. Between 2010 and 2014, Wittemyer et al. (2014) estimate that nearly 34,000 African elephants were slaughtered for ivory per annum out of a population believed to be between 430,000 to 680,000 (Elephant Database 2013). Currently, elephants are listed as "vulnerable" under the International Organization for Conservation of Nature (IUCN) "Red List" of threatened species (Blanc 2008). Swanson (1994) characterizes the main factors leading to extinction to be: (*i*) open access to the resource, (*ii*) a high price relative to cost of harvesting, and (*iii*) a low growth rate relative to the rate of harvesting. The African elephant fulfils each of these criteria. Since a number of species have been pushed to or near extinction by human actions in the past, there is much concern that this most charismatic of mega-fauna may be in danger.[2]

The extinction of elephants may, however, be delayed or even avoided because of the happy event of the rapid rise in production of a close substitute for elephant ivory—ivory from the mammoth (*Mammuthus primigenius*), a species that humans may have previously pushed to extinction (Smith 1975). The collapse of the Soviet Union in the early 1990s heralded the rise of Russian mammoth ivory as an important substitute for elephant ivory (Martin et al. 2010, 2011), with mammoth ivory now accounting for perhaps 20% of all ivory production. A large stock of mammoth tusks, perhaps as many as ten million carcasses – several hundred years' worth of supplies at current production levels – lies beneath the Arctic tundra (Lister and Bahn 2007). Thus, mammoth ivory has the

[1]Trade in Asian elephant (*Elephas maximus*) ivory was banned in 1975. The Asian elephant population is between 41,410 to 52,345 (Sukumar 2003). Poaching is less severe for the Asian elephant because some males and all female Asian elephants lack tusks (Dawson and Blackburn, 1991).

[2]The population of passenger pigeon (*Ectopistes migratorius*), a wild North American bird, was 3 to 5 billion at the time of arrival of the Europeans in North America, constituting 25 to 40 percent of the total bird population of the United States. With mass deforestation due to European settlement and commercial exploitation of pigeon meat, by the mid 1880s, the passenger pigeon completely disappeared (Yeoman, 2014; Bucher, 1999). Other examples of extinction due to over-exploitation include the Dodo bird (*Raphus cucullatus*) (extinct in 1755) and the Tasmanian tiger (*Thylacinus cynocephalus*) (1933), and the near-extinction of the American bison in the 1870s (Taylor 2011) and the Eastern bowhead whale (1911) (Allen and Keay 2001, 2004).

potential to be an important substitute for elephant ivory. Interestingly, substitutes have long played an important role in elephant ivory. In the mid-19th century, an important use of ivory was in the production of billiard balls. Since one elephant tusk was required to make a single set of billiard balls, concern over ivory supplies led New York suppliers to offer a $10,000 reward for finding a substitute. This inspired John Wesley Hyatt in 1869 to invent nitrocellulose, the first industrial plastic, as a substitute for ivory (Miodownik 2014).[3]

Using a general equilibrium bioeconomic model, this paper analyzes how poaching of elephants is affected when mammoth ivory becomes available as a close substitute to elephant ivory. Because mammoths are extinct, mammoth ivory is a non-renewable resource, though one whose reserves are equal to hundreds of years' production at current levels. Elephant ivory, in contrast, is a renewable but exhaustible resource, produced by poachers.[4] We calculate how the elephant population evolves with and without the mammoth ivory substitute. Not surprisingly, the presence of a mammoth ivory substitute lowers the demand for elephant ivory. This is important, however, because extinction occurs only if the elephant population is reduced below a critical minimum viable population level. We show that the presence of a substitute causes this critical minimum viable population level to occur at a lower number of elephants, which means that the presence of a substitute could save an endangered species from extinction for populations between these critical minimum population levels.

We also examine whether the evidence is consistent with the poaching and storage equilibrium of Kremer and Morocom (2000), where poachers store ivory for when the elephant population becomes extinct. We show that while the poaching and storage equilibrium is consistent with rising legal prices of elephant ivory and with rising mammoth ivory production, it is inconsistent with rising elephant populations and with rising elephant ivory interdiction seizures.

We empirically estimate the magnitude of the effect that Russian mammoth ivory has had upon African elephant poaching since 1990. Our measure of African elephant poaching is elephant ivory interdiction seizures, the only available measure of elephant ivory production. In addition, we estimate the effect Russian mammoth ivory production

[3]Although Hyatt's invention of nitrocellulose was inspired by the prize, no evidence exists that he was awarded it. This might be because nitrocellulose balls often exploded when they collided (Miodownik 2014). Billiard balls are now made from a strong crack-resistant plastic called phenolic resin.

[4]There is a small amount of elephant ivory which is legally harvested, mostly by big game hunters. Section 2 below discusses some CITES permitted elephant ivory sales.

has had upon imputed prices of legally allowed sales of African elephant ivory. Because mammoth ivory is often discovered when mining for minerals, our analysis of the post-ban era interdiction seizures of elephant ivory uses the Russian GDP share of mining as an instrumental variable to identify the effect mammoth ivory has had upon elephant ivory interdiction seizures and permitted sales prices. We also examine the effect upon elephant ivory seizures and prices of changes in Chinese and African income per capita, of African institutional quality, and of permitted elephant ivory sales.

We find that a one tonne (1000 kilograms) increase in Russian mammoth ivory exports causes interdiction seizures of illegal African elephant ivory to decrease by as much as 0.8 tonnes. Since an average African elephant produces about 10 kilograms of ivory, and since kill and interdiction seizures estimates suggest that less than 12% of poached ivory is seized, the 84 tonnes of Russian mammoth ivory exports produced on average per annum between 2010-2012 may have reduced elephant ivory harvesting by over 500 tonnes per year. To put this into perspective, this means it has saved over 50,000 elephants from being poached each year. Thus, absent mammoth ivory, the elephant poaching may have been as high as 85,000 animals per year, more than two and a half times current poaching rates of 34,000 animals per year, and nearly as high as the annual poaching rate just before the CITES ban on elephant ivory trade.[5] At population levels between 430,000 to 680,000 African elephants, this additional harvest would likely be unsustainable absent the mammoth ivory substitute. We also find that elephant ivory prices may have been reduced by 80$ to 120$ per kilogram as a result of mammoth ivory trade.

This paper contributes to the renewable resource literature on extinction (e.g., Gordon 1954, Clark 1973, Cropper 1988, Swanson 1994, Kremer and Morocom 2000) by explicitly considering the role a substitute plays on the extraction of an open access renewable resource both theoretically and empirically. Most bioeconomic models for open access renewable resources, in contrast, relegate substitutes to the background by simply postulating a downward sloping demand curve for the good being investigated (e.g., Gordon 1954, Clark 1973, Cropper 1988, Swanson 1994, and Kremer and Morcom 2000). But such a partial equilibrium approach may be inappropriate when substitutes potentially play a transformative role in the exploitation of a resource. The extinction of the sperm whale, for example, whose oil provided bright, odourless illumination – in contrast to tallow candles

[5] In the pre-ban era, between 1950 and 1988 approximately 55,000 African elephants were killed for ivory per year on average and around 100,000 animals were killed per year at the peak during the 1980s (Barbier et al. 1990).

and other types of whale oil – is believed to have been averted due to the development of kerosene as a substitute (Fouquet and Pearson 2006). Furthermore, horns from the white rhinoceros can be used to substitute the horns from the endangered black rhinoceros (Brown and Layton 2001). Since there often exists close substitutes for a renewable resource, kerosene for whale oil, modern medicines for rhinoceros horn and ducks, geese, and chicken for passenger pigeons, understanding the role the mammoth ivory substitute may play in preventing the extinction of elephants may inform new approaches to conservation efforts outside of elephants.

The paper also extends a growing literature on the ivory trade and the effect of the CITES ban (e.g., Barbier et al. 1990, Bulte et al. 1999, Kremer and Morcom 2000, Sukumar 2003, Martin et al. 2010, 2011, Wittemyer et al. 2014), by providing empirical evidence as to the magnitude of the substitution effect mammoth ivory has had upon elephant poaching. Fischer (2002) suggests that the legal trade in ivory could make it easier for poachers to "launder" their illegal ivory. While this may be the case for the two major CITES approved sales and for the relatively minor trade in hunting trophies, it probably is not the case for mammoth ivory, since the two are easily distinguishable; Martin and Vigne (2010) and Martin and Martin (2010, 2011) have found evidence that markets in Hong Kong and elsewhere clearly distinguish between the two types of ivory.[6] Brown and Layton (2001) have argued that dehorning the rhinoceros and supplying the horns at a price lower than the opportunity cost of harvesting rhinos illegally creates a substitute to rhinoceros poaching.

The remainder of the paper is organized as follows. Section **??** provides a description of the events leading up to the CITES ban on elephant ivory trade and of the events subsequent to the ban. Section **??** presents the general equilibrium theoretical model, which is used to motivate the empirical analysis. Section **??** presents the empirical analysis of the effect of mammoth ivory upon elephant poaching and provides estimates of the magnitude of the substitution effect mammoth ivory has had upon elephant poaching and prices. Section **??** concludes.

[6] Other arguments conservationists raise are that the legal sale of mammoth ivory could remove the stigma of consuming ivory, which may shift out the demand for elephant ivory. The evidence presented below, however, suggests that the net effect of sales of mammoth ivory have been a reduction, not an increase, in the demand for elephant ivory.

2 Background

This section provides background on elephant and mammoth ivory developments post-World War II, with the discussion divided between the pre-ban and post-ban eras. Detailed descriptions of the data sources, and summary statistics are contained in the Appendix.

Pre-Ban Ivory Trade

Prior to the CITES ban on trade in elephant ivory in 1989, the 30 African countries with elephant populations all exported elephant ivory. The CITES ban was the third step in a series of tightening restrictions on elephant ivory trade (Barbier et al. 1990). The first CITES action was the 1976 listing of elephants under CITES Appendix II, which required exporters to issue certificates for exports and importers to demonstrate that their imports had certificates. This, however, had the important loophole that only raw ivory required certificates, so exporters began to work the ivory sufficiently to avoid the need for a certificate. In response, in 1986, CITES further tightened control over ivory trade by forcing the exporting countries to submit a Management Quota System before they were issued export certificates. This system collapsed largely because the exporting countries were unwilling to restrict their own exports when the verification of other's exports was not possible. With the African elephant population diminishing from between three and five million in the 1930s and 1940s (World Wildlife Fund, African elephant) and then more than halving from 1,343,100 in 1979 to 622,700, in 1989, all commercial trade in elephant ivory was banned by listing African elephant ivory in Appendix I of CITES (Barbier et al. 1990).

African ivory exports per year averaged about 300 tonnes in the 1950s, 400 tonnes in the 1960s, 700 tonnes in the 1970s, and nearly 800 tonnes by the 1980s, reaching its peak of 1,162 tonnes in 1980. Barbier et al. (1990) note that because average tusk size was decreasing as the large male elephants were eliminated by poachers, the decline in the late 1980s in ivory production may not have corresponded to a decline in animals killed by poachers.[7] Exports declined after 1986 in part due to exporting countries switching to illegal trade rather than submitting management quotas from CITES.

[7] According to statistics from Shoshani (1992, p. 73), average tusk weight of the African elephant was 26 lbs. 7 oz. (12 kg.) in 1970, but only 6 lbs. 10 oz. (3 kg.) in 1990.

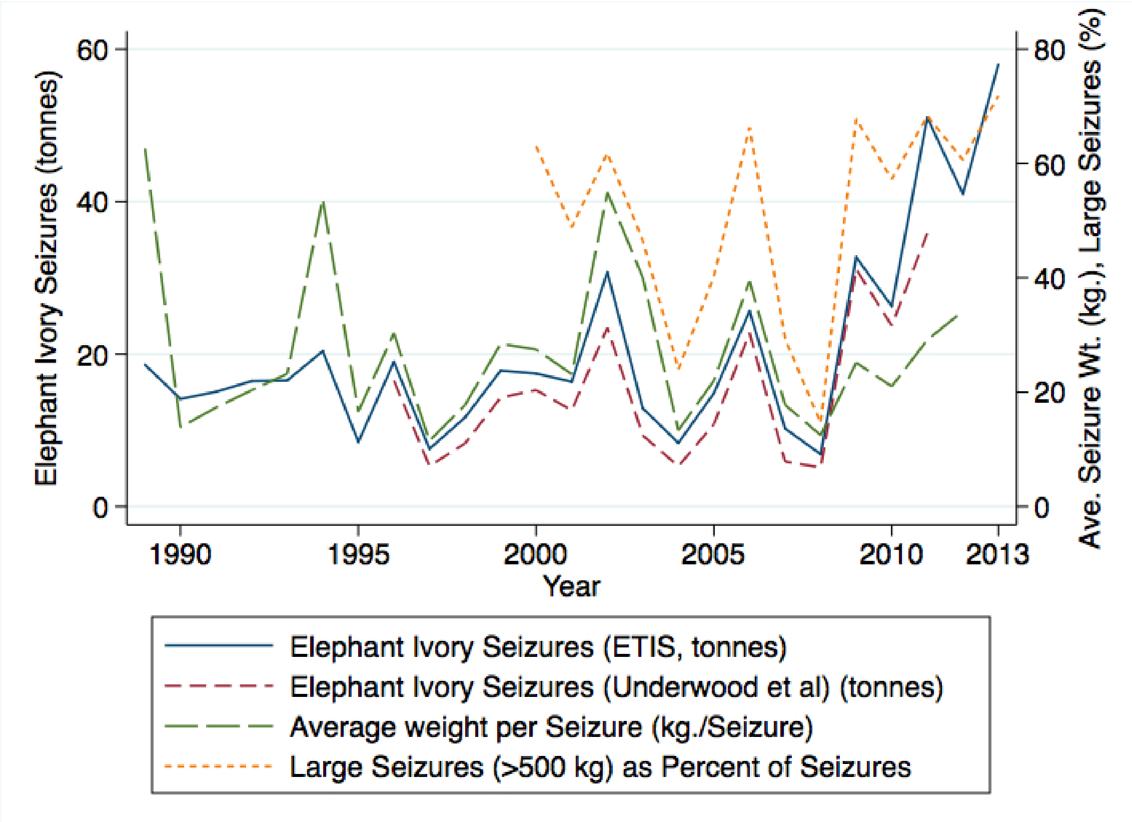

Figure 1: Post-Ban Elephant Ivory Seizures, Average Seizures Weight, and Large Seziures Weight as Percent of Total Seizures, 1989-2013.

Post-Ban Ivory Trade

Following the 1989 CITES ban on elephant ivory trade, the Elephant Trade Information System (ETIS), a sub-organization of CITES, began monitoring illegal trade in elephant ivory and ivory related products. In spite of the trade ban, ETIS data show that elephant ivory seizures averaged over twenty tonnes per year since 1989, and seizures 2009-2012 have increased to 39.4 tonnes per year on average. However, since not all illegal ivory trades are seized, the ETIS ivory seizure data represents only a fraction of poaching. Using the estimate by Wittemyer et al. (2014) that 33,630 elephants were killed per year during 2010-12, and comparing that with the average of 39.4 tonnes of ETIS seizures, suggests that only about 11.7% of the poached ivory was seized.

Figure **??** shows the post-ban African elephant ivory seizures for the period 1989-2013. The solid line is ETIS seizures. The dashed line from 1996-2011 is the Underwood et al. (2013) reconstruction of seizures.[8] The long-dashed line is average seizure weight per elephant ivory seizure, and the short-dashed line is the percentage of seizures from seizures in which 500 kilograms or more was seized. Seizures of elephant ivory have been on the rise since 2010. This could be the result of an increase in ivory demand, stricter law enforcement, or both.[9] In the empirical section below, we attempt to sort out these different effects. Peaks in average seizure size and in proportion of large seizures correspond to the peaks in total weight seized.

Figure **??** shows several estimates of the elephant population in Africa, the effective range of elephants, and the median proportion of elephant carcasses found to have been killed illegally across a number of sites in Africa. The elephant population numbers range from definitely observed, to probably exist, to possibly exist, to the highest possible speculated population. This data is based on surveys conducted in 1995, 1998, 2002, 2007, and 2013 by IUCN/SSC African Elephant Specialist Group. All estimates concur that the population was rising in the decade prior to 2007, but has been declining since. Interestingly, the decade of rising population was associated with a declining range. In addition, the Proportion of Illegally Killed Elephants (PIKE), a carcass survey data by Monitoring The Illegal Killing of Elephants (MIKE), shows that the median proportion (across a number of sites throughout Africa) of elephant carcasses which were killed illegally has been sharply increasing since 2009.[10]

Mammoth ivory, from the large woolly elephant which became extinct around 10,000 years ago, has become an important source of ivory in the post-ban era. Mammoth ivory can be crafted in the same way as elephant ivory, competes with the elephant ivory-crafted artefacts and is demanded by ivory customers. Nearly 50,000 mammoth carcasses have been

[8] Underwood et al. (2013), examined how the ETIS seizures varied with factors such as rule of law across African countries. Their data series, which excludes seizures for which they could not determine the weight of seizures, is almost perfectly correlated with the raw ETIS seizures data ($r = 0.97$, $p < 0.01$), as can be seen in Figure **??**.

[9] Milliken et al. (2004, 2012) and Milliken (2014) caution against reading too much into the trend in ETIS seizures, since the number of countries reporting seizures and the quality of seizures reporting have changed over time. However, the trend in the Underwood et al. (2013) reconstruction, which attempts to extract the true trend, is highly correlated with the ETIS seizures.

[10] The number of illegally killed elephants reported in PIKE are downward biased as not all illegally killed elephants carcasses are found, not all illegally killed elephants are reported, and the PIKE surveys cover only part of Africa. According to Wittemyer et al. (2014) around 33,600 elephants were illegally killed in Africa each year for 2011-2013, whereas PIKE data reports from 2011-2013, each year on average counted around 1,000 elephants illegally killed.

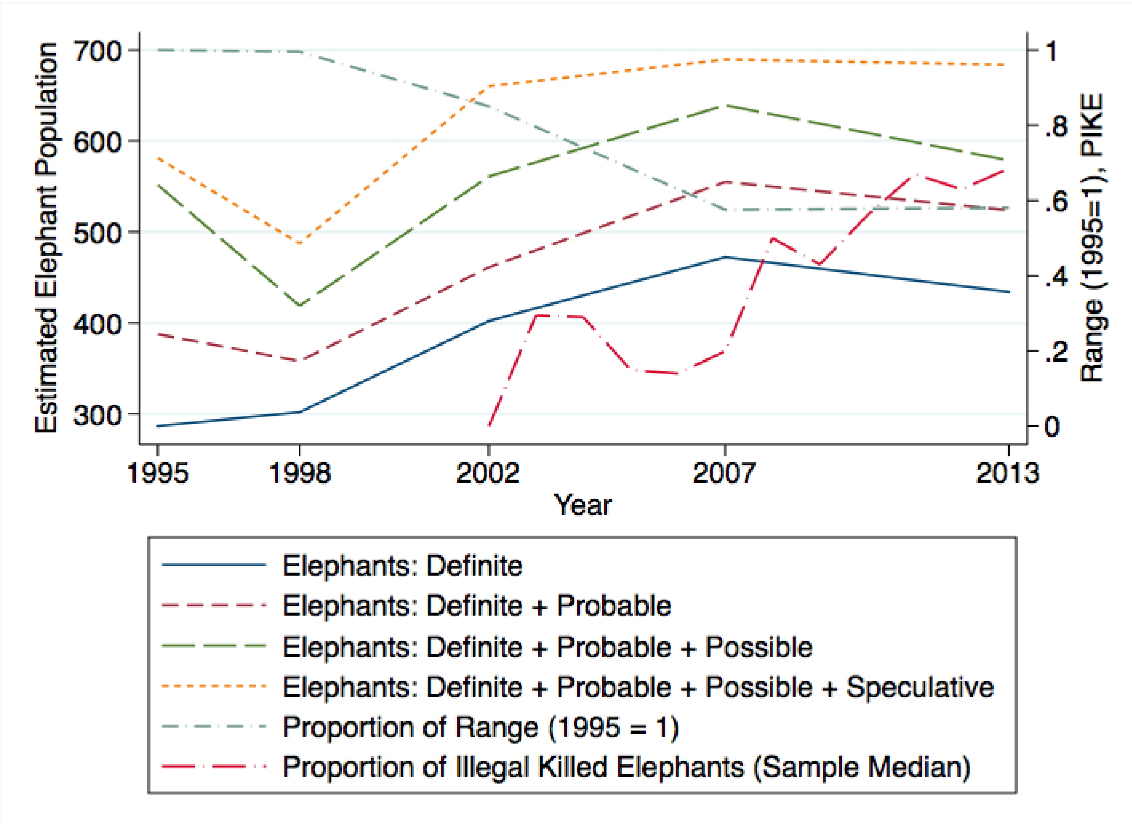

Figure 2: Post-Ban African Elephant Population and Range Estimates, 1995-2013, and Proportion of Illegally Killed Elephants, 2002-2013.

excavated in the 250 years since Siberia became a part of Russia in the 17th century, and stock of around 10 million mammoth carcasses are thought to lie beneath the permafrost in the Arctic tundra (Lister and Bahn 2007). These are exploited by the mammoth tusk hunters every summer. Although mammoth hunters are required to have permit from the Russian government to sell mammoth ivory, many mammoth hunters operate without a valid permit (Larmer 2013); thus, mammoth ivory can be considered as an open access resource.

Data on mammoth ivory trade is available from the UN COMTRADE database. In Figure **??**, the solid line shows Russian mammoth ivory exports for the period 1988 to

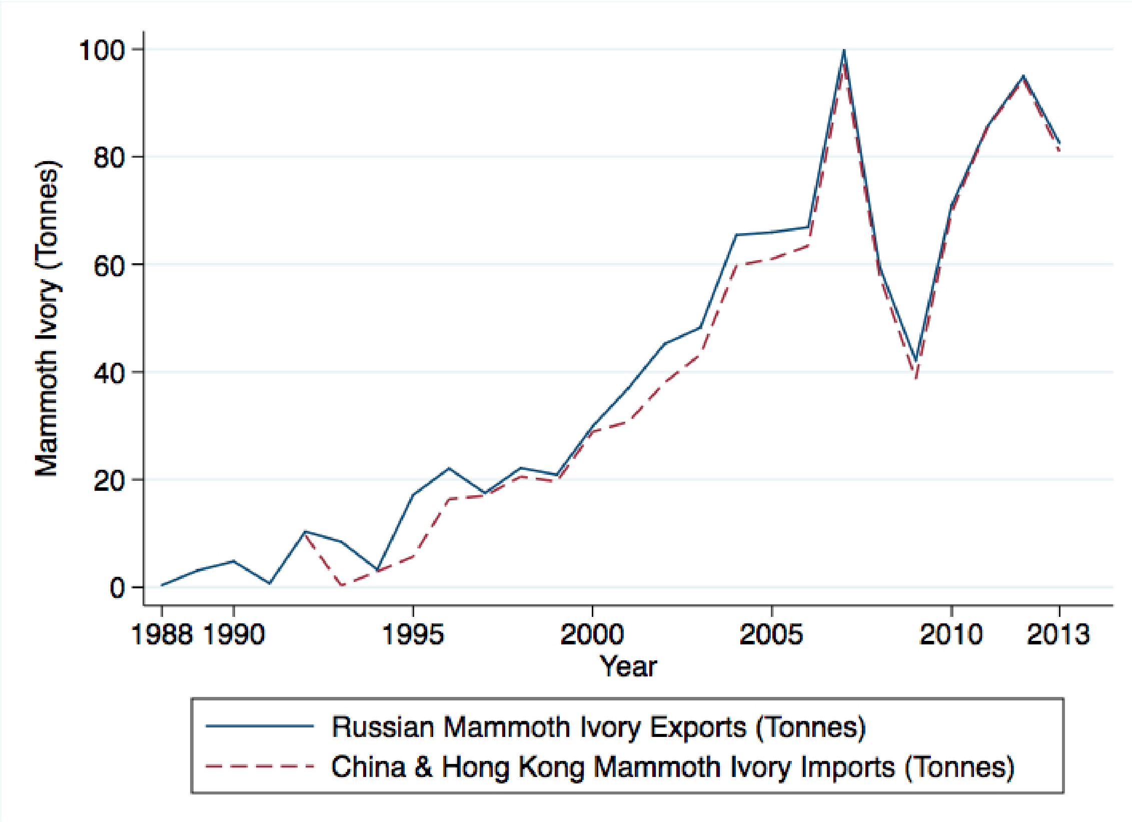

Figure 3: Post-Ban Russian Mammoth Ivory Exports and Hong Kong & China Mammoth Ivory Imports, 1988-2013.

2013, defined as the sum of the rest of the worlds' ivory imports from Russia.[11] Russian mammoth ivory exports have been increasing steadily, averaging approximately 17 tonnes per year for 1991-2000 and averaging 60 tonnes per year for 2001-2013.[12] Also shown in Figure **??** are the combined mammoth ivory imports to Hong Kong and China (dashed line).[13] Hong Kong and China's combined average annual mammoth ivory imports account

[11]We used the rest of the world's imports from Russia rather of Russian exports because Russian export statistics were not available for all years and partner countries.

[12]Given that an average mammoth tusk weighs between nine and 45 kg (Lister and Bahn 2007), 60 tonnes of mammoth ivory is equivalent to between 1,300 and 6,600 mammoth carcasses. If Russia exports 60 tonnes mammoth ivory every year, it would take between 150 and 750 years to exhaust the ten million mammoth carcass stock.

[13]Hong Kong's mammoth ivory import statistics are available only after 1995, while China's mammoth ivory import statistics are available from 1991.

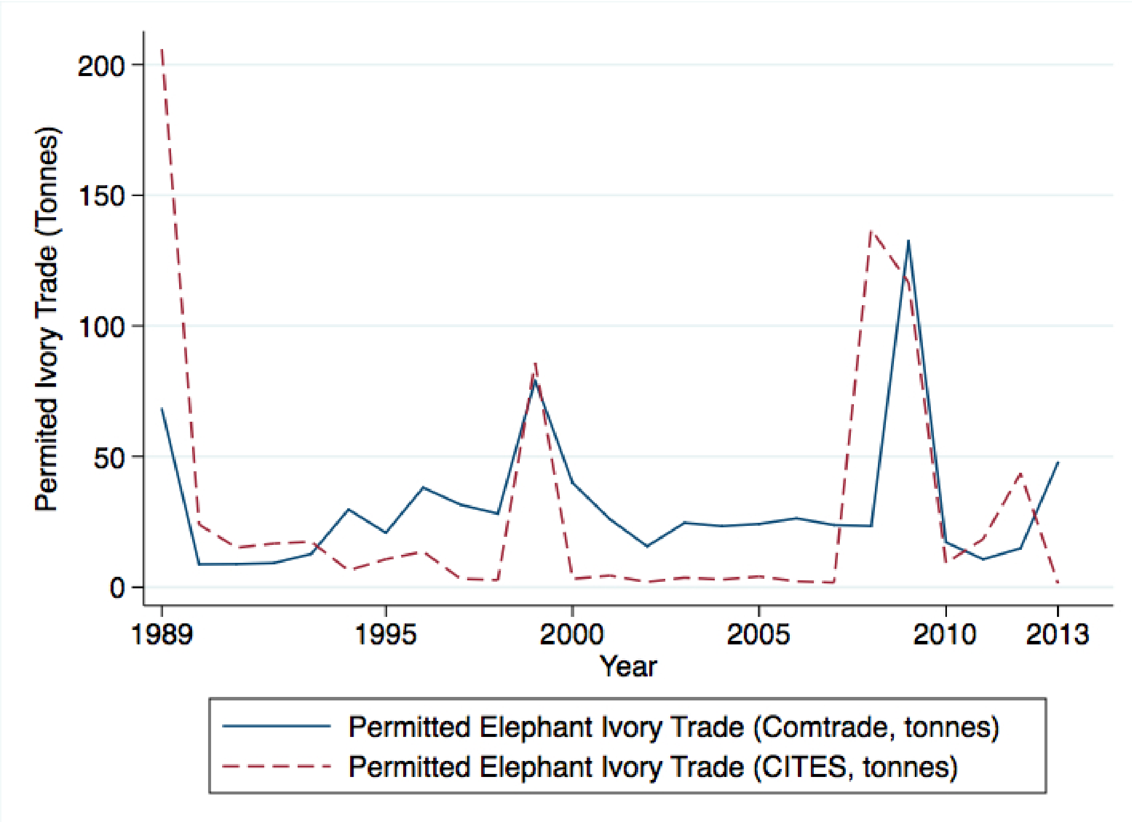

Figure 4: Post-Ban Permitted African Elephant Ivory Exports (Tonnes), 1989-2013.

for over 95% of total Russian exports since the mid 1990s. Mammoth ivory trade declined by more than 50% during the Great Recession, but that has subsequently recovered.

In the post-ban era, some elephant ivory trade has been permitted. This includes hunting trophies, privately owned ivory crafts, government confiscated stockpiles, and ivory from elephants killed before the 1989 ban. In addition, there were two CITES approved African elephant ivory auctions. In 1999, 50 tonnes of elephant ivory was auctioned to Japanese dealers at an average price of 103$/kg, and in 2008, 101.8 tonnes of elephant ivory was auctioned at an average price of 157$/kg, where Chinese dealers bought 62 tonnes and Japanese dealers bought the remainder (Stiles 2009). Figure **??** shows permitted elephant ivory trade in the post-ban era from two different sources. The solid line shows permitted trade from the UN COMTRADE data, defined the sum of the non-African countries'

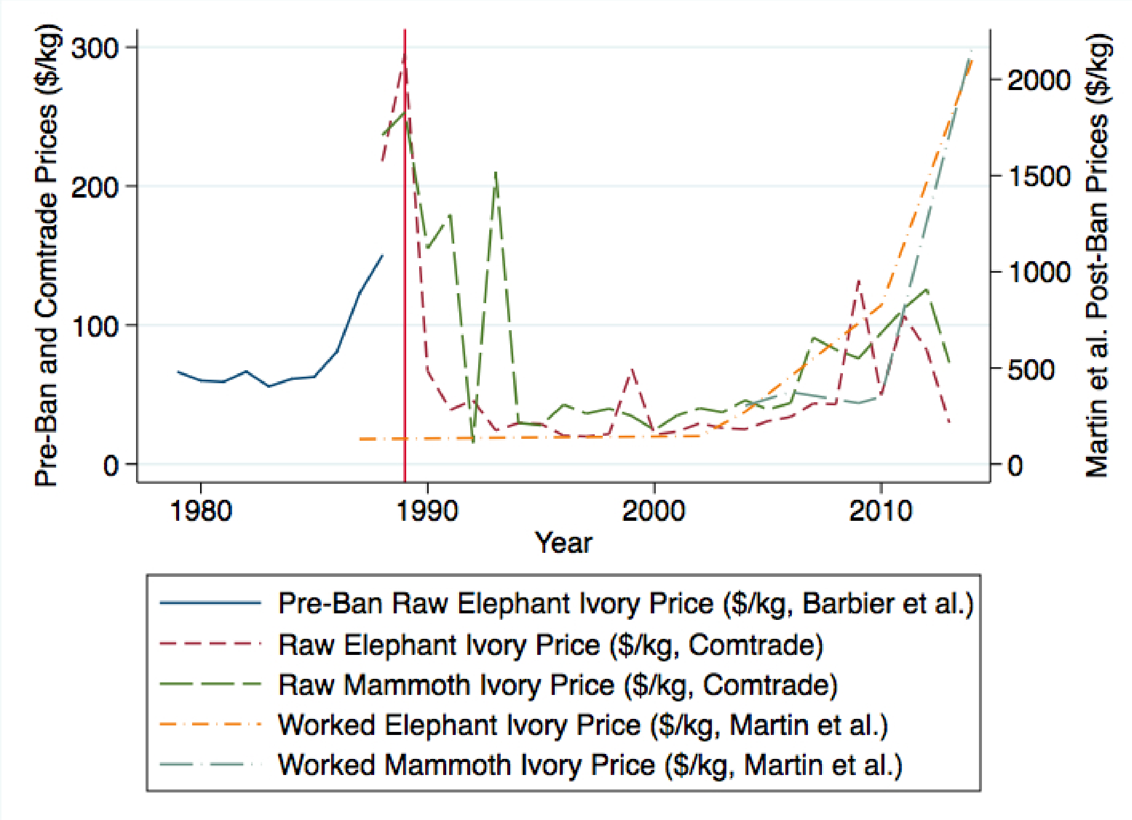

Figure 5: Elephant and Mammoth Ivory Prices.

imports from Africa.[14] The dashed line shows permitted trade data from the CITES Trade database.[15] Legal exports of elephant ivory to the rest of the world since 1989 have averaged approximately 31 tonnes per year. In the CITES Trade database data, permitted trade in African elephant ivory averaged approximately 30 tonnes per annum. The two spikes in the permitted trade in African elephant ivory represents CITES approved ivory sales in 1999 and 2008.

Finally, Figure **??** displays (nominal) elephant and mammoth ivory prices, both pre-

[14]We also measured this data as African countries' legal exports of elephant ivory, but that data shows little trend and high volatility.

[15]Permitted trade data on elephant ivory from CITES trade database is available for three categories: whole tusk, raw ivory pieces, and carved ivory. All three categories are summed up to calculate net legal trade on elephant ivory. UN COMTRADE data, however, reports *"Ivory, its powder & waste, unworked"*. Thus, there are some differences between these two statistics.

and post-ban, collected from several sources. The vertical line corresponds to the 1989 CITES ban on elephant ivory trade. Pre-ban prices (left-scale) from Barbier et al. (1990) approximately doubled in the decade leading up to the ban on ivory trade. Post-ban prices (also left-scale) are from UN COMTRADE, calculated by dividing the value of exports by the quantity of exports. These show that elephant ivory permitted trade prices were very high right after the ban, much lower in the mid 1990s, and have started to rise again in the late 2000s. These permitted trade elephant ivory prices, however, are imputed from small quantities of sales. Mammoth ivory prices, which are based upon larger and more continuous quantities of sales, were very volatile until the mid 1990s, when they settled down to around $50 per kilogram. Like elephant ivory prices, mammoth ivory prices started to rise in the late 2000s. A second source of data (right-scale) is the average whole-sale price of raw elephant and mammoth ivory from market surveys conducted by Martin et al. (2006, 2011, 2014) for the years 1987, 2002, 2004, 2006, 2009, 2010, and 2014.These averages are substantially higher than the UN COMTRADE prices for both mammoth and elephant ivory. Both sets of series, however, the imputed prices from trade data and market surveys data, show that elephant and mammoth ivory prices have sharply increased in the late 2000s.

An important implication of the variation in prices and production of mammoth and elephant ivory in the post-ban era is that mammoth and elephant ivory are imperfect but close substitutes, since both were being consumed in positive quantities even as prices varied. This implication is explored in the theoretical analysis to which we now turn.

3 Theoretical Model

We assume mammoth ivory is an imperfect substitute to elephant ivory. Both poachers and mammoth hunters are assumed to compete under conditions of open access. In the the first section, we ignore the possibility of storage of elephant ivory (Kremer and Morocom 2000). In the second subsection, we allow for storage.

Elephant and Mammoth Ivory when No Storage of Elephant Ivory Occurs

The elephant population growth rate is the difference between the net birth function $G(x)$ and harvest rate h:

$$\frac{dx(t)}{dt} = G[x(t)] - h(t), \qquad\qquad x(0) = x_0, \tag{1}$$

The net birth function $G(x)$ has the properties that $G(x) > 0$ for $0 < x(t) < K$, that $G(x) < 0$ for $x(t) > K$, and that $G(0) = G(K) = 0$, where K is the carrying capacity of the population. Therefore, absent poaching, the elephant population is viable for all $x(t) > 0$.[16]

The stock of mammoth ivory at time t is $S(t)$. Since the stock is exhaustible with mammoth tusk collected at rate y, the stock S declines according to

$$\frac{dS(t)}{dt} = -y(t), \qquad S(0) = S_0. \tag{2}$$

Assume that there are two types of goods in the economy, ivory I, and all other goods z. There are, however, two types of ivory, elephant ivory h, and mammoth ivory y. For each good, there is only one factor of production, labor. The total labor endowment L is allocated among the three sectors. So the labor market clearing condition is:

$$L = L_h(t) + L_y(t) + L_z(t), \tag{3}$$

where L_h, L_y, and L_z are the labor allocated to each goods' production.

The production functions for the harvest rate h, mammoth tusk collection rate y, and all other goods production z are each constant returns to scale. These production functions are:

$$h(t) = \frac{L_h(t)}{c[x(t)]}, \qquad y(t) = \frac{L_y(t)}{m}, \qquad z(t) = L_z(t). \tag{4}$$

One unit of h requires $c(x)$ units of labor; one unit of y requires m units of labor; and one unit of z requires 1 unit of labor. The unit labor requirement for elephant ivory harvesting, $c(x)$, has two sorts of cost embedded in it: the production cost and the cost of bearing the risk of extracting a resource illegally. Both costs are decreasing with x, since a larger stock makes the prevention of poaching more difficult, and it makes it easier to find animals to poach. Thus $c'(x) < 0$. In addition, $c(x)$ is bounded so that the maximum marginal cost of poaching elephant is $c(0) = \bar{c} < \infty$. This assumption is crucial to the determination of whether extinction is possible, since the demand functions must be such that willingness to pay (WTP) exceeds harvesting costs as the population approaches zero. For simplicity, we assume finding one mammoth tusk does not affect the probability of finding another tusk. Thus the labour requirement for mammoth tusk collection rate m is constant.

[16] Alternatively, it is possible that the population growth function exhibits critical depensation, where $G(x) < 0$ for some $0 < x(t) < \underline{x}$.

Firms pay their workers wage w per unit of labor and earn p_h for elephant ivory, p_m for mammoth ivory, and p_z for all other goods. Thus profits for each sector are given by:

$$\begin{aligned}\Pi_h &= p_h h - wL_h = p_h \frac{L_h}{c(x)} - wL_h,\\ \Pi_y &= p_y y - wL_y = p_y \frac{L_y}{m} - wL_y,\\ \Pi_z &= p_z z - wL_z = p_z L_z - wL_z,\end{aligned} \tag{5}$$

where the values of h, y, and z are substituted from equation (4). Firms take their prices as given. Free entry implies that for wage $w = 1$, the equilibrium prices are,

$$p_h = c(x), \qquad p_y = m, \qquad \text{and} \qquad p_z = 1. \tag{6}$$

Each representative consumer's utility is given by

$$U_i = \left[\left(\frac{h}{L}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{y}{L}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{z}{L}\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \qquad \sigma > 1, \tag{7}$$

where h/L, y/L, and z/L are per capita consumption of each good. The parameter σ is the elasticity of substitution among the goods. We assume that $\sigma > 1$, so that these goods are each-others substitute. If the goods were instead complements, $\sigma < 1$, then either extinction of elephants or exhaustion of mammoth ivory would cause utility to go to zero, since no amount of the numeraire good z could compensate for the lost ivory. Since extinctions of animals consumed by humans have occurred, this seems implausible.

Each L identical individuals, supplies one unit of labor to the firms and earns wage, $w = 1$ for each unit of labor. Each individual's budget constraint is therefore

$$1 = c(x)\frac{h}{L} + m\frac{y}{L} + \frac{z}{L} \tag{8}$$

Each individual chooses their consumption of elephant and mammoth ivory and the numeraire good to maximize (**??**) subject to (**??**). Solving the optimization problem yields the equilibrium aggregate demand functions for elephant ivory, mammoth ivory and other goods, as function of the prices $c(x)$ and m:[17]

$$h^*(x) = \frac{Lc(x)^{-\sigma}}{1+c(x)^{1-\sigma}+m^{1-\sigma}}, \quad y^*(x) = \frac{Lm^{-\sigma}}{1+c(x)^{1-\sigma}+m^{1-\sigma}}, \quad z^*(x) = \frac{L}{1+c(x)^{1-\sigma}+m^{1-\sigma}}. \tag{9}$$

Absent a substitute, i.e. when $m \to \infty$, the aggregate demand for elephant ivory becomes:

$$h^0(x) = \frac{Lc(x)^{-\sigma}}{1+c(x)^{1-\sigma}} \qquad \text{for} \quad \sigma > 1. \tag{10}$$

Now we characterize the equilibrium demand functions in the presence of a substitute. First, both types of ivory demands are decreasing in their own prices. Differentiating eacy ivory demand with respect to its own price yields

$$\frac{dh^*(x)}{dc(x)} = \frac{-Lc(x)^{-\sigma}}{(1+c(x)^{1-\sigma}+m^{1-\sigma})^2}\left[\sigma c(x)^{-1}(1+m^{1-\sigma})+c(x)^{-\sigma}\right] < 0,$$

and

$$\frac{dy^*(x)}{dm} = \frac{-Lm^{-\sigma}}{[1+c(x)^{1-\sigma}+m^{1-\sigma}]^2}\left[\sigma m^{-1}(1+c(x)^{1-\sigma})+m^{-\sigma}\right] < 0.$$

Second, both types of ivory demands are increasing in other ivory's price when they are substitutes ($\sigma > 1$). Differentiating each ivory demand with respect to the other ivory price yields,

$$\frac{dh^*(x)}{dm} = -\frac{(1-\sigma)m^{-\sigma}Lc(x)^{-\sigma}}{[1+c(x)^{1-\sigma}+m^{1-\sigma}]^2} > 0 \qquad \text{when} \qquad \sigma > 1,$$

and

$$\frac{dy^*(x)}{dc(x)} = -\frac{(1-\sigma)c(x)^{-\sigma}Lm^{-\sigma}}{[1+c(x)^{1-\sigma}+m^{1-\sigma}]^2} > 0 \quad \text{when} \quad \sigma > 1.$$

Thus if $\sigma > 1$, so that mammoth and elephant ivory are substitutes, elephant harvesting rises when mammoth ivory collection costs rise, and mammoth ivory demand is increasing in the elephant harvesting cost. This implies that the harvest rate of a resource increases when the cost of producing the substitute good rises.

Next, we show the effect having a substitute has upon demand:

[17] The equilibrium labor used in each sector can be calculated from the production functions from (4): $L_h^* = \frac{Lc(x)^{(1-\sigma)}}{1+c(x)^{(1-\sigma)}+m^{(1-\sigma)}}$, $L_y^* = \frac{Lm^{(1-\sigma)}}{1+c(x)^{(1-\sigma)}+m^{(1-\sigma)}}$, and $L_z^* = \frac{L}{1+c(x)^{(1-\sigma)}+m^{(1-\sigma)}}$. Summing L_h^*, L_y^*, and L_z^* yields L, so all individuals are employed and each sector uses some portion of the total labor, L.

Proposition 1. *Equilibrium demand for elephant ivory is lower when the mammoth ivory substitute exists.*

Proof.

$$\frac{h^*(x)}{h^0(x)} = \frac{\frac{Lc(x)^{-\sigma}}{1+c(x)^{1-\sigma}+m^{1-\sigma}}}{\frac{Lc(x)^{-\sigma}}{1+c(x)^{1-\sigma}}} = \frac{1+c(x)^{1-\sigma}}{1+c(x)^{1-\sigma}+m^{1-\sigma}} < 1 \qquad \text{for all} \quad 0 < m < \infty.$$

□

Thus in the presence of a substitute, the harvest rate $h^*(x)$ of a resource is lower than the harvest rate $h^0(x)$ when there is no substitute. This is true even as elephants approach extinction, as the following shows:

$$\lim_{x \to 0} \frac{h^*(x)}{h^0(x)} = \frac{1+\bar{c}^{1-\sigma}}{1+\bar{c}^{1-\sigma}+m^{1-\sigma}} < 1 \qquad \text{for all} \quad 0 < m < \infty.$$

Next, consider the effect of the elephant population size has upon the elephant ivory harvest rate and the mammoth tusk collection rate. Differentiating the equilibrium harvest rate from (**??**) with respect to population stock $x(t)$ gives:

$$\frac{dh^*(x)}{dx} = \underbrace{\frac{dh^*(x)}{dc(x)}}_{<0} \underbrace{c'(x)}_{<0} > 0, \quad \text{and} \quad \frac{dy^*(x)}{dx} = \underbrace{\frac{dy^*(x)}{dc(x)}}_{>0} \underbrace{c'(x)}_{<0} < 0.$$

Thus, the larger is the elephant stock, the higher is the poaching rate and the lower is the mammoth ivory collection rate, since an increase in the stock lowers to cost of poaching elephants and mammoth and elephant ivory are substitutes.

Now, we turn to an analysis of how the elephant population dynamics are affected by the presence of a substitute. The analysis is shown In Figure **??**, which displays the growth function, $G(x)$, and the equilibrium poaching rates $h^*(x)$ and $h^0(x)$, with and without the substitute, respectively. The poaching rate is higher without a substitute than with a substitute for all stock levels, and both poaching rates are increasing in the elephant stock since the cost of poaching decreases with the stock.

A steady-state occurs when the poaching rate equals the biological growth rate so that $dx/dt = 0$. The values x_u^* (x_u^0) and x_s^* (x_s^0) correspond to the unstable and stable steady

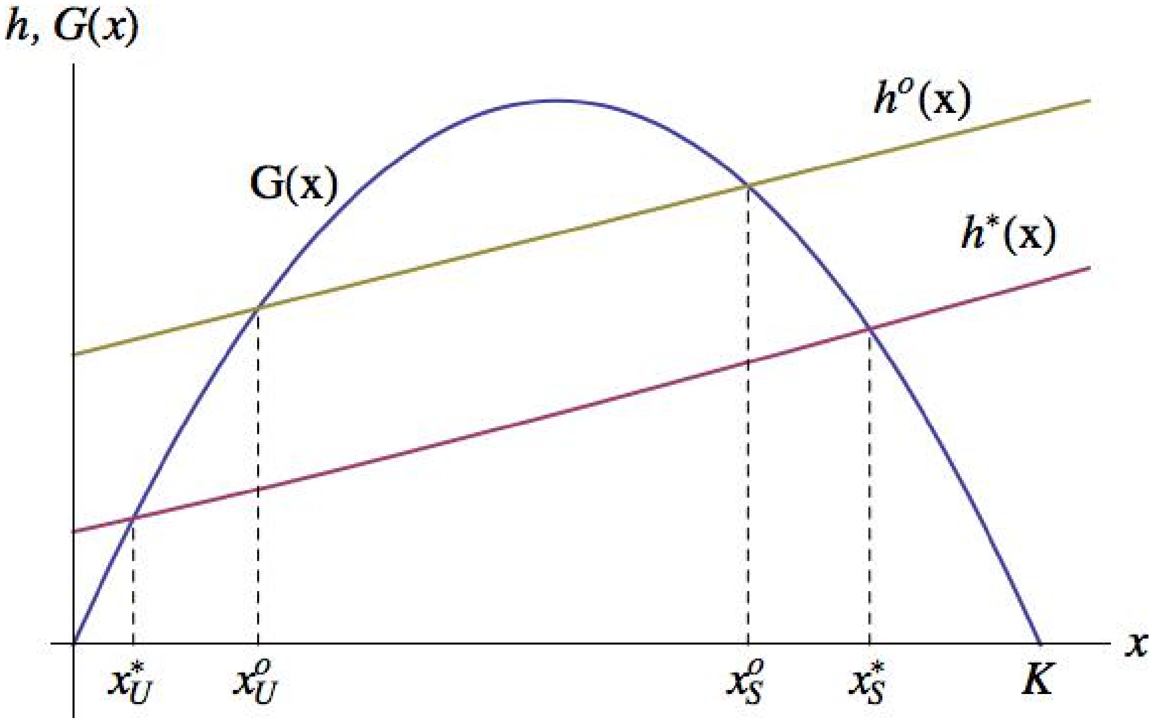

Figure 6: Elephant Population Growth and Equilibrium Harvest Rates.

states for demand $h^*(x)$ ($h^0(x)$), respectively.[18] The equilibria x_u^* and x_u^0 are unstable as to the left of each the poaching rate is higher than the growth rate and to the right the growth rate is higher than the poaching rate. The equilibria x_s^* and x_s^0 are stable because to the left of each the population growth rate exceeds the poaching rate and to the right the poaching rate exceeds the growth rate.

Absent a substitute, there are three possible steady-state levels of the elephant population. If the initial level of population x_0 is less than x_u^0, then the population will become extinct since $h^0(x) > G(x)$ in this interval causing $\dot{x} < 0$. If x_0 is in the interval $(x_u, x_s]$, the growth rate of the elephant population is positive ($\dot{x} > 0$) and when $x > x_s$, the growth rate of the elephant population is negative ($\dot{x} < 0$). Thus for $x_0 > x_u$ the elephant population will always move towards the stable steady state x_s^0. Finally, if x_0 is exactly at x_u, the elephant population remains there forever since at $x = x_u$, $\dot{x} = 0$.

[18] If there is a critical depensation level of stock $\underline{x}$ such that for $x \epsilon [0, \underline{x})$, that $G(x) < 0$, then $\underline{x} < x_u^* < x_u^0$, so the analysis below holds for this case as well.

In the presence the of mammoth ivory substitute, the equilibrium level of harvest rate of elephants is $h^*(x)$ and the equilibrium level of mammoth tusk collecting rate is $y^*(x)$. So long as both stocks are positive, $h^*(x)$ and y^* are functions of $c(x)$ and m. Once the mammoth ivory is exhausted, however, the demand for elephant ivory switches to $h^0(x)$, since $S \to 0$ is equivalent to $m \to \infty$. At time $t = 0$, the initial elephant population is x_0 and mammoth ivory stock is S_0. If the mammoth ivory stock is exhausted at time $t = T_s$, then $x(T_s)$ represents the elephant stock from where the elephant population starts to approach it's final equilibrium. The steady state level of x after the mammoth tusk stock is exhausted depends on the position of $x(T_s)$ relative to x_u^0: if $x(T_s) > x_u^0$, then x_s^0 is the steady state; if $x(T_s) = x_u^0$ then x_u^0 is the steady state; and if $x(T_s) < x_u^0$, then the elephant population goes extinct.

When the substitute is inexhaustible, these equilibria completely characterize the dynamics and steady-state outcomes for any initial elephant stock, x_0. But when the substitute is exhaustible, as in the case of mammoth ivory, the equilibria approach paths become more complicated. The next proposition characterizes how the equilibrium evolves for different initial elephant stock x_0 and for various positive mammoth ivory stocks S_0:

Proposition 2. *When there exists a mammoth ivory substitute to elephants, then for initial elephant population stock $x_0 \in (x_u^*, x_u^0]$ and for sufficiently high substitute mammoth stock S_0, the elephant population will avoid extinction. However, if $x_0 \leq x_u^* < x_u^0$, extinction occurs even when there is a substitute, and if $x_0 > x_u^0 > x_u^*$, the elephant population converges to the stable steady state x_s^0 for all mammoth stocks.*

Proof. When $x_0 < x_u^*$, then $h^0(x) > h^*(x) > G(x)$, which implies that $\dot{x} < 0$ whether mammoth ivory exists or not. Thus elephant extinction occurs absent a policy intervention. It may occur even before the mammoth ivory stock is exhausted.

When $x_0 = x_u^*$, then $h^*(x) = G(x)$ as long as the mammoth ivory stock is exploited. But once the stock of mammoth ivory is exhausted, the poaching rate shifts upwards to $h^0(x_u^*) > G(x_u^*)$, thus elephants become extinct, with mammoth ivory giving elephants only a temporary reprieve.

When $x_0 \in (x_u^*, x_u^0]$, $\dot{x} = G(x) - h^*(x) > 0$. Thus, if S_0 is large enough so that $x(T_s) > x_u^0$, where $S_0 = \int_0^{T_s} y^*(x)dt$ implicitly defines T_s, then the elephant population approaches the stable steady-state x_s^0. Conversely, if $x(T_S) < x_u^0$, then once the mammoth ivory stock is exhausted, the elephant population converges to the extinction equilibrium.

When $x_0 > x_u^0$, then $h^*(x) < h^0(x) < G(x)$, which implies that $\dot{x} > 0$. Thus, for all initial mammoth ivory stocks S_0, the elephant population eventually converges to x_s^0. $\square$

To summarize, our theory shows that the presence of a substitute causes demand to shift down to $h^*(x)$ from $h^0(x)$, which this causes the unstable steady-state x_u^* to be at a lower level than x_u^0. Thus, when $x_0 \in (x_u^*, x_u^0]$, if the stock of mammoth ivory is sufficiently large to allow the elephant stock to build to x_u^0, then the presence of the mammoth ivory substitute saves elephants from extinction.

Our theory, however, assumes that the supply of both mammoth ivory and elephant ivory is perfectly elastic at prices m and $c(x)$, respectively, and that each ivory demand depends only upon the relative prices of the two ivories. Figures **??**, **??**, and **??** showed that elephant ivory seizures and mammoth ivory production and both elephant and mammoth ivory prices have been rising. Thus, it is probably more accurate to think that the short-run ivory supply curves are each upwards sloping with m and $c(x)$ supply shifters. The rise of Russian mammoth ivory production was thus due to a lowering of m, which shifts the mammoth ivory supply downward. Coupling this with rising demand for both ivories, due to rising incomes in Asia, explains why both prices and output have been rising for each type of ivory. Under this interpretation, the decrease in equilibrium elephant ivory production to h^* from h^0 due to relaxation of the mammoth ivory trade would still occur, though this would be somewhat offset by rising incomes shifting demands for both types of ivory h^* and y^* back upwards.

Elephant and Mammoth Ivory when Storage of Elephant Ivory Occurs

Finally, there is one other alternative to consider, namely Kremer and Morocom's (2001) hypothesis that ivory poachers may be culling elephants to store the ivory for production once elephants become extinct.

First, observe that even under a poaching and storage equilibrium, a reduction in m still causes the demand for elephant ivory to decrease due to substitution effects. This lowers the benefit of storing elephant ivory, since a reduction in m lowers the demand for elephant ivory whether from stores or from poaching. Thus the large stocks of mammoth ivory reduce the gains from storing elephant ivory for sales subsequent to elephants' extinction.[19]

[19] It might be thought that ivory poachers might store ivory for when the mammoth ivory is exhausted. But given an estimated 10 million mammoth carcasses, at average Russian mammoth ivory export of about 60 tonnes per year and at 9 to 45 kg. per mammoth carcass, it would take between 150 to 750 years to exhaust the mammoth ivory stock. It is doubtful that any poacher is that patient.

A second reason to believe that the poaching and storage equilibrium is not occurring has to do with the most important implication of the poaching and storage equilibrium, which is how it affects the elephant population. The elephant population growth rate is the difference between the net birth function $G(x)$ and the sum of the harvest rate h for current consumption and the elephant ivory storage rate v for future consumption:

$$\frac{dx(t)}{dt} = G[x(t)] - h(t) - v(t), \qquad x(0) = x_0, \tag{11}$$

The elephant ivory stores V grow at the rate of the difference between the storage rate v and the sales rate from stores a,

$$\frac{dV(t)}{dt} = v(t) - a(t), \qquad V(0) = V_0. \tag{12}$$

Mammoth ivory stocks with or without storage continue to decline at the rate of mammoth ivory production (**??**), $\dot{S} = -y$.

Assume that the ivory producers do not sell from the elephant ivory storage before the elephant are driven to extinction (i.e., $a = 0$ while $h > 0$). Hence, with positive elephant ivory storage, and no sales from stores, elephant ivory stores are rising, $\frac{dV}{dt} = v$.

For poachers to wish to hold elephant ivory stores, the price of elephant ivory must be expected to grow at the rate of market interest rate:

$$\frac{\dot{p}_h}{p_h} = r. \tag{13}$$

But under open access, the elephant ivory price satisfies (**??**), so that $p_h = c(x)$. Differentiating this equation with respect to time leads to

$$\dot{p}_h = c'(x)\dot{x}, \tag{14}$$

which implies that $\dot{x} < 0$, since $\dot{p}_h = p_h r > 0$ and since $c'(x) < 0$. Thus, elephant ivory storage causes the elephant population to decline over time, a result which is independent of the rate of additions to stores v. Moreover, the storage condition (**??**) implies that the elephant ivory price increases over time. Then, due to the substitution effect between elephant and mammoth ivory, the positive growth rate of elephant ivory price causes mammoth ivory demand to increase, $\dot{y} > 0$, and causes equilibrium elephant ivory demand to decrease, $\dot{h} < 0$. These results are summarized as follows:

Proposition 3. *When elephant ivory is stored in the presence of mammoth ivory substitute, (i) the elephant population strictly declines,* (*ii*) *the elephant ivory price increases over time,* (*iii*) *the mammoth ivory demand increases, and* (*iv*) *and elephant ivory demand decreases.*

Recall that the data shows that the permitted trade elephant ivory price is rising over time (Figure **??**), supporting condition (*ii*) from Proposition **??**, and that mammoth ivory demand is growing over time (Figure **??**), supporting condition (*iii*)) from Proposition **??**. But Figure **??** does not show the elephant population to be declining over time, violating condition (*i*) from Proposition **??**, nor does Figure **??** show that ETIS seizures, which should be positively correlated with elephant ivory production h, are falling, violating condition (*iv*) from Proposition **??**. Thus, while it is possible that elephant poachers are rationally storing elephant ivory for use post-extinction (since we do not observe v), the presence of mammoth ivory production lowers the incentive to engage in storage, and the observed rising elephant population and rising interdictions are each inconsistent with the storage equilibrium, casting doubt upon this hypothesis.

On the other hand, increasing demand for both elephant and mammoth ivory, and increasing elephant populations are each consistent with the poaching, no-storage equilibrium in which rising Asian incomes are driving up demand (thereby increasing ivory prices by moving up their respective supply curves), but in which the elephant population is above the minimum critical level, x_u^*, causing the elephant population to rise. Thus, given the large stock of mammoth ivory, it is possible that the extinct mammoth may be able to save elephants from a similar fate.

4 Empirical Analysis

Now we turn to an empirical analysis of the effect of that mammoth ivory production has had upon African elephant ivory poaching and elephant ivory prices.

Methodolgy

In principle, having both price and production data, we would like to estimate the equilibrium demand functions (**??**). The problems of doing this, however, are insurmountable: mammoth and elephant prices are each endogenously determined, which would require separate instrumental variable instruments for each; further, we only observe elephant ivory seizures rather than elephant ivory demand; and finally, we do not observe the black market prices for elephant ivory, only the implied prices of permitted ivory trade.

Therefore, we instead estimate reduced form equations in which elephant ivory seizures and elephant ivory permitted trade prices are regressed against Russian mammoth ivory exports and other control variables. This allows us to measure the effect mammoth ivory production has had upon elephant ivory seizures and elephant ivory prices, and it reduces the potential endogeneity problems to only mammoth ivory being an endogenous right-hand-side regressor.

The effect Russian mammoth ivory exports have had upon African elephant ivory seizures and permitted sales prices of elephant ivory is estimated by the following regressions:

$$\begin{aligned}\text{African Elephant Ivory Seizures}_t &= \alpha_0 + \alpha_1 \,\text{Russian Mammoth Ivory Production}_t \\ + \alpha_2 \,\text{Institutional Quality}_t &+ \alpha_3 \,\text{Africa Per Capita GDP}_t + \alpha_4 \,\text{China Per Capita GDP}_t \\ &+ \alpha_5 \,\text{Legal Harvest}_t + \varepsilon_{1t}, \qquad t = 1989, \ldots, 2013,\end{aligned}$$

and

$$\begin{aligned}\text{African Elephant Ivory Permitted Trade Price}_t &= \beta_0 + \beta_1 \,\text{Russian Mammoth Ivory Production}_t \\ + \beta_2 \,\text{Institutional Quality}_t &+ \beta_3 \,\text{Africa Per Capita GDP}_t + \beta_4 \,\text{China Per Capita GDP}_t \\ &+ \beta_5 \,\text{Legal Harvest}_t + \varepsilon_{2t}, \qquad t = 1989, \ldots, 2013.\end{aligned}$$

Each regression includes as explanatory variables Russian mammoth ivory exports (the variable of interest), measures of the institutional quality and economic conditions of the African countries (supply shifters), China GDP per capita (demand shifters), and the tonnage of permitted trade in African elephant ivory. All other factors which might explain elephant ivory seizures or elephant ivory permitted trade prices are left in the error terms.

Since our objective is to determine the effect that Russian mammoth ivory exports have had upon elephant ivory poaching, the tonnage of Russian mammoth ivory exports is the key variable of interest. But because mammoth and elephant ivory are substitutes, elephant ivory harvests and prices may also affect mammoth ivory exports, generating the potential for reverse causality. To deal with the reverse causality problem we use an instrumental variable approach. The instrument we use is motivated by the observations of Canada Fossils president Pierre Parré, who noted in a CBC interview that "the global mining boom...is feeding the mammoth boom,"[20] and that ivory prices were inversely correlated with the gold price.[21] The idea is that as miners search for gold and other minerals in the Russian Arctic, they incidentally discover mammoth tusks, thereby increasing Russian mammoth ivory exports. The problem with using gold prices as the instrument, however, is that mining in Africa may, perhaps through the illegal "blood diamond" networks, be associated with elephant ivory smuggling. Therefore, instead, we use as our instrument the Russian GDP share of mineral rents (excluding energy). This is expected to be correlated with Russian mammoth ivory exports, and it should have no effect upon African elephant poaching or prices, since neither Russia nor Africa are large mining producers relative to the world market.[22,23]

Figure **??** shows how Russian mammoth ivory exports correlate with the Russian mineral rents GDP share and the real gold price. Russian mammoth ivory exports are highly correlated both with Russian mineral rents GDP share ($r = 0.896$, $p < 0.01$) and with the real gold price ($r = 0.625$, $p < 0.01$). Russian mineral rents GDP share are correlated both with the rise in Russian mammoth ivory exports 1990-2007, and the fall in 2008 and 2009, and subsequent rise. In contrast, real gold prices cannot explain either the rise in Russian mammoth ivory exports pre-2001, nor the fall in mammoth ivory exports in 2008 and 2009.

Now, let us turn to the control variables. The first control variable used in our analysis is the China GDP per capita variable, which is used to control for changes in demand for ivory. While China is not the only consumer of ivory, the rapid rise in China GDP per capita has been identified by Martin et al. (2006, 2010) as a contributor to the continued poaching of elephants. Furthermore, we noted in Figure **??** that over 95% of mammoth ivory exports have gone to China and to Hong Kong, indicating that this is the market in which mammoth and elephant ivory interact the most.

Second, we control for the institutional quality in Africa because African law enforcement influences the proportion of elephant ivory that is seized. We control for institutional quality in two ways. The "Polity 2" index measures the average level of democracy across African countries, with the assumption that more democratic countries have higher in-

[20]See Peter Evans, "Mammoth ivory trade raises fears for elephants," CBC News, 29 September, 2010.

[21]Personal communication with Mr. Parré, May 30, 2014.

[22]The African and Russian shares of world production are 9% each for gold, 7% each for copper, 6% each for iron and steel, 4% each for aluminium, and 2% (Africa) and 7% (Russia) for lead (source: Table 4, 2012 USGS *Minerals Yearbook*, "African Summary" and "Europe and Central Asia Summary").

[23]Neither elephant ivory seizures nor the legally permitted average sales price are highly correlated with Russian mineral rents GDP share ($r = 0.409$, $p = 0.053$ for seizures and $r = 0.415$, $p = 0.049$ for prices).

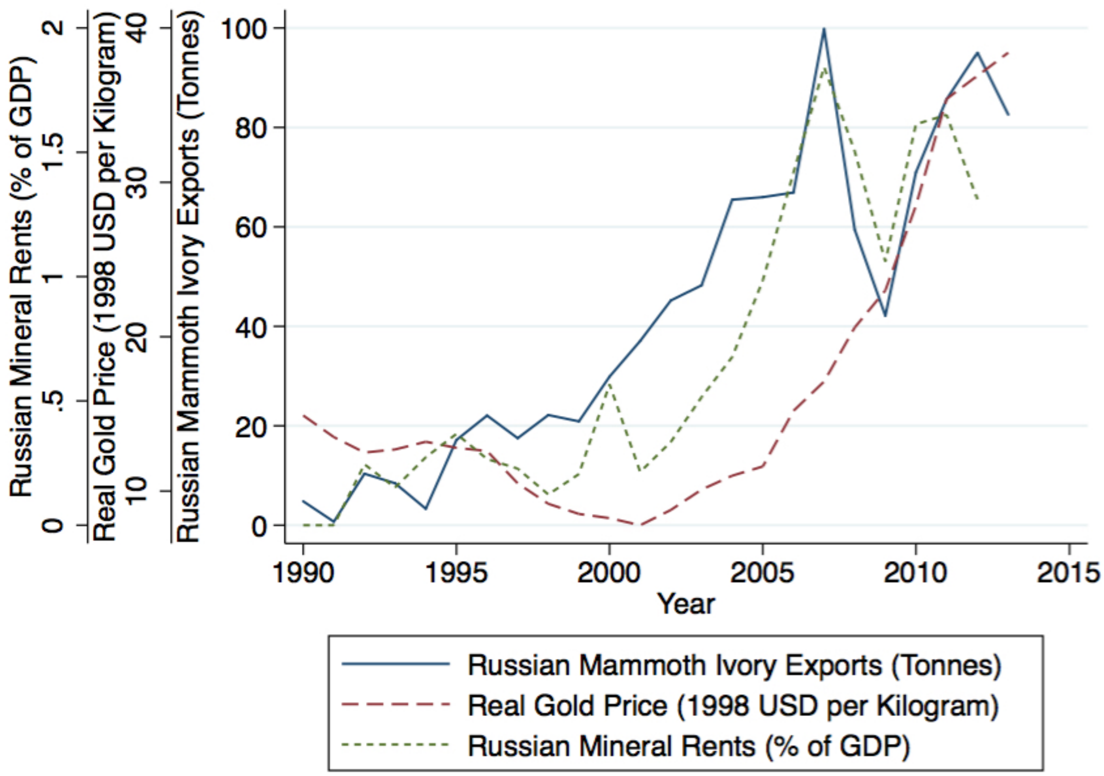

Figure 7: Russian Mammoth Ivory Exports, and the Instruments, Russian Mineral Rents and the Real Gold Price, 1989-2013

stitutional quality.[24] To relate this index more directly to elephant poaching, we weight the Polity 2 Index by the number of Ivory seizures by country and use the average of the weighted Polity 2 index for the African countries where elephants poaching occurs.[25] The second measure, which is only available from 1996 forward, is the World Bank's "Rule of Law" index. Again, this is measured as the average rule of law index weighted by the

[24]The Polity 2 index for each country is a weighted average of measures of its electoral competitiveness and openness, the nature of political participation, and the extent of checks on executive authority. The Polity 2 index values range from -10 to $+10$, with more autocratic countries having lower numbers and more democratic countries having higher numbers.

[25]Alternative measures such as the simple average and median across all African countries and the minimum Polity 2 measure across all African countries were also tried. The simple average and median Polity 2 variables produced similar results to the weighted average, but the minimum Polity 2 variable could not be used, as it had almost no variation, equalling around -2.3 in every year.

number of elephant ivory seizures across the 54 African countries.[26]

We also control for the per capita income within Africa since this represents the opportunity cost to those engaged in elephant poaching. The average per capita GDP of the African countries is weighted by the numbers of seizures in across countries to more accurately reflect conditions in countries with elephants.

Other variables included are the legal sales of elephant ivory allowed by CITES (for which we have two separate measures, one from CITES and one from COMTRADE statistics). In addition, we include a time trend variable to capture other temporal effects not otherwise measured. Finally, several relevant variables could not included in the regressions. These include the elephant population and range variables, which are only available for the years 1995, 1998, 2002, 2007 and 2013. Similarly, the Martin price survey data is only available for the years 1987, 2002, 2004, 2006, 2009, 2010, and 2014, and the PIKE data, which is only available 2002-2013, it is based on surveys which vary from year to year in their geographic representation. Now, let us turn to the econometric results.

Elephant Ivory Seizures Estimation Results

First, consider the post-ban regression of the effect of Russian mammoth ivory exports have had upon seizures of elephant ivory. We estimate this effect using both ordinary least squares and instrumental regressions of elephant ivory seizures on Russian mammoth ivory exports. The instrumental variable results reported in Table **??** use Russian mineral rents GDP share to instrument Russian mammoth ivory exports.[27]

Since theory does not guide us as to which institutional quality variables or which of the two sources for legal ivory trade should be included, we report several specifications. All specifications include Russian mammoth ivory exports, the demand shifter China GDP per Capita, and the linear time trend. Column (1) contains just these three variables; column (2) adds Weighted Average of Polity 2 and Weighted Average of Africa GDP per capita; columns (3) and (4) include the Polity 2 index, Africa GDP per capita, and African permitted trade in elephant ivory from CITES trade database and UN COMTRADE database,

[26]For the years 1997, 1999 and 2001, we impute the rule of law index for each African country as the average of the year preceding and the year following, since the index was only available in even numbered years between 1996 and 2002. As with the Polity 2 variable, we tried other measures such as the simple (unweighted) average, median, and the minimum across countries rule of law index. All of these produced results similar in sign and magnitude.

[27]In the appendix, OLS regression results are reported in Table **??** and the first-stage regression for the IV model are reported in Table **??**. The OLS results for Russian mammoth ivory exports are smaller in magnitude than the IV results, and are less likely to be statistically significant.

Table 1: Elephant Ivory Seizures Instrumental Regression Results, 1989-2013

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory (Tonnes)	**-0.552	**-0.638	***-0.772	*-0.823	***-0.411	*-0.543	*-0.371
	(0.149)	(0.185)	(0.167)	(0.291)	(0.0902)	(0.190)	(0.118)
China GDP per Capita (1000s of 2005 USD)	*8.464	***6.815	***10.14	***5.951	***10.98	**10.83	***11.09
	(3.134)	(1.468)	(1.553)	(1.165)	(2.026)	(3.174)	(2.268)
Time Trend	0.258	0.0185	0.604	1.415	-1.498	-0.354	-1.696
	(1.056)	(1.257)	(0.534)	(1.554)	(1.337)	(2.518)	(1.592)
Weighted Average Africa GDP per Capita (1000s)		-14.36	-5.488	-11.82	***-22.12	-17.92	***-22.94
		(6.944)	(3.124)	(7.600)	(3.749)	(8.158)	(4.010)
Weighted Average Polity2		1.935	-0.316	1.578			
		(1.219)	(0.959)	(1.366)			
Weighted Average Rule of Law					**53.44	48.15	**55.88
					(13.29)	(27.54)	(13.27)
Legal Elephant Ivory Trade (Tonnes, CITES)			*-0.197			-0.0992	
			(0.0688)			(0.0779)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				-0.165			0.0353
				(0.0855)			(0.0352)
Constant	-509.3	0.714	-1184.1	-2781.5	3060.7	768.2	3455.2
	(2100.5)	(2512.7)	(1059.2)	(3097.6)	(2659.6)	(5008.6)	(3169.1)
Observations	23	23	23	23	17	17	17
R^2	0.293	0.354	0.514	0.294	0.648	0.701	0.655
F	8.920	20.14	19.67	26.73	99.96	40.44	117.1

Notes: Dependent variable: Elephant Ivory Seizures (tonnes). Newey-West standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

respectively; columns (5) through (7) repeat columns (2)-(4), using the Weighted Average of Rule of Law instead of Polity 2 to control for institutional quality.

All specifications show that an increase in Russian mammoth ivory exports reduce African elephant ivory seizures. In the IV regressions, the negative correlation between elephant ivory seizures and Russian mammoth ivory exports is larger in magnitude, with elephant ivory seizures decreasing by between -0.37 to -0.82 tonnes per tonne of Russian mammoth ivory. The estimated coefficients of Russian mammoth ivory are statistically significant in all specifications, though only at the 10% level when Rule of Law is used.[28]

Chinese GDP per capita is strongly positively correlated with elephant ivory seizures, with an increase of $1000 USD of Chinese per capita income causing between a six to eleven tonnes increase in elephant ivory seizures, depending upon the specification. The Polity

[28]The first stage IV regressions of the instrumental regressions using Russian mineral rents as IV in Table **??** in the Appendix show that the the Russian mineral rents GDP share are positively correlated with Russian mammoth ivory exports.

2 variable is statistically insignificant in all specifications. The Rule of Law variable is positive in sign and is statistically different from zero in specifications (5) and (7). Finally, the two measures of legal elephant ivory trade are mostly statistically insignificant except in column (3). Nevertheless, the negative sign suggests that legal sales may have reduced poaching. African GDP per capita is negative in all specifications, but is statistically different from zero only in columns (5) and (7). The time trend variable is statistically insignificant in all specifications.

Elephant Ivory Price from Permitted Trades Estimation Results

Next, we turn to the regressions on permitted trade prices. Table **??** presents the instrumental variables results for the post-ban elephant ivory permitted trade price regressions. Since the right-hand-side regressors are identical to those for the seizures regressions, the instrumental variable first-stage regressions are the same as those given in Table **??**.

For the most part, the results of the effect of Russian mammoth ivory exports on African elephant ivory permitted trade prices is much weaker than the effect upon seizures.[29] The effect of Russian mammoth ivory is estimated to be negative in every specification and significant in all but in column (4).

Other notable results are that the effect of China GDP per capita is positive in all specifications, which is consistent with demand from China driving the market, and the effect of an increase in the Polity 2 variable, which corresponds to a increase in the political competitiveness of the average African country, has a negative effect upon prices. Finally, legal sales in elephant ivory appear to have had a positive effect upon elephant ivory prices. Elephant ivory prices may affect the legal elephant ivory trade as well. This reverse causality cannot not be resolved by our analysis, which may explain this result.

Thus, for each tonne of Russian mammoth ivory exports, we find that the price of elephant ivory decreases by about half a dollar to a dollar and a half per tonne. At the rate of 84 tonnes per year observed over the past couple of years in the data, this implies that elephant ivory permitted trade prices would be between 40 and 120 dollars per kilogram higher, had mammoth ivory not been available. Again, this is broadly supportive of the hypothesis that mammoth ivory production has reduced the incentive for poaching of elephants.

[29] The OLS results find that the coefficient on Russian Mammoth Ivory is much weaker, with many coefficients for Russian Mammoth Ivory estimated to be positive in sign. See Table **??** in the Appendix.

Table 2: Permitted Elephant Ivory Price Instrumental Variable Regression Results, 1989-2013.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory (Tonnes)	***-1.048	**-1.112	**-1.036	-0.565	**-1.165	*-0.881	-0.158
	(0.229)	(0.316)	(0.341)	(0.433)	(0.282)	(0.366)	(0.362)
China GDP per Capita (1000s of 2005 USD)	***27.64	***24.90	***23.03	***27.49	***16.37	***16.81	**21.86
	(4.183)	(2.611)	(1.894)	(1.903)	(3.229)	(2.684)	(5.764)
Time Trend	-3.042	-2.032	-2.363	**-6.184	4.243	1.721	-2.315
	(1.826)	(1.284)	(1.248)	(2.004)	(2.698)	(2.763)	(4.588)
Weighted Mean African GDP per Capita (1000s)		-7.865	* -12.83	**-15.49	-16.17	**-24.89	***-34.74
		(6.282)	(5.370)	(4.262)	(11.35)	(7.531)	(4.696)
Weighted Mean Polity2		-2.560	-1.299	-1.485			
		(2.519)	(2.840)	(2.443)			
Weighetd Mean Rule of Law					*79.04	**89.34	**124.0
					(32.16)	(22.39)	(28.55)
Legal Elephant Ivory Trade (Tonnes, CITES)			0.110			0.210	
			(0.139)			(0.160)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				***0.497			***0.821
				(0.115)			(0.0768)
Constant	6058.0	4072.6	4743.2	**12345.8	-8402.7	-3349.4	4691.3
	(3633.6)	(2548.1)	(2476.4)	(3989.3)	(5360.4)	(5498.9)	(9133.7)
Observations	23	23	23	23	17	17	17
R^2	0.596	0.642	0.662	0.822	0.711	0.743	0.955
F	78.85	91.89	105.4	543.6	109.1	98.08	365.0

Notes: Dependent variable: Elephant Ivory Prices in nominal U.S. dollars per kilogram. Newey-West standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Robustness Checks

Since time series data such as we are using may suffer from co-integration problems, inducing a spurious regression result, we checked for this using the Dickey-Fuller (DF) test. The DF test statistic for the Elephant Ivory Seizures and Russian Mammoth ivory exports are -0.934 and -2.474, which are greater than the critical values at 1%, level of significance, indicating that both of the variables may have a unit root. Therefore, in Table **??**, we repeated the seizures instrumental variable regressions, using first differences in all variables.[30] The estimated coefficients for Russian mammoth ivory range between -0.02 to -0.6, but are statistically weak, except in column (1). Results from the level IV regressions and first-difference IV regressions are similar in both sign and magnitude for our coefficient of interest, Russian mammoth ivory, suggesting that the estimated relationship between ele-

[30]The first stage difference regression results are presented in the Appendix in Table **??**.

Table 3: Elephant Ivory Seizures IV Regression First-Difference Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory (Tonnes)	**-0.293	-0.309	-0.608	0.0279	-0.360	-0.607	-0.0214
	(0.0803)	(0.191)	(0.311)	(0.209)	(0.130)	(0.456)	(0.156)
China GDP per Capita (1000s of 2005 USD)	7.962	7.728	12.52	6.379	8.552	10.34	7.734
	(4.942)	(10.22)	(7.006)	(6.788)	(5.241)	(5.704)	(5.040)
Weighted Average Africa GDP per Capita (1000s)		-1.554	4.065	0.689	*-17.16	*-18.36	*-13.96
		(12.30)	(3.995)	(6.613)	(5.572)	(7.318)	(5.480)
Weighted Average Polity2		-0.393	-1.643	-0.981			
		(2.790)	(1.762)	(1.365)			
Weighted Average Rule of Law					*49.57	63.90	*30.52
					(17.06)	(38.71)	(13.59)
Legal Elephant Ivory Trade (Tonnes, CITES)			-0.126			-0.0879	
			(0.126)			(0.125)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				**0.138			**0.134
				(0.0463)			(0.0332)
Constant	-0.397	-0.180	0.0381	-0.864	-0.633	0.319	-2.006
	(1.294)	(2.453)	(1.327)	(2.083)	(2.595)	(3.834)	(2.441)
Observations	22	22	22	22	16	16	16
R^2	0.067	0.079	0.061	0.211	0.252	0.312	0.316
F	6.670	1.167	4.778	12.11	2.791	2.290	15.08

Notes: Dependent variable: Elephant Ivory Seizures (tonnes). All variables are in first-differences: $\Delta Z_t = Z_t - Z_{t-1}$. Newey-West standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

phant ivory seizures and Russian mammoth ivory exports does not result from a spurious regression.

The Dickey-Fuller(DF) Test Statistic for the Elephant Ivory price from permitted trade is -2.21, which is greater than the critical values at 1% level of significance, indicating there is a unit root in the elephant ivory price from permitted trade process. Thus, Table **??** repeats the permitted price instrumental variable regressions,in first differences for all variables. From the first-difference instrumental variable regressions, the estimated coefficients of Russian mammoth ivory range between -0.3 to -1.7, and are statistically significant four of seven specifications. Results from the first-difference IV price regressions are similar to the results of the elephant ivory price regression in levels in both sign and magnitude; again, this supports our claim that mammoth ivory exports has reduced poaching.

Table 4: Elephant Ivory Permitted Trade Price Instrumental Variable First Difference Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory (Tonnes)	***-1.621	**-1.719	-1.388	-0.228	*-1.455	-0.631	**-0.335
	(0.409)	(0.442)	(0.864)	(0.346)	(0.529)	(0.594)	(0.0854)
China GDP per Capita (1000s of 2005 USD)	**39.69	**38.56	*33.36	***34.58	11.31	4.771	*14.04
	(12.35)	(12.29)	(15.33)	(7.886)	(17.63)	(14.36)	(5.867)
Weighted Average Africa GDP per Capita (1000s)		-7.245	-11.76	-1.505	**-42.59	**-41.32	***-40.16
		(14.49)	(7.938)	(4.957)	(13.09)	(10.07)	(5.299)
Weighted Average Polity2		-2.753	-1.262	-3.117			
		(2.623)	(3.860)	(1.798)			
Weighted Average Rule of Law					**196.4	**155.7	***163.4
					(44.67)	(39.73)	(19.53)
Legal Elephant Ivory Trade (Tonnes, CITES)			0.129			0.319	
			(0.286)			(0.151)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				***0.753			***0.806
				(0.0678)			(0.0453)
Constant	-6.801	-5.195	-5.393	**-9.927	8.152	4.865	2.413
	(4.820)	(3.482)	(3.270)	(2.706)	(7.096)	(4.615)	(2.548)
Observations	22	22	22	22	16	16	16
R^2	.	0.001	0.098	0.768	0.381	0.383	0.945
F	10.40	4.897	4.061	192.5	7.727	70.96	1804.8

Notes: Dependent variable: Elephant ivory prices in nominal U.S. dollars per kilogram. All variables are in first-differences: $\Delta Z_t = Z_t - Z_{t-1}$. Newey-West standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Implied Mammoth Ivory Effect on Elephant Poaching

How economically meaningful is the observed negative correlation between elephant ivory seizures and Russian mammoth ivory harvests? From the Table **??**, the IV results suggest that one tonne of Russian mammoth ivory exports decreases elephant ivory seizures by between -0.37 to -0.82 tonnes. How much is that in elephants?

Since not all illegal African elephant ivory harvests are seized (and not all seizures are reported to ETIS), elephant ivory ETIS seizures data are inherently downward biased (Milliken 2014). Table **??** shows the calculation of implied reduced number of elephants killed as a result of mammoth ivory production, combining the estimates of elephant kills from Wittemyer et al. (2014) with ETIS seizures and our regression results on the effect of mammoth ivory exports upon seizures. Column (1) shows estimates of elephants killed for each year 2010-2012 from the two different methods Wittemyer et al. (2014) used (their so-called 'model' approach and the 'estimation' approach). Column (2) reports ETIS

Table 5: Implied Effect of Mammoth Ivory on Elephant Poaching

	Year	(1) Elephants Killed Wittemyer et al. (No. Animals)	(2) Ivory Seizures ETIS (Tonnes)	(3) % Seized (ETIS Seizures/ Wittemyer et al. Kills)	(4) RU Mammoth Ivory Exports (Tonnes)	(5) Reduced Seizures by Mammoth Ivory (Tonnes)	(6) Reduced Kills by Mammoth Ivory (No. Animals)
Model	2010	21,477	26.3	12.2	71.0	49.7	40,621
Model	2011	39,692	51.0	12.8	85.7	60.0	46,667
Model	2012	38,828	41.0	10.6	95.0	66.5	62,972
Empirical	2010	29,124	26.3	9.0	71.0	49.7	55,084
Empirical	2011	41,044	51.0	12.4	85.7	60.0	48,252
Empirical	2012	31,616	41.0	13.0	95.0	66.5	51,087
Average		33,630	39.4	11.7	83.9	58.7	50,813

seizures for these years. Column (3) uses columns (1) and (2) and the assumption that each elephant killed produces 10 kg of ivory to estimate the percentage of elephant ivory that is interdicted. Column (4) presents the Russian mammoth ivory exports for each of the three years. Column (5) uses the average regression coefficient of -0.7 to calculate the ETIS seizures reduced by the presence of mammoth ivory exports. Column (6) uses the interdiction percentage to estimate the reduction in the number of elephants poached as a result of the Russian mammoth ivory exports. The last row contains the average results for each column for 2010-2012.

Based on the analysis of Wittemyer et al. (2014), on average around 33,600 elephants were illegally being poached every year between 2010 and 2012. Assuming an average tusk weight of 10 kg. per elephant killed, this corresponds to roughly 330 tonnes of elephant ivory being harvested illegally every year.[31] The ETIS seizures, in contrast, averaged 39.4 tonnes of elephant ivory per year during these three years. Thus, ETIS seizures represented on average only 11.7% of illegal elephant ivory poaching in Africa. Russian mammoth ivory production during this period averaged nearly 84 tonnes per year. Given the coefficient of -0.7 tonnes of seizure reduced per tonne of mammoth ivory, Russian mammoth ivory exports have reduced seizures by approximately 59 tonnes per year. Given an interdiction rate of 11.7%, this implies that mammoth ivory production during this period reduced ivory poaching by 508 tonnes of elephant ivory harvest per year or saved slightly more than 50,800 elephants from being poached. Thus, rather than 33,600 elephants per year being poached for ivory, had there been no mammoth ivory exports during this period,

[31] The average tusk size may be smaller than this. Shoshani (1992) estimates that tusk size had diminished to about 3 kg per elephant by the 1990s. At these rates, the 33,600 elephants killed would amount to about 100 tonnes of elephant ivory being harvested, which means that the ETIS seizures would amount to about 40% of harvesting. At these numbers, the effect of mammoth ivory drops to about 15,200 elephants per year being saved by mammoth ivory, which corresponds to a total of 48,000 elephants per year poached.

over 84,400 elephants per year would have been slaughtered for their ivory. Given African elephant population estimates of around 500,000 elephants, these would have translated to poaching rates of around 17% per year, or about 10% higher than the estimates in Wittemyer et al. (2014). A final way to look at this coefficient is to note that the estimated 10 million mammoth ivory carcases in Siberia, whose combined weight (at 18 to 90 kg. per animal) may be between 18,000 to 90,000 tonnes, would save anywhere from 12 to 63 million African elephants from being poached.

Of course, these are all-else-constant results. A worsening of institutional quality in Africa, an increase in income per capita in China, or a reduction in permitted elephant ivory sales could undo the positive effects mammoth ivory has had upon reducing elephant poaching in Africa.

5 Discussion and Conclusions

This paper studies both theoretically and empirically the effect that the development of Russian exports of mammoth ivory has had upon the poaching of African elephants.

Our theory shows that the presence of a substitute lowers the rate of poaching relative to what it would be absent the substitute. This lowers the minimum viable population of elephants, which makes it possible that the lower harvest rate allows the population to recover sufficiently to avoid extinction. We also show that the observed rising elephant population and rising elephant ivory interdictions are inconsistent with a poaching and storage equilibrium.

Our empirical analysis shows that at the current production levels of over 80 tonnes mammoth ivory per year, mammoth ivory production may save as many as 50,000 African elephants from being poached each year. Since current poaching rates are about 34,000 elephants per year, absent the mammoth ivory trade the poaching rate would more than double, likely endangering elephants. Thus, it may be said that the mammoth are possibly preventing the elephant in following them to extinction. We also find that mammoth ivory has reduced elephant ivory prices by between 80$ to 120$ per kilogram.

These results suggests that policies which make the substitutes readily available for renewable resources will lower demand for that resource, and may mitigate against over-exploitation of the species.

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Appendix

A. Data and Sources

African elephant population: Source: Population estimates for the years 1995, 1998, 2002, 2007, and 2012 are from African Elephant Specialist Group (AfSEG) which can be found in http://www.elephantdatabase.org/. Elephant population estimates for 1981 and 1989 are from Barbier et al. (1990), and elephant population estimates for 1979 and 1987 are from Stiles (2004). Units: thousands of animals. (http://www.elephantdatabase.org/report/Loxodonta_africana).

Range: Source: Range estimates for the years 1995, 1998, 2002, 2007, and 2012 are from African Elephant Specialist Group (AfSEG). Units: Millions of square kilometers of land area thought to be the existing range of wild elephants.

(http://www.elephantdatabase.org/report/Loxodonta_africana).

Pre-Ban African ivory production: Pre-ban African ivory production data is from Barbier et al. (1990). Units: tonnes (1000 kilograms).

Pre-Ban African ivory prices: Pre-ban African ivory price data is from Barbier et al. (1990). Units: nominal dollars per kilogram.

Polity 2: Source: Centre for Systemic Peace An index of a country's election's competitiveness and openness, the nature of political participation, and the extent of checks on executive authority. Polity score ranges from -10 to $+10$, where -10 to -6 correspond to autocracies, -5 to 5 correspond to anocracies, and 6 to 10 correspond to democracies (Marshall et al. 2014). (http://www.systemicpeace.org/polityproject.html).

Rule of Law: Source: World Bank.(http://info.worldbank.org/governance/wgi/index.asp)

ETIS Seizures Source:1989-1995 data is from Milliken et al. (2004, Table 5, pp. 17-18) 1996-2010 data is from Milliken et al. (2012, Table 1, p. 4). 2011-2013 data is imputed from Milliken (2014, Figure 1, p.2). The combined weight of all elephant ivory seizures made by authorities throughout the world. The data Units: tonnes (1000 kilograms).

ETIS Average Seizure Weight The average seizure weight is calculated from dividing ETIS Seizures (in kilograms) by the "Number of elephant product seizures" summed over all countries. Source: Number of seizures data 1989-2010 is from MIKE document SC61 Doc. 44.2 (Rev. 1) (Table 7, pp. 38-45). Number of seizures data 2011-2013 is from Milliken (2014, Figure 1, p.2). Units: kilograms per seizure.

ETIS Large (>500 kilogram) Seizures This variable is calculated as the total weight of seizures where greater than 500 kilograms was seized, divided by the weight of total seizures. Source: Total large seizures 2009-2013 is from Milliken (2014, Table 1, p. 8). Total large seizures 2000-2008 is from CITES Standing Committee Report (2012, Table 2, p. 17). Units: Percent of total seizures.

Russian Mammoth Ivory Exports: Source: UN Comtrade. Product code *HS 050710*, series *"Ivory, its powder & waste, unworked"*. Calculated as the sum over all countries of imports from Russia. Units: tonnes (1000 kilograms).

Russian Mammoth Ivory Price: Source: UN Comtrade. Series number: Calculated as the sum to the total value mammoth ivory over all countries of imports from Russia. Units: nominal dollars per kilogram.

China GDP per Capita: Source: Penn World Table 7.1. Units: thousands of constant 2005 U.S. Dollars.

Russian Mineral Rents (% of GDP): Source: World Bank Development Indicators, series code: NY.GDP.MINR.RT.ZS. Data description: "Mineral rents are the difference between the value of production for a stock of minerals at world prices and their total costs of production. Minerals included in the calculation are tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate." Units: Percent of GDP.

Real Gold Price: Source: U.S. Geological Survey, Historical Statistics (data series 140). Average of U.S. import and export price. Units: 1998 U.S. dollars per kilogram. (http://minerals.usgs.gov/minerals/pubs/historical-statistics/).

Legal Ivory Trade, CITES: Source: UNEP World Conservation Monitoring Centre. CITES Trade Database. Cambridge, UK. http://www.cites.org/eng/resources/trade.shtml. Calculated as the sum of whole tusk, ivory pieces, and carved ivory of exports from all African countries. Re-exports, i.e. trade within the African countries were excluded. Units: tonnes (1000 kilograms).

Legal Ivory Trade, WITS: Source: UN Comtrade. Product code *HS 050710*, series *"Ivory, its powder & waste, unworked"*. Calculated as the sum, excluding re-exports, of exports from all African countries. Units: tonnes (1000 kilograms).

Legal Ivory Trade Price, WITS: Source: UN Comtrade. Product code *HS 050710*, series *"Ivory,* *its powder & waste, unworked"*. Calculated as the sum, excluding re-exports, of the average value of exports from all African countries. Units: nominal dollars per kilogram.

PIKE: Source: MIKE reports to CITES (2013, 2014). Mean proportion of illegal killed elephants over all sites. Units: Proportion of kills which were illegal (0 to 1 in value).

B. Supplementary Tables

Table 6: Summary Statistics for Variables Used in Regression Analysis

Variable	Observations	Mean	Std. Dev.	Min	Max
Elephant Ivory Seizures (Tonnes, ETIS)	25	21.9	13.1	6.9	58.0
Russian Mammoth Ivory Exports (Tonnes)	25	41.0	31.3	0.7	99.8
Russian Mining Share (Percent of GDP)	23	0.68	0.60	0.00	1.84
China GDP per Capita (2005 USD)	25	4,279	2,605	1,288	9,798
Weighted Average Polity2 Index of African Countries	25	2.65	2.46	-5.01	5.68
Weighted Average Rule of Law of African Countries	18	-0.62	0.24	-.92	-0.22
Weighted Average GDP per Capita of African Countries (2005 USD)	25	1571.5	315.69	1198.51	2048.998
Legal Elephant Ivory Trade (Tonnes, CITES)	25	30.1	51.5	1.4	205.9
Legal Elephant Ivory Trade (Tonnes, Comtrade)	25	31.4	27.2	8.8	132.6
Raw Elephant Ivory Export Price (Nominal USD per Kilogram)	25	53.51	57.8	19.87	295.55
Raw Mammoth Ivory Export Price (Nominal USD per Kilogram)	25	77.82	62.88	15.33	253.14

Table 7: Elephant Ivory Seizures Ordinary Least Squares Regression Estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory (Tonnes)	-0.163	-0.249	-0.311	-0.229	*-0.359	*-0.484	-0.281
	(0.192)	(0.166)	(0.171)	(0.317)	(0.132)	(0.182)	(0.296)
China GDP per Capita (1000s of 2005 USD)	**10.12	**8.882	**10.26	**8.882	11.87	10.80	12.14
	(2.697)	(2.845)	(2.876)	(2.943)	(5.733)	(6.078)	(6.257)
Time Trend	-1.793	-1.741	-1.515	-1.853	-2.135	-0.804	-2.615
	(0.979)	(1.206)	(1.281)	(2.000)	(3.502)	(3.857)	(4.236)
Weighted Average Africa GDP per Capita (1000s of 2005 USD)		-8.755	-5.261	-8.968	**-21.64	-17.10	*-22.71
		(7.619)	(6.149)	(9.459)	(6.675)	(7.788)	(10.18)
Weighted Average Polity2		1.241	-0.350	1.327			
		(1.798)	(1.290)	(2.460)			
Weighted Average Rule of Law					50.60	42.65	52.55
					(26.05)	(29.25)	(32.77)
Legal Elephant Ivory Trade (Tonnes, CITES)			-0.0733			-0.0885	
			(0.0860)			(0.105)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				0.0160			0.0594
				(0.132)			(0.122)
Constant	3571.6	3488.6	3032.9	3711.9	4326.1	1660.4	5284.2
	(1946.0)	(2405.4)	(2555.1)	(3986.0)	(6973.8)	(7682.0)	(8436.2)
Observations	25	25	25	25	18	18	18
R^2	0.638	0.669	0.712	0.669	0.771	0.805	0.778
F	6.743	5.113	5.449	3.864	25.77	18.87	23.60

Notes: Dependent variable: Russian Mammoth Ivory Exports (Tonnes). HC3 type Standard Errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 8: Permitted Elephant Ivory Price OLS Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory (Tonnes)	0.316	-0.0717	0.602	1.468	-0.696	-0.177	0.107
	(1.395)	(1.155)	(0.839)	(1.918)	(1.290)	(1.247)	(0.647)
China GDP per Capita (1000s of 2005 USD)	*47.67	28.48	13.61	28.48	5.454	9.886	8.234
	(20.69)	(18.34)	(7.708)	(17.19)	(17.39)	(13.34)	(17.92)
Time Trend	-19.08	-5.675	-8.121	-14.54	3.500	-2.032	-1.460
	(10.10)	(8.839)	(6.571)	(10.98)	(10.92)	(9.272)	(7.661)
Weighted Average Africa GDP per Capita (1000s of 2005 USD)		16.80	-20.99	-0.0439	8.824	-10.05	-2.128
		(29.23)	(27.28)	(29.93)	(50.73)	(36.05)	(47.32)
Weighted Average Polity2 Index		-19.43	-2.215	-12.68			
		(14.20)	(5.092)	(8.710)			
Weighted Average Rule of Law					-35.33	-2.285	-15.13
					(168.2)	(121.9)	(172.9)
Legal Elephant Ivory Trade (Tonnes, CITES)			0.793			0.368	
			(0.505)			(0.492)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				1.268			0.613
				(0.720)			(0.527)
Constant	38025.5	11312.2	16240.6	28965.0	-6997.9	4082.5	2894.9
	(20117.3)	(17603.3)	(13132.4)	(21839.9)	(21785.4)	(18502.4)	(15301.1)
Observations	26	25	25	25	18	18	18
R^2	0.375	0.555	0.813	0.774	0.441	0.566	0.601
F	1.810	1.075	1.769	1.407	0.677	1.252	1.656

Notes: Dependent variable: Elephant Ivory Prices in nominal U.S. dollars per kilogram. HC3 type Standard Errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 9: First Stage IV Regression Results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mineral Rents (% of GDP)	23.19	21.24	18.93	15.67	** 27.29	*23.60	*23.95
	(13.20)	(14.35)	(11.79)	(13.82)	(8.458)	(8.198)	(10.72)
China GDP per Capita (1000s of 2005 USD)	-3.897	-4.946	-1.733	-4.880	-5.776	-5.260	-5.751
	(5.678)	(5.037)	(4.795)	(3.935)	(6.039)	(5.970)	(5.988)
Time Trend	** 3.619	2.885	*3.046	**4.110	*5.745	*6.187	*5.849
	(1.169)	(1.392)	(1.326)	(1.108)	(2.319)	(2.418)	(2.376)
Weighted Average Africa GDP per Capita (1000s of 2005 USD)		-14.62	-5.901	-7.176	*-25.58	-18.00	-20.27
		(7.476)	(6.847)	(7.230)	(10.59)	(9.987)	(11.68)
Weighted Average Polity2		2.558	0.471	1.383			
		(2.239)	(1.993)	(1.951)			
Weighted Average Rule of Law					**105.4	**86.38	*87.31
					(28.72)	(25.91)	(34.95)
Legal Elephant Ivory Trade (Tonnes, CITES)			*-0.158			**-0.0985	
			(0.0647)			(0.0248)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				*** -0.236			-0.0979
				(0.0500)			(0.0667)
Constant	**-7201.1	-5706.0	* -6045.6	**-8158.1	*-11345.4	*-12252.9	*-11567.8
	(2322.3)	(2777.3)	(2640.5)	(2213.1)	(4642.9)	(4839.8)	(4754.8)
Observations	23	23	23	23	17	17	17
R^2	0.884	0.904	0.928	0.936	0.934	0.950	0.941
F	47.41	51.35	43.27	66.96	39.54	35.82	29.40

Notes: Dependent variable: Russian Mammoth Ivory Exports (Tonnes). Robust Standard Errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 10: First Stage IV First-Difference Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mineral Rents (% of GDP)	*31.87	*31.24	21.18	23.51	*30.54	20.07	25.82
	(13.69)	(13.69)	(14.39)	(18.62)	(12.57)	(12.61)	(18.28)
China GDP per Capita (1000s of 2005 USD)	8.628	8.483	10.92	7.374	3.262	4.630	3.131
	(15.38)	(16.24)	(15.45)	(16.81)	(18.12)	(16.38)	(18.62)
Weighted Average Africa GDP per Capita (1000s)		-3.674	3.560	-4.412	-12.20	-9.696	-11.77
		(12.88)	(10.77)	(12.84)	(10.65)	(8.447)	(10.60)
Weighted Average Polity2		1.171	-0.553	1.313			
		(2.986)	(2.215)	(3.025)			
Weighted Average Rule of Law					*76.71	*70.34	73.54
					(33.15)	(22.78)	(38.15)
Legal Elephant Ivory Trade (Tonnes, CITES)			-0.136			-0.122	
			(0.0823)			(0.0589)	
Legal Elephant Ivory Trade (Tonnes, Comtrade)				-0.101			-0.0611
				(0.0756)			(0.0798)
Constant	-0.855	-1.253	-0.615	-0.441	2.747	3.130	2.948
	(4.146)	(4.561)	(4.696)	(4.565)	(6.063)	(5.998)	(5.945)
Observations	22	22	22	22	16	16	16
R^2	0.370	0.379	0.496	0.426	0.612	0.723	0.629
F	4.185	2.068	2.464	19.56	3.657	5.146	12.91

Notes: Dependent variable: Russian Mammoth Ivory Exports (Tonnes). All variables are in first-differences: $\Delta Z_t = Z_t - Z_{t-1}$. Robust standard Errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$