

RESEARCH ARTICLE

# Elephants and mammoths: the effect of an imperfect legal substitute on illegal activity

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## Abstract

In response to the CITES ban on trade in elephant ivory, mammoth ivory began to be produced in post-Soviet Russia. We investigate how this substitute to elephant ivory has affected the poaching of elephants. We argue that the early success of the 1989 ivory ban at increasing the African elephant population was driven in part by increasing supply of mammoth ivory. The more recent increases in poaching appear to be driven by increasing demand and falling African institutional quality. We find that absent the 80 tonnes of Russian mammoth ivory exports per annum 2010–2012, elephant ivory prices would have doubled from their \$100 per kilogram level and that the current poaching level of 34,000 elephants per year may have increased by as many as 55,000 elephants per year on a population of roughly half a million animals.

**Keywords:** endangered species; conservation; extinction; elephant ivory; economic substitutes

**JEL Classification:** Q21; Q28; Q38

## 1. Introduction

Elephants have been poached for their ivory since antiquity (Barbier *et al.*, 1990). The African Elephant (*Loxodonta africana*) population, which was between three to five million in the 1930s and 1940s (World Wildlife Fund, 2015), fell to about 1,300,000 by 1979, and to around 600,000 in 1989 (Barbier *et al.*, 1990). This led to international commercial trade in African elephant ivory being declared illegal in 1989 under the Convention on International Trade in Endangered Species (CITES).<sup>1</sup> Yet continued poaching threatens elephants with extinction. Wittemyer *et al.* (2014) estimated that between 2010 and 2012 about 34,000 African elephants were poached annually. This is between 5 and 8 per cent of a population believed to number between 400,000 and 630,000 (Thouless *et al.*, 2016).

<sup>1</sup>Trade in Asian elephant (*Elephas maximus*) ivory, from a population of between 41,410 and 52,345 (Sukumar, 2003), had already been banned in 1975. Poaching is less severe for the Asian elephant because some males and all female Asian elephants lack tusks (Dawson and Blackburn, 1991).

Elephants are listed as ‘vulnerable’ under the International Union for Conservation of Nature (IUCN) ‘Red List’ of threatened species (Blanc, 2008). Since these poaching rates are unsustainable, there is much concern for the plight of elephants.

Following the collapse of the Soviet Union in the early 1990s, however, ivory from extinct mammoth (*Mammuthus primigenius*) carcasses became available as a substitute for elephant ivory (Martin and Martin, 2010, 2011), with Russian mammoth ivory exports rising to about 85 metric tonnes per year since 2010. A large stock of mammoth tusks, from perhaps as many as 10 million carcasses, lies beneath the Arctic tundra (Lister and Bahn, 2007).

This paper examines the effect exports of Russian mammoth ivory had upon the illegal market for elephant ivory.<sup>2</sup> We provide estimates of this impact by analyzing data from two sources. These include a time series of the aggregate world tonnage of seizures of elephant ivory, and a panel of the number of elephant ivory seizures by country using all countries in the world. Our methodology is to use mammoth ivory supply to explain the observed interdictions of elephant ivory. To deal with the potential endogeneity between mammoth and elephant ivory, we utilize an instrumental variable approach. Because mammoth ivory is often discovered incidentally to mining operations, we use the Russian mining industry rents as an instrumental variable to identify the effect mammoth ivory has had upon elephant poaching and elephant ivory interdictions.

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. At 10 kilograms of ivory per elephant, and an estimated 12 per cent interdiction rate, the 84 tonnes of Russian mammoth ivory exports produced on average per year between 2010–2012 may have reduced elephant ivory poaching by as many as 50,000 animals per year. At the current African elephant population levels of between 400,000 and 630,000 animals, absent mammoth ivory poaching would be well beyond sustainable levels. By way of comparison, poaching in the decade prior to the ban was about 100,000 animals per year (Barbier *et al.*, 1990), so our estimates suggest that as much as three-quarters of the reduction (50,000 out of 66,000 fewer animals poached) may be due to the present levels of mammoth ivory exports. We also find that absent mammoth ivory, elephant ivory prices might have been double their current levels, and we argue that this is likely the mechanism by which mammoth ivory has affected elephant poaching.

There is a growing literature on the effect substitutes have upon illegal activity. Fischer (2004) suggests that the legal trade in substitute ivory could make it easier for poachers to ‘launder’ their illegal wares (see also Stiles, 2004, 2009; Bulte and Damania, 2005; Bulte *et al.*, 2007). While this may be the case for elephant ivory grandfathered in the 1989 ban,<sup>3</sup> and for elephant ivory made available in the 1999 and 2008 CITES approved sales of

<sup>2</sup>This question is of interest beyond the example of elephants and mammoth ivory. The 2008 Amendment to the Lacey Act (16 U.S.C. SS 3371–3378) in the United States prohibits importation of products from a number of endangered species. In a highly publicized case, in 2009 and again in 2011, the U.S. Fish and Wildlife Service confiscated hardwoods from Madagascar and India, respectively, from the Gibson Guitar Company, which subsequently paid \$350,000 in fines and forfeited hardwoods valued at \$250,000 for Lacey Act violations (Revkin, 2012).

<sup>3</sup>In 1997, 462 tonnes of elephant ivory stores were held by 27 sub-Saharan African countries (Milliken, 1997). Martin and Martin (2011, table 1) document that stocks of pre-ban elephant ivory in Hong Kong averaged about 230 tonnes between 2004 and 2010.

African stockpiles, as well as for the relatively minor trade in hunting trophies,<sup>4</sup> it probably is not the case for mammoth ivory. Martin and Vigne (2011), Martin and Martin (2010, 2011), and Vigne and Martin (2014) find that markets in Hong Kong and China generally distinguish between the two types of ivory, and that when they do not, the two can be easily identified. Thus for ivory, it is difficult to pass off illegal elephant ivory as its legal mammoth ivory substitute, which may explain why mammoth ivory trade is still legal.

The remainder of the paper is organized as follows. Section 2 describes the events leading to the CITES ban on elephant ivory trade and presents stylized facts about the post-ban era. Section 3 presents a theoretical model, which distinguishes among different equilibria using the stylized facts and motivates the empirical analysis. Section 4 empirically analyses the effect mammoth ivory has had upon elephant ivory interdictions, elephant poaching, and elephant ivory prices. Section 5 uses our empirical estimates to determine the magnitude of the effect that mammoth ivory has had on reducing poaching. Section 6 concludes.

## 2. The mammoth and the elephant ivory markets

This section provides background on the elephant and mammoth ivory trade. Data sources and summary statistics are contained in the online appendix.

### 2.1 Pre-ban ivory trade

Prior to the CITES ban on trade in elephant ivory in 1989, 30 of the 37 African countries with elephant populations exported elephant ivory. Total 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). The decline in ivory production in the late 1980s, however, may not have corresponded to a decline in animals killed by poachers, because average tusk size was decreasing as the large male elephants were eliminated by poachers.<sup>5</sup>

The CITES ban was the third step in a series of tightening restrictions on elephant ivory trade. In 1976, CITES listed elephants in Appendix II, which required exporters to issue certificates for exports and importers to demonstrate that their imports had certificates. In 1986, CITES further tightened control over ivory trade by forcing the exporting countries to submit a management plan including harvest quotas for elephants before CITES would issue export certificates. Reported exports declined after 1986, perhaps in part due to exporting countries switching to illegal trade rather than submitting management quotas from CITES. This system collapsed because the exporting countries were unwilling to restrict their own exports when the verification of others' exports was not possible. This led to all international trade in elephant ivory being banned by listing African elephant ivory in Appendix I, effective January 1990 (Barbier *et al.*, 1990).

<sup>4</sup>This problem also occurs with the suggestion by Brown and Layton (2001) 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.

<sup>5</sup>Shoshani (1992: 73) estimates that 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.

## 2.2 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. Figure 1 shows the worldwide post-ban African elephant ivory seizures for the period 1989–2013. The line marked with circles is worldwide tonnage (in metric tonnes) of elephant ivory seizures (raw and worked). The line marked with squares shows the worldwide number of interdictions resulting in a seizure. It is clear that both the total tonnage and total number of seizures increased during the period 2010–2013.<sup>6</sup> Elephant ivory seizures have averaged over 20 tonnes per year since 1989, and seizures from 2009–2012 averaged 40 tonnes per year. Since not all illegal ivory trades are seized, however, the ETIS ivory seizure data represents only a fraction of poaching.<sup>7</sup> The number of interdictions occurring in Africa are also shown (triangles). The African seizures data is not available after 2010, but it remains fairly constant through 2010. Finally, the line marked with diamonds shows the Proportion of Illegally Killed Elephants (PIKE), a survey of elephant carcasses by Monitoring the Illegal Killing of Elephants (MIKE). The PIKE data shows that across survey sites the median proportion of elephant carcasses which were killed illegally has been increasing since those surveys began in 2002, suggesting that the rising interdictions reflects an increase in poaching. This increase could be the result of an increase in ivory demand, stricter law enforcement, or both.<sup>8</sup> Below, we attempt to sort out these different effects.

Figure 2 shows estimates of the elephant population in Africa and the effective African range of elephants from surveys in 1995, 1998, 2002, 2006, and 2013. The elephant population estimates are given as ‘definite’ (i.e., directly observed) (circles), ‘probable’ (squares), ‘possible’ (diamond), and ‘speculative’ (triangles). All estimates show that the African elephant population was rising in the decade prior to 2007, but has been declining since.<sup>9</sup> Interestingly, the decade of unambiguously rising elephant population occurred in spite of a declining range. The line marked with an ‘x’ shows elephant range estimates relative to the range in 1995.<sup>10</sup>

Mammoth ivory, from the large woolly elephant relative which became extinct in the Holocene, 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

<sup>6</sup>Much of the increase in the number of interdictions, however, is due to China, where interdictions averaged 60 per year in 2000–2008 but rose to over 700 per year in 2009–2010.

<sup>7</sup>Using the Wittemyer *et al.* (2014) estimate that 33,630 elephants were killed per year during 2010–2012, and comparing that with the average of 40 tonnes of ETIS seizures, suggests that, at 10 kg of ivory per elephant, about 12 per cent of poached ivory was seized.

<sup>8</sup>Milliken (2014) and Milliken *et al.* (2004, 2012) caution that the number of countries reporting seizures and the quality of seizures reporting have changed over time. Underwood *et al.* (2013) attempted to create an estimate that was free of these problems. The correlation between the worldwide sum of the Underwood *et al.* (2013) reconstruction and the ETIS seizures is  $r = 0.97$  ( $p < 0.01$ ).

<sup>9</sup>The IUCN/SSC data is further broken down by region, with the largest population in southern Africa (69.3 per cent of the total ‘definite’ in 2013, up from 59.7 per cent in 1995). That data shows that while overall the African definitely observed elephant population decreased by 1.2 per cent per annum between 2007 and 2013, the elephant population in west and central Africa (the smallest populations of the four regions, 5 per cent of the total in 2013) increased by 1.2 per cent and 0.1 per cent per annum, respectively, over this period. Only the population in east Africa fell between 2007 and 2013, but its decline of about 50,000 elephants was greater than the gains in the other three areas.

<sup>10</sup>A referee suggests, however, that Botswana and Zimbabwe have unsustainable populations. The range per ‘definite’ elephant is about 1 km<sup>2</sup> in these countries compared to over 5 km<sup>2</sup> in Tanzania and Kenya.

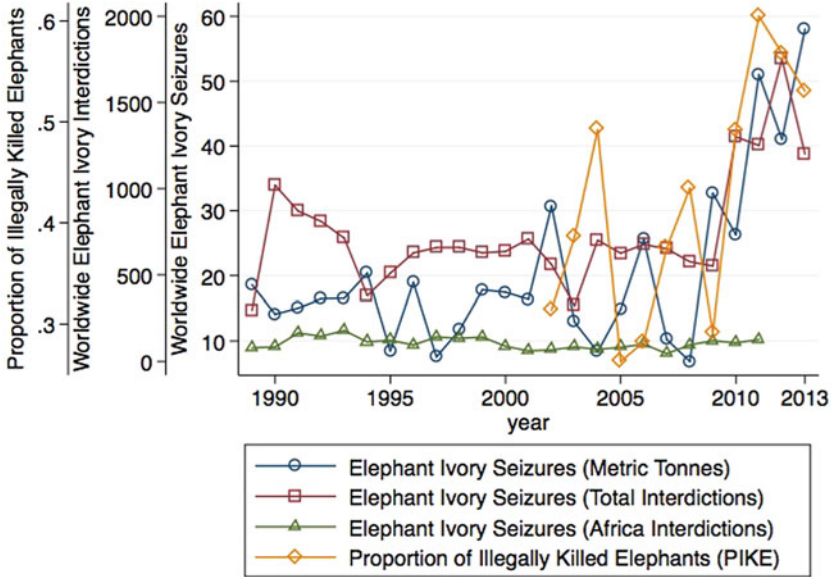


Figure 1. Elephant ivory seizures, number of interdictions, 1989–2013, and proportion of illegally killed elephants, 2002–2013.

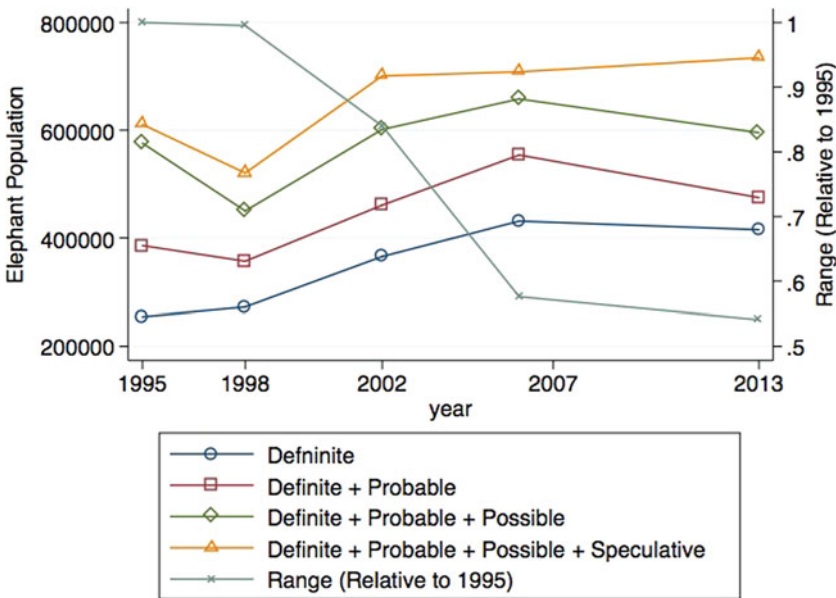


Figure 2. African elephant population and range estimates, 1995–2013.

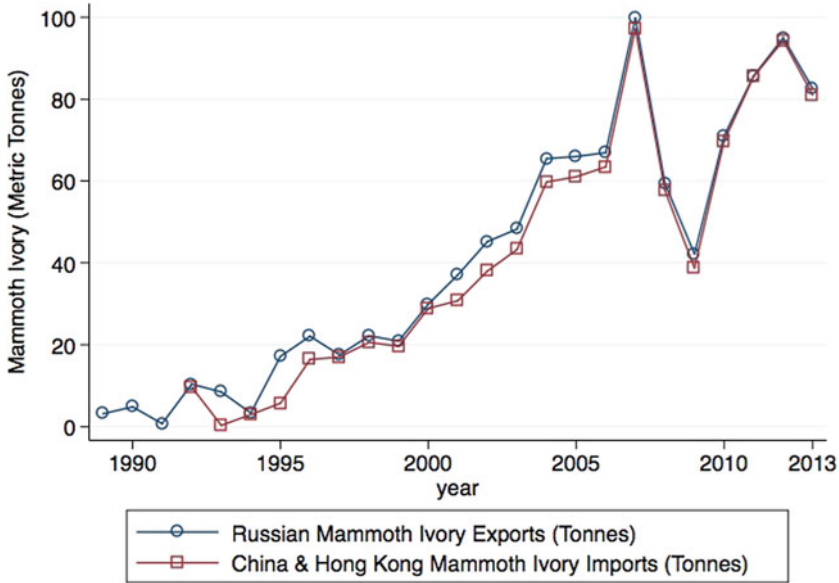


Figure 3. Russian mammoth ivory exports and Hong Kong plus China mammoth ivory imports, 1988–2013.

ivory-crafted artifacts and is demanded by ivory customers (Martin and Martin, 2010). Nearly 50,000 mammoth carcasses have been excavated in the 250 years since Siberia became a part of Russia in the 17th century, though that trade had mostly vanished during the Soviet era, and a stock of around 10 million mammoth carcasses are thought to lie beneath the permafrost in the Arctic tundra (Lister and Bahn, 2007). This stock is exploited by the mammoth tusk hunters every summer. Although mammoth hunters are required to have permits from the Russian government to sell mammoth ivory, many mammoth hunters operate without a valid permit (Larmer, 2013); thus, mammoth ivory is an exhaustible resource exploited under conditions of open access.

In figure 3, the line marked with circles shows Russian mammoth ivory exports for the period 1988 to 2013. Russian mammoth ivory exports have been increasing, averaging approximately 17 tonnes per year for 1991–2000 and averaging 60 tonnes per year for 2001–2013.<sup>11</sup> Mammoth ivory trade declined by more than 50 per cent during the Great Recession, but has subsequently recovered. Also shown in figure 3 are the total mammoth ivory imports in Hong Kong, Macao, and China (squares).<sup>12</sup> Hong Kong, Macao, and China’s combined average annual mammoth ivory imports account for over 95 per cent of total Russian exports.

<sup>11</sup> Given that an average mammoth tusk weighs between 9 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 of mammoth ivory every year, it would take between 150 and 750 years to exhaust the 10 million mammoth carcass stock.

<sup>12</sup> Mammoth ivory import statistics for Hong Kong are available only after 1995, while mammoth ivory import statistics for China are available from 1991.

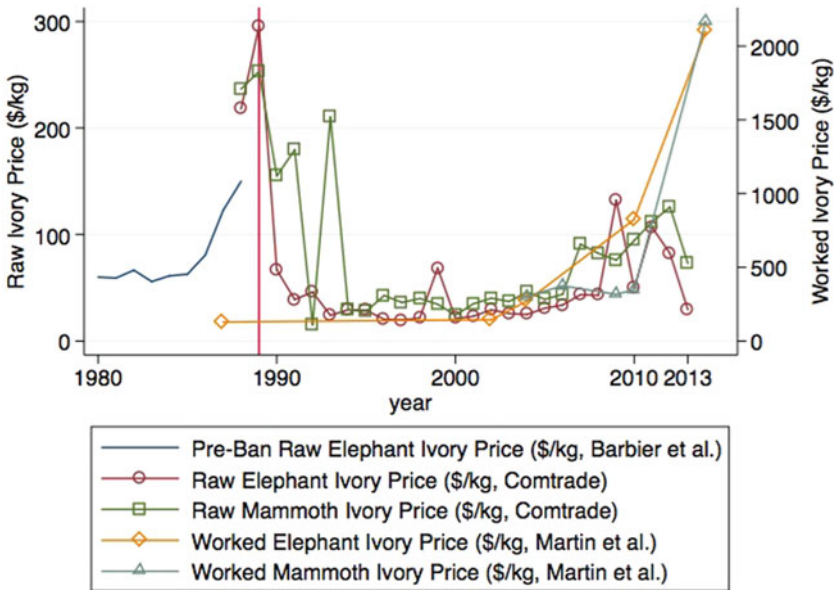


Figure 4. Elephant and mammoth ivory prices.

Figure 4 displays (nominal) elephant and mammoth ivory prices in dollars per kilogram, both pre- and post-ban, collected from several sources. The vertical line corresponds to the 1989 CITES ban on elephant ivory trade. Raw ivory prices (left-scale) pre-ban from Barbier *et al.* (1990) roughly doubled in the decade leading up to the ban on ivory trade. Post-ban raw prices are from UN COMTRADE, calculated from export data. These show that elephant ivory permitted trade prices were very high right after the ban, much lower in the mid 1990s, but started to rise again in the late 2000s. Permitted 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, though both have fallen again at the end of the sample. A second source of data (right-scale) is the average wholesale price of worked elephant and mammoth ivory from market surveys collected from Martin (2006), Martin and Martin (2010, 2011), Martin and Vigne (2011) and Vigne and Martin (2014) for the years 1987, 2002, 2004, 2006, 2009, 2010, and 2014. The worked ivory prices show a substantially larger increase post-2010 than do raw ivory prices for both mammoth and elephant ivory, suggesting an increase in the demand for workmanship by consumers.

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.

Some elephant ivory trade has been permitted in the post-ban era. This includes hunting trophies, privately owned ivory crafts and raw ivory from elephants killed before the 1989 ban. CITES approved two major African elephant ivory auctions post-ban: 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, 2004, 2009). Hsiang and Sekar (2016) argue that increased poaching can be traced to the 2008 sale. Rising demand, as suggested both by rising Chinese incomes and by rising ivory prices, may have played a role in the increase in poaching. Furthermore, Moyle (2014) attributes the increase in ivory trade to the convergence of lower shipping cost, interest rate declines, and rising instability in Africa.

### 3. Theoretical analysis

To motivate our empirical analysis and to provide an explanation of the stylized facts documented in section 2, we extend Kremer and Morcom’s (2000) model of poaching with storage. We extend their model by considering (1) substitution between mammoth and elephant ivory, and (2) the effects of key demand and supply shifters.

Let  $h$  be the number of elephants poached,  $E$  be the stock of elephants,  $q$  be the number of mammoth tusks dug out of the tundra,  $M$  be the stock of remaining mammoth tusks,  $X$  be the stores of elephant ivory,  $p$  be the black market price of elephant ivory,  $m$  be the legal price of mammoth ivory,  $y$  be the income in the ivory demand region,  $I$  be the institutional quality in the elephant supply region,  $R$  be a supply shifter for Russian mammoth ivory, and  $r$  be the risk adjusted rate of return expected by those who store elephant ivory.

Letting  $\dot{z} \equiv dz/dt$  denote the time derivative of variable  $z$ , we follow Kremer and Morcom (2000) and express the equation of motion for elephants as

$$\dot{E} + \dot{X} = G(E) - h, \quad E(0) = E_0 > 0, \tag{1}$$

where  $G(E)$  is the biological growth function, which has the properties that  $G(E) > 0$  for  $0 < E < K$ ,  $G(E) < 0$  for  $E > K$ , and that  $G(0) = G(K) = 0$ , for the carrying capacity,  $K$ , of elephants. Thus, the elephant population is measured in ivory units, so that elephants can be turned into stores, and stores into consumption, both at a 1:1 ratio.

The exhaustible mammoth ivory stock is reduced at the rate of extraction,  $q$  :

$$\dot{M} = -q, \quad M(0) = M_0 > 0. \tag{2}$$

The demand and supply for illegal elephant ivory is

$$h = D^e(p, m, y), \quad \text{and} \quad h = S^e(p, E, I), \tag{3}$$

where the superscript ‘ $e$ ’ is for ‘elephants’ and where subscripts denote partial derivatives when a variable and time periods when a number. For demand it is assumed that  $D_p^e < 0$  (the quantity demanded is decreasing in own price),  $D_m^e \geq 0$  (substitution effects are non-negative), and  $D_y^e \geq 0$  (income effects are non-negative). For elephant poaching supply,  $S_p^e \geq 0$  (supply is possibly less than perfectly elastic),  $S_E^e > 0$  (a larger elephant population yields higher poaching levels for a given price), and  $S_I^e \leq 0$  (rising institutional quality lowers poaching for a given price) for supply. This is an open access supply curve, with no rents accruing to poachers.



Similarly, the demand and supply for mammoth ivory (superscript ‘*m*’ for ‘mammoth’) is given by

$$q = D^m(m, p, y), \quad \text{and} \quad q = S^m(m, R), \tag{4}$$

where  $D^m_m < 0$  (demand is decreasing in own-price),  $D^m_p \geq 0$  (substitution effects are non-negative), and  $D^m_y \geq 0$  (income effects are non-negative), and where  $S^m_m \geq 0$  (supply may be less than perfectly elastic). Again, this supply curve reflects the open access supply curve, so there are no rents, except for infra-marginal producers’ surplus when the supply curve is less than perfectly elastic (i.e. when  $S^m_m > 0$ ). The supply shifter  $R$  increases the quantity supplied at any price, so that  $S^m_R > 0$ . The main candidate for the mammoth supply shifter  $R$  is that mammoth ivory is produced not just by ivory hunters specifically looking for ivory, but also by miners, road builders, and others who are digging in the tundra and who incidentally find mammoth ivory. We use this mammoth ivory shifter in the empirical section to help us identify the effects that mammoth ivory has had upon elephant poaching.

Kremer and Morcom (2000), in contrast, assume that  $D^e_m = D^m_p = D^e_y = D^m_y = S^m_R = S^e_I = 0$  and that the supply curves  $S^e$  and  $S^m$  are perfectly elastic in own price, though their (inverse) elephant supply curve is shifted by the elephant population size, with  $p = c(E)$ , where  $c'(E) < 0$ . Extinction is possible in Kremer and Morcom because at price  $c(0)$ , demand is still positive:  $h = D^e(c(0)) > 0$ . We are making a similar assumption, though our notation does not allow such a simple statement of the extinction condition.

Kremer and Morcom (2000) identify three types of equilibrium ‘subpaths’ that may occur. These are the ‘poaching, no storage’ (PNS) subpath, where  $h > 0$  and  $X = \dot{X} = 0$ , the ‘storage, no poaching’ (SNP) subpath, where  $h = 0$ , and  $\dot{X} < 0$  while  $X > 0$ , and the ‘poaching with storage’ (PWS) subpath, where  $h > 0$  and  $X > 0$ . Each subpath may also exist here, though which are consistent with the observed trends is to be determined.

In either the SNP or PWS subpaths, where storage of elephant ivory occurs, the equilibrium elephant ivory price satisfies Hotelling’s rule, so that those holding stores are indifferent between producing from their stores today or holding their stores for sale in the future,

$$\dot{p}/p = r > 0. \tag{5}$$

In a PWS equilibrium, extinction of elephants eventually occurs. Let  $X_E(E)$  denote the stores as a function of the elephant population along the PWS extinction path.  $X_E(0)$  is the quantity of elephant ivory stores at the moment  $T_E$  when elephants become extinct that can satisfy future demand for elephant ivory when price obeys Hotelling’s rule given by (5),

$$X_E(0) = \int_{T_E}^{\infty} D^e(p_{T_E} e^{r(t-T_E)}, m_t, y_t) dt. \tag{6}$$

The elephant ivory price is anchored by the poaching price  $p_{T_E}$ , at the moment of extinction of elephants, implicitly defined by  $0 = S^e(p_{T_E}, 0, I_{T_E})$ , so that the last elephant is poached. The price  $p_{T_E}$ , and hence,  $X_E(0)$ , also depend upon the prevailing institutional quality  $I_{T_E}$  at time  $T_E$ , and  $X_E(0)$  also depends upon the future income levels  $y_\tau$ ,  $\tau \geq T_E$ , and upon the mammoth stock at the moment elephants become extinct,  $M_{T_E}$ , since that affects the future mammoth ivory prices  $m_\tau$ , for  $\tau \geq T_E$ . Observe that a decrease in the

mammoth ivory price  $m$  causes demand for elephant ivory to fall, since  $D_m^e > 0$ , so that  $X_E(0)$  decreases as well.

Now, let us turn to an analysis of the subpaths.

### 3.1 The PNS subpath–simplest case

There are two poaching, no storage (PNS) equilibrium subpaths to consider. In the *extinction* PNS subpath, the harvest rate  $h$  is greater than the population growth rate  $G(E)$ , so  $\dot{E} < 0$ . In the *sustainable* PNS subpath,  $h < G(E)$ , so that  $\dot{E} > 0$ . Both PNS subpaths have zero stores of elephant ivory  $X = \dot{X} = 0$ , and each has a positive elephant population  $E$ .

To gain intuition for the PNS subpaths, consider the case in which the mammoth ivory market affects the elephant ivory market, but not vice versa. Thus, the poaching equilibrium price  $p$  and output  $h$  is given by the pair of equations  $h = S^e(p, E, I)$  and  $h = D^e(p, m, y)$ , where the elephant population  $E$ , the mammoth ivory production  $q$ , the mammoth ivory price  $m$ , demand region income  $y$ , and institutions  $I$  are parameters. Using Cramer’s Rule, it follows that the poaching rate and the ivory price vary according to

$$dh = \underbrace{\frac{D_p^e S_E^e}{D_p^e - S_p^e}}_{(+)} dE + \underbrace{\frac{D_p^e S_I^e}{D_p^e - S_p^e}}_{(-)} dI + \underbrace{\frac{-S_p^e D_m^e}{D_p^e - S_p^e}}_{(+)} dm + \underbrace{\frac{-S_p^e D_y^e}{D_p^e - S_p^e}}_{(+)} dy, \tag{7}$$

$$dp = \underbrace{\frac{S_E^e}{D_p^e - S_p^e}}_{(-)} dE + \underbrace{\frac{S_I^e}{D_p^e - S_p^e}}_{(+)} dI + \underbrace{\frac{-D_m^e}{D_p^e - S_p^e}}_{(+)} dm + \underbrace{\frac{-D_y^e}{D_p^e - S_p^e}}_{(+)} dy. \tag{8}$$

Thus, all else constant, the equilibrium poaching rate  $h$  is increasing in the stock of elephants  $E$ , the price of mammoth ivory  $m$ , and the demand region income  $y$ , and is decreasing in institutional quality  $I$ . The equilibrium poaching price  $p$  is decreasing in the stock of elephants  $E$ , but increasing in the mammoth ivory price  $m$ , the institutional quality  $I$ , and demand region income  $y$ . Both  $h$  and  $p$  are independent of the mammoth ivory production  $q$ , and supply conditions in Russia, except through how those affect the mammoth ivory price,  $m$ .

Hence, the implicit solution to the open access poaching level  $h^*(E) \equiv h(E; I, m, y)$  is increasing in  $E$ , so that for  $h^*(0) > G(0)$  and  $h^*(E) < G(E)$  for some  $E > 0$ ,  $h^*(E)$  will intersect  $G(E)$  at least twice, e.g., at  $0 < E_u^* < E_s^* < K$ , with  $E_s^*$  stable and  $E_u^*$  unstable.<sup>13</sup> To see the stability, note that if  $E < E_u^*$  or  $E > E_s^*$ , then  $h^*(E) > G(E)$  so that  $\dot{E} < 0$ , while if  $E_u^* < E < E_s^*$ , then  $G(E) > h^*(E)$  so that  $\dot{E} > 0$ . Thus, below  $E_u^*$ , extinction occurs, and above  $E_u^*$ , the poaching equilibrium approaches the steady-state,  $E_s^*$ . Let  $h^\infty(E) \equiv \lim_{m \rightarrow \infty} h(E; I, m, y)$  denote the equilibrium elephant ivory demand when mammoth

<sup>13</sup>To see why the intercept may be positive, consider the case where supply is given by  $p = c(E)$  as in Kremer and Morocom (2000), and utility is Cobb-Douglas in  $h$  and  $q$  with income  $y$  and prices  $c(E)$  and  $m$ . Then demand for poached ivory is  $h^*(E) = \alpha y/c(E)$ , where  $\alpha$  is the income share to poached ivory. So as long as  $\lim_{E \rightarrow 0} c(E) < \infty$ ,  $h^*(0) > 0$ . In our case, this happens for inverse demand  $p = \hat{D}(h)$  and inverse supply  $p = \hat{S}(h, E)$ , that as  $E \rightarrow 0$ , that  $\hat{D}(0) > \hat{S}(0, 0)$ , or that the demand intercept is above the supply intercept for the supply curve where  $E = 0$ .

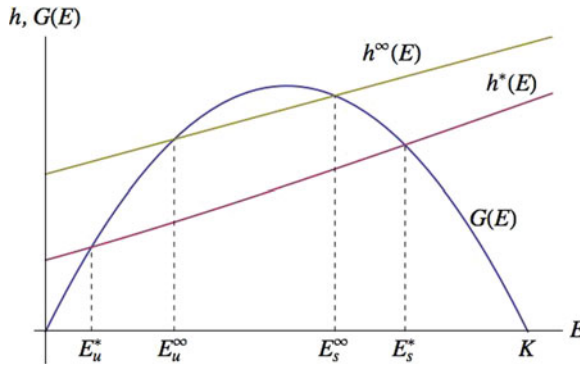


Figure 5. Poaching-No Storage population dynamics, with and without a substitute.

ivory production is prohibitively expensive. It follows from (7) that  $h^\infty(E) > h^*(E)$  for all  $E$ . These harvest rates are shown in figure 5. Note that  $0 < E_u^* < E_u^\infty < E_s^\infty < E_s^* < K$ .

Two conclusions immediately follow. First, the coincidental timing of the CITES ban on elephant ivory trade in 1989 and the collapse of the Soviet Union in 1991–1992 resulted in two separate causal effects. The CITES ban raised institutional quality  $I$  by increasing international pressure on poaching. By (7) and (8), this lowered the poaching rate  $h$  and increased the poaching price  $p$ . The collapse of the Soviet Union, however, lowered the cost of mammoth ivory  $m$ , which lowers both the poaching rate  $h$  (the shift from  $h^\infty(E)$  to  $h^*(E)$  in figure 5) and the poaching ivory price  $p$  (due to substitution effects). Thus, the falling elephant ivory prices in the early 1990s were an artifact of the fall in mammoth ivory prices, not the increase in international pressure on poaching (whose effect would be to raise, not lower, elephant ivory prices), though both effects cause poaching to decrease. This effect upon ivory prices occurred in spite of only a small quantity of mammoth ivory reaching the market in the early years of the ban.<sup>14</sup>

Second, at the pre-ban poaching rate,  $h^\infty(E)$ , for the population of elephants to be falling requires that  $E$  is below its unstable equilibrium,  $E_u^\infty$ . But with mammoth ivory becoming available, at the harvest rate  $h^*(E)$ , the new unstable population level  $E_u^*$  was below the current population level,  $E$ . This would account for the recovery of the elephant population observed in the two decades following the ban. Since the elephant population at the time of the ban was about 600,000 elephants, and was falling, and since the ‘probable’ elephant population in 1995 was 386,000, and was rising, we conclude that  $E_u^\infty > 600,000$  elephants and that  $E_u^* < 386,000$  elephants.

### 3.2 The sustainable PNS subpath

Now consider what happens when prices and quantities in both markets simultaneously clear. In that case, in addition to the poaching market conditions, the PNS equilibrium also has the equivalent conditions in the mammoth ivory market, along with the

<sup>14</sup>The other effect, which is not explicitly modeled here, is that the CITES ban itself reduced demand by those buyers who were either persuaded by the argument against consuming ivory or were simply unwilling to risk buying a good which was now illegal.

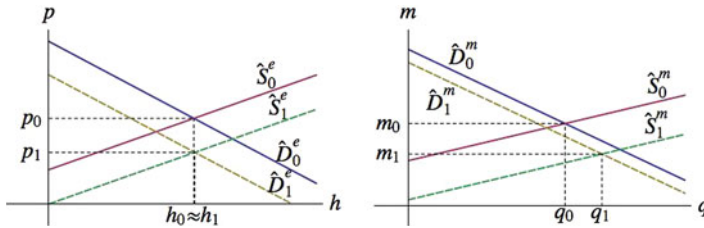


Figure 6. The sustainable PNS equilibrium. a. Elephants. b. Mammoths.

equations of motion for the stocks:

$$h = S^e(p, E, I) = D^e(p, m, y) \quad q = S^m(m, R) = D^m(m, p, y)$$

$$X = \dot{X} = 0, \quad \dot{E} = G(E) - h \quad \text{and} \quad \dot{M} = -q. \quad (9)$$

Let us determine whether the sustainable PNS equilibrium is capable of explaining the first two decades of the ban. Consider what happens when  $\dot{E} > 0$  and  $\dot{R}$  is greater than zero. The equilibrium when only the causal effects are the increase in the population of elephants and the increase in Russian mineral production is shown in figure 6, which is drawn with inverse supply and demand curves labelled  $\hat{D}$  and  $\hat{S}$  respectively, with price as a function of quantity, to distinguish them from the demand and supply curves used in the text, in which quantity is written as a function of price. The direct effects are that an increase in the population of elephants  $E$  shifts the (inverse) elephant poaching supply curve down to  $\hat{S}_1^e$  from  $\hat{S}_0^e$  because the cost of poaching drops as the elephant population increases, and an increase in Russian mining activity  $R$  shifts the mammoth supply down to  $\hat{S}_1^m$  from  $\hat{S}_0^m$  because more mammoth are found incidentally to mining. These direct effects cause both ivory prices to fall, since the supply shifts move to lower price levels on the demand curves. The indirect effect is that as both commodities' prices fall, the demand for each type of ivory falls because now its substitute has become cheaper. Thus, in equilibrium, both ivory prices fall, and for a similar magnitude shifts in demand and supply in elephant ivory, the elephant poaching stays about the same, and when the shift in mammoth ivory supply is greater than the shift in mammoth ivory demand, mammoth ivory production rises.<sup>15</sup> Thus:

**Proposition 1.** *With an increase in the elephant population due to being in the sustainable PNS equilibrium, and with a shift in mammoth ivory supply as the Russian mining industry expands, all of the pre-2007 stylized facts can be explained: poaching is falling, the elephant population rises, prices of both ivory fall, and mammoth ivory production rises.*

*Proof :* See the online appendix. □

<sup>15</sup>Increases in income reduce or reverse the shift in the demand curves, causing both production and prices to increase. Increases in institutional quality in Africa reduce or reverse the shift in the supply of elephant ivory, causing production to fall relative to  $h_1$  and the poaching price to rise relative to  $p_1$ . Thus, these had negligible impact in this era.

This shows both that the PNS sustainable equilibrium is consistent with the pre-2007 stylized facts, and that the increasing supply of mammoth ivory is a necessary part of that explanation.

### 3.3 The poaching with storage subpath, PWS

In the PWS subpath, the equilibrium elephant ivory price obeys the storage condition (5), supply and demand for mammoth ivory are given by (4), respectively, and net additions to stores defined by (1):

$$\dot{p} = rp, \quad q = S^m(m, R) = D^m(m, p, y), \quad \text{and} \quad \dot{X} + \dot{E} = G(E) - h, \quad (10)$$

and the supply and demand for elephant ivory satisfying

$$\left\{ \begin{array}{l} h = S^e(p, E, I) \quad \& \quad h + s = D^e(p, m, y) \\ h = D^e(p, m, y) \quad \& \quad h + s = S^e(p, E, I) \end{array} \right\} \quad \text{as} \quad \dot{X} = \begin{cases} -s < 0 \\ s > 0 \end{cases} \quad (11)$$

Kremer and Morcom (2000) show that the PWS extinction path is the locus  $X = X_E(E)$  which approaches the extinction stores level  $X_E(0)$  as elephants become extinct.<sup>16</sup> Since  $\dot{E} < 0$  along this locus,<sup>17</sup>  $dX/dE = X'_E(E) = \dot{X}/\dot{E}$ , which implies that  $\dot{X} < 0$  occurs for  $E < \tilde{E}_u$  and for  $E > \tilde{E}_s$ . In addition, during a *cull*, the PWS extinction path  $X_E(E)$  can be approached by killing elephants and turning them into stores at rate  $dX/dE = -1$ . The important implication is that either along the extinction path  $X_E(E)$  or during a cull, the elephant population is decreasing. Stores, however, may be either increasing or decreasing. Furthermore, along either  $X_E(E)$  or during a cull, the price of elephant ivory  $p$  must be rising at the rate of interest. An example of the PWS equilibrium in stores-elephants space, including the shaded area where getting to the locus  $X = X_E(E)$  is made possible by a cull, is shown in figure 7.

Do there exist conditions under which the PWS equilibrium reproduces the stylized facts observed post-2007? Post-2007, the overall African elephant population was falling, poaching and interdictions were rising, and both ivory prices were rising. The fall in the elephant population shifts the supply so that fewer elephants are poached for a given price. Suppose, as shown in figure 8, that initially the elephant poaching price is at  $p_0$ , where given demand  $\hat{D}_0^e$ , demand for elephant ivory is  $h_0$ , but given supply  $\hat{S}_0^e$  elephants are being poached at rate  $h_0 + s_0$ , with  $s_0$  being added to stores. This corresponds to an elephant population  $E_0$  in figure 7 such that  $\tilde{E}_u < E_0 < \hat{E}$ , where stores are increasing and the population of elephants is decreasing. Once the elephant population is reduced to  $\tilde{E}_u$ , net additions to stores are zero, so that at the corresponding price  $p_1$ , the new

<sup>16</sup>The Kremer and Morcom (2000) method is to use  $p = c(E)$  and  $\dot{p} = rp$  to conclude that  $\dot{E} = rc(E)/c'(E)$ . Thus, from (1), we have that  $\dot{X} = G(E) - h^*(E) - rc(E)/c'(E)$ . This has  $\dot{X} = 0$  at points  $\tilde{E}_u^* < E_u^*$  and  $\tilde{E}_s^* > E_s^*$ , as shown in figure 7.

<sup>17</sup>In Kremer and Morcom (2000), this occurs because time differentiating the poaching condition  $p = c(E)$  and using the storage condition that  $\dot{p} = rp$  implies that  $\dot{E} = rc(E)/c'(E) < 0$ . In the general model, however, there are two cases. When  $\dot{X} < 0$ ,  $h = S^e(p, E)$  and  $\dot{p} = rp$ . Thus,  $\dot{h} = S_p^e \dot{p} + S_E^e \dot{E}$ . Since  $\dot{p} > 0$  moves up the supply curve and  $\dot{E} < 0$  shifts the supply curve downwards, we may set  $\dot{h} \approx 0$ , from which it follows that  $\dot{E} = (-S_p^e/S_E^e)\dot{E} < 0$ . In the second case where stores are accumulating,  $h + \dot{X} = S^e(p, E)$ ,  $h = D^e(p)$  and  $\dot{p} = rp > 0$ . Thus,  $\dot{h} = D_p^e \dot{p} < 0$  from demand, and from supply  $\dot{h} + \dot{X} = S_p^e \dot{p} + S_E^e \dot{E}$ . Neglecting  $\dot{X}$  since the supply curve shifts down when  $\dot{E} < 0$  and  $\dot{p} > 0$  reduces demand, so that  $\dot{X} \approx 0$ , we are left with  $\dot{E} = (D_p^e - S_p^e)/S_E^e < 0$ . Thus,  $\dot{E} < 0$  in the PWS.

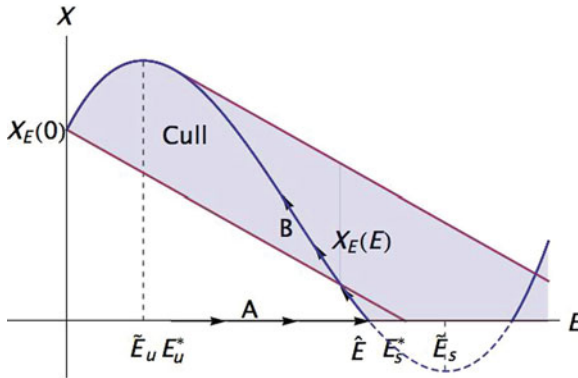


Figure 7. The population and stores dynamics in the PWS equilibrium.

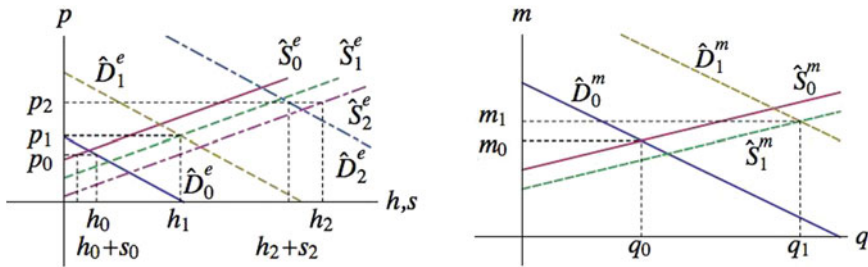


Figure 8. The PWS equilibria. a. Elephants. c. Mammoths.

supply  $\hat{S}_1^e$  and demand  $\hat{D}_1^e$  intersect at poaching level  $h_1$  with  $s_1 = 0$ . Further reductions in the elephant stock drive  $E_2 < \tilde{E}_u$ . This shifts the supply to  $\hat{S}_2^e$ , and given demand  $\hat{D}_2^e$ , the price  $p_2$  satisfying the poaching condition results in poaching of  $h_2$ , and total demand equal to  $h_2 + s_2$ , so that some demand is satisfied from stores.<sup>18</sup>

Therefore, during this sequence all of the elephant poaching indicators satisfy the post-2007 stylized facts. But this means that the demand for elephant ivory must have been shifting faster than the supply of elephant ivory to be in this equilibrium. There are two things that can cause that: increases in income, and increases in the price of the mammoth ivory substitute. Since continued increases in the mining industry in Russia cause the mammoth ivory supply curve to shift so that a greater mammoth ivory is supplied at a given price, then for both mammoth ivory production and the mammoth ivory price to rise, it must be that the demand for mammoth ivory is shifting outwards faster than the supply of mammoth ivory.

The next proposition shows that the first part of the PWS subpath, where stores are being accumulated,  $\dot{X} > 0$ , is consistent with the post-2007 era observations that

<sup>18</sup>During a cull, the demand is satisfied from current kills,  $h = D^e(p, m, y)$ , while total poaching is  $h + s = S^e(p, E, I)$ , and the poaching condition that  $\dot{p}/p = r$  must hold, so that a cull has the same properties as the PWS equilibrium at a case like  $p = p_0$  in figure 8.

both ivory outputs and both ivory prices are rising, but the elephant population is falling.<sup>19</sup>

**Proposition 2.** *In the post-2007 era, elephant poaching and interdictions,  $s + h$ , and mammoth ivory output,  $q$ , have been rising, prices of both types of ivory, elephant,  $p$ , and mammoth,  $m$ , have been rising, and the elephant population,  $E$ , has been falling. This is consistent with the PWS equilibrium where  $\dot{X} > 0$  as long as (1) the effects of higher illegal elephant ivory price increases dominate the effect of lower elephant population, and (2) demand side price and income effects dominate supply side effects in both Russian and African markets.*

*Proof:* See the online appendix. □

An equilibrium which is consistent with the stylized facts is thus the line sequence A to B in figure 7. In this equilibrium, pre-2007 is in the poaching, no storage equilibrium, starting from an elephant population greater than  $E_u^*$  and therefore increasing, moving to the right along line segment A. Along this segment, the elephant population is rising. Increasing activity in Russian mining contributed to rising mammoth ivory production, which causes both elephant and mammoth ivory prices to fall, and held poaching somewhat in check. But by 2007, the elephant population had risen to the point where it intersects the locus  $X_E(\hat{E})$  at point  $\hat{E}$ . Since the biological population in 2006 was estimated to be 628,000 elephants (according to the ‘probable’ estimate), this places  $\hat{E}$  somewhere above 628,000 animals. Thereafter, the equilibrium is on the poaching with storage equilibrium path  $X_E(E)$ , along the segment denoted B. For this equilibrium to be possible, two things must occur. First, the locus  $X_E^*(E)$  associated with the harvest level  $h^*(E)$  when price  $m$  is finite must have shifted down enough that at  $\hat{E}$  stores be zero,  $X_E^*(\hat{E}) = 0$ . This is possible, since we know that demand for elephant ivory would fall once mammoth ivory becomes available. Second,  $\hat{E}$  must occur to the left of the cull line associated with  $X_E^*(0)$ . We cannot say much about whether this is true or not, except to note that if it is a cull that is occurring, it is a slow motion cull, at least relative to the destruction of the American bison, which with comparable sized herds, was driven nearly to extinction in less than a decade (Taylor, 2011). Then post-2007, the elephant population is falling, stores are rising, and prices are rising both to compensate holders of stores and because the elephant population is falling, making poaching more expensive.

In the online appendix we show that the extinction PNS equilibrium is also consistent with rising ivory prices and with a falling elephant population observed in the post-2007 period, and that the SNP equilibrium is inconsistent with both the pre-2007 period and with the post-2007 period.

### 3.4 Implications from the theory

In our empirical work which follows, we make use of the insights from these equilibria. The first insight from the theory is that the mammoth ivory supply shifter of Russian mining industry revenue affects mammoth ivory production directly, and then affects elephant ivory production and prices through changes in mammoth ivory production. Second, we see that the post-2007 stylized facts require controlling for demand effects.

<sup>19</sup> Analysis of the case where  $\dot{X} < 0$  is left to the online appendix.

Thus, we include both China's income and CITES permitted elephant ivory sales as demand shifters. In addition, we control for institutional quality in Africa. These are described in more detail in the next section.

#### 4. Empirical analysis

Now we turn to an empirical analysis of the effect that mammoth ivory production has had upon African elephant ivory poaching. We first describe the methodology as it is applied to the worldwide tonnage of elephant ivory seizures and to the implied prices of legally traded elephant ivory. Then we present the results, first for the time series of elephant ivory seizures and prices, and then for a panel of the ETIS number of elephant ivory interdictions by country for the world.

##### 4.1 Methodology

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

$$\begin{aligned} \text{Dependent Variable}_t = & \alpha_0 + \alpha_1 \text{ Russian Mammoth Ivory Exports}_t \\ & + \alpha_2 \text{ Institutional Quality}_t + \alpha_3 \text{ China Per Capita GDP}_t \\ & + \alpha_4 \text{ CITES Permitted Sales}_t + \alpha_5 t + \varepsilon_t, \quad t = 1989, \dots, 2013, \end{aligned} \quad (12)$$

where the dependent variables are the total tonnage of elephant ivory seizures or the imputed price of CITES permitted trades. Each regression includes as explanatory variables Russian mammoth ivory exports (the variable of interest), measures of institutional quality in the African countries (supply shifters), China GDP per capita (demand shifters), the tonnage of CITES approved sales in African elephant ivory, and a time trend.

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 this problem we use an instrumental variable approach.

The instrument we use is motivated by three points. In an interview, Canada Fossils president Pierre Parré, noted that 'the global mining boom... is feeding the mammoth boom' (Evans, 2010), and that ivory prices were inversely correlated with the gold price (personal communication with Mr. Parré, 30 May 2014). As miners search for gold and other minerals in the Russian Arctic, they may incidentally discover mammoth tusks, thereby increasing Russian mammoth ivory exports. Second, the sparsely populated Yakutiya region of Russia, where mammoth ivory tusks are found, is principally a mining region (Larmer, 2013). Third, our theoretical model suggests that while a mammoth supply shifter may affect the ivory market, it does so by its affect upon the mammoth ivory market. Therefore, we use as our instrument the value of Russian mineral rents (excluding energy).<sup>20</sup>

<sup>20</sup>The problem with using gold prices as the instrument is that mining in Africa may, perhaps through the illegal 'blood diamond' networks, be associated with elephant ivory smuggling. The simple correlation between ETIS seizures and the real gold price is  $r = 0.80$ .



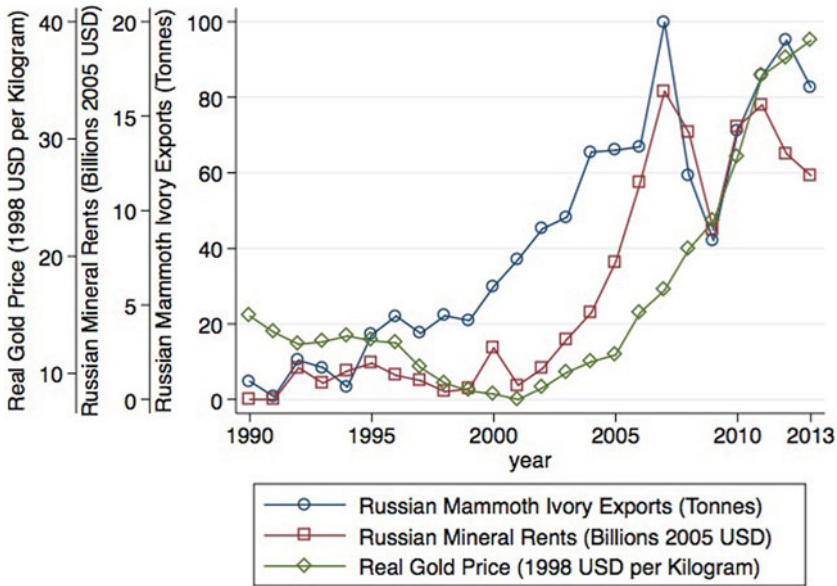


Figure 9. Russian mammoth ivory exports, and the instruments, Russian mineral rents, 1989–2014.

Figure 9 shows how Russian mammoth ivory exports correlate with the Russian mineral rents and with gold prices. Russian mammoth ivory exports are highly correlated with Russian mineral rents ( $r = 0.89$ ) though less so with gold prices ( $r = 0.59$ ). Russian mineral rents correlate with the rise in Russian mammoth ivory exports 1990–2007, the fall in exports in 2008 and 2009, and the subsequent rise in exports post 2008. Furthermore, Russian mineral rents are only weakly correlated with African elephant ivory interdictions ( $r = 0.47$ ) and with elephant ivory prices ( $r = 0.03$ ),<sup>21</sup> suggesting that it satisfies all of the requirements of an instrumental variable.

Now, let us turn to the control variables. Martin *et al.* (2006, 2010) identify the rise in China’s GDP per capita as a contributor to the continued poaching of elephants. We noted in figure 3 that over 95 per cent of mammoth ivory exports have gone to China and to Hong Kong, indicating that this is the market where mammoth and elephant ivory interact.

We also control for institutional quality in Africa, since that is where the poaching occurs and from where most flows of ivory begin. The ‘Polity II’ index is the African mean level of a democracy index.<sup>22</sup> More democratic countries may have higher

<sup>21</sup>This is not surprising, since neither Russia nor Africa are large mining producers relative to the world market. The African and Russian shares of world production are 9 per cent each for gold, 7 per cent each for copper, 6 per cent each for iron and steel, 4 per cent each for aluminium, and 2 per cent (Africa) and 7 per cent (Russia) for lead (source of data is table 4, 2012 USGS *Minerals Yearbook*, ‘African Summary’ and ‘Europe and Central Asia Summary’).

<sup>22</sup>The Polity II index 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 II index values range from –10 to +10, with more autocratic countries having lower numbers and more democratic countries having higher numbers.

institutional quality. This index has been rising. A second measure is the World Bank's 'Rule of Law' Index, which is only available from 1996 forward.<sup>23</sup> The Rule of Law Index African average was rising in the beginning of the sample, but has lately been falling. A third measure of institutional quality is expenditures on public order as a percentage of GDP. This data, from IMF statistics on government expenditures, is a direct measure of enforcement, but it is available for only a sample of countries within each year.<sup>24</sup> The African mean of expenditures on public order measure has been increasing throughout the sample. The final measure of institutional quality is a Conflict Index, which aggregates data on assassinations, coups, revolutions, riots, purges, general strikes, government crises and anti-government demonstrations. The African mean for this index has risen dramatically since 2007.<sup>25</sup>

We include CITES data on permitted sales of elephant ivory to control for possible effects from the sales in 1999 and 2008, and we include a time trend variable to capture other temporal effects not otherwise measured.

Several variables, however, could not be included in the aggregate seizures and ivory price regressions. These include the elephant population and range variables, which are only available for a few 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. The MIKE survey data in illegal kills of elephants, which is only available 2002–2013, is not included in the time-series analysis, but it and the number of interdictions by country, only available 1989–2010, are examined separately in the panel estimations.

In the panel estimations, the institutional quality variables are country-specific. In the time-series price and seizures regressions, these are the simple averages over all African countries.

Now, let us turn to the econometric results.

#### 4.2 *Instrumental variable estimation results*

Since the instrumental variable first-stage regression (of Russian mammoth ivory exports on Russian mineral rents) is the same for both the worldwide elephant ivory seizures and for the elephant ivory price regressions, we begin by showing the results from that first-stage regression.

The first-stage regressions for the IV model are reported in table 1. Since theory does not guide us as to which institutional quality variables should be included, we report seven specifications for each dependent variable. All specifications include Russian mammoth ivory exports, the demand shifter China GDP per capita, institutional quality measure Polity II, and a linear time trend. Column (1) contains just these three

<sup>23</sup>Because the Rule of Law Index was only available in even numbered years between 1996 and 2002, for the years 1997, 1999 and 2001, we impute the Rule of Law Index as the average of the year preceding and the year following for each country.

<sup>24</sup>This measure includes expenditures on policing and courts, as well as expenditures on public safety (e.g., fire protection). In the panels, we imputed missing values with the value from the non-missing adjacent year for that country. The IMF data also contains a measure of expenditures on environmental protection, but this data was only available for the last few years of the sample, so it could not be used.

<sup>25</sup>Moyle (2014: 12) notes that another indicator of falling institutional quality is the rise in refugee numbers in Africa post-2008. He also attributes part of the rise in poaching to falling transportation costs.

**Table 1.** Time series first-stage instrumental variable regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mineral Rents <sup>a</sup>	2.455* (1.217)	1.931 (1.196)	3.913** (1.758)	3.527** (1.398)	3.827 (2.319)	3.827 (2.319)	3.148** (1.313)
China GDP per Capita <sup>b</sup>	-6.207 (4.459)	-4.412 (7.237)	-23.20* (12.31)	-18.00 (10.95)	-22.69 (16.56)	-22.69 (16.56)	-14.02 (10.99)
Polity II Index <sup>c</sup>	-2.193 (1.828)	28.47* (14.23)	-6.798** (3.030)	-8.883** (3.585)	-5.203 (3.978)	-5.203 (3.978)	-4.959* (2.729)
Time Trend	4.929*** (1.473)	-0.717 (5.446)	10.68*** (3.687)	9.712** (3.435)	10.35** (4.283)	10.35** (4.283)	8.093** (3.227)
Rule of Law Index <sup>c</sup>		-247.0 (140.9)					
Conflict Index <sup>c</sup>			19.51 (11.70)	12.64 (10.77)	19.35 (17.16)	19.35 (17.16)	8.987 (11.79)
CITES Elephant Ivory Sales <sup>d</sup>				-0.0993 (0.0599)			-0.169*** (0.0497)
Expenditures on Public Order <sup>c,e</sup>					-2.194 (17.19)	-2.194 (17.19)	-3.295 (11.40)
Constant	-9809*** (2933)	1298 (10893)	-21266*** (7344)	-19343** (6842)	-20606** (8547)	-20606** (8547)	-16108** (6432)
Observations	25	18	25	25	24	24	24
R <sup>2</sup>	0.901	0.888	0.914	0.929	0.910	0.910	0.943
F	60.25***	22.92***	55.23***	39.52***	40.94***	40.94***	51.08***

Notes: Dependent variable: Russian Mammoth Ivory Exports (tonnes). Robust Standard Errors in parentheses. Significance levels: \*\*\**p* < 0.01, \*\**p* < 0.05, \**p* < 0.1 Units: <sup>a</sup>Billions of 2005 US\$. <sup>b</sup>Thousands of 2005 U.S. Dollars. <sup>c</sup>African mean. <sup>d</sup>Tonnes. <sup>e</sup>Percent of GDP.

variables; column (2) adds the Rule of Law Index and column (3) includes instead the Conflict Index. Column (4) adds the tonnage of CITES permitted elephant ivory sales to column (3) controls. Columns (5)–(7) repeat columns (2)–(4) but adding Expenditures on Public Order.

The coefficient on Russian mineral rents is positive in each specification and is statistically significant in four of the seven regressions. A billion dollar increase in Russian mineral rents is associated with an increase of two to four tonnes in Russian mammoth ivory exports. The instrument is weak in the sense that the partial *F* statistic for the instrument is less than 10 in value in every regression.

It is interesting that China GDP per capita is negative in every specification (though statistically significant only in model (3)), suggesting that mammoth ivory may be an inferior good. The time trend is positive and significant in all but model (2). Except for the Polity II index, the African institutional variables are mostly insignificant. The permitted ivory trade is negative (and significant in model (7)), suggesting that part of the decline in mammoth exports in 2008–09 may have been due to the large sale of African elephant ivory in 2008. Overall, about 90 per cent of the variation in mammoth ivory exports is explained by these variables in the time series.

### 4.3 *Elephant ivory seizures estimation results*

Now, let us consider the effect Russian mammoth ivory exports may have had upon seizures of elephant ivory. We estimate this effect using instrumental variable estimation regressions of elephant ivory seizures on Russian mammoth ivory exports.

The instrumental variable results reported in table 2 use Russian mineral rents to instrument Russian mammoth ivory exports. All specifications show that an increase in Russian mammoth ivory exports reduce African elephant ivory seizures. The estimated coefficients of Russian mammoth ivory are statistically significant in all specifications. One tonne of Russian mammoth ivory exports causes elephant ivory seizures to decrease by between 0.4 and 1.1 tonnes.

Chinese GDP per capita is positively correlated with elephant ivory seizures, and statistically significant in five of the seven specifications with an increase of US\$1000 of Chinese per capita income resulting in a 6 to 20 tonne increase in elephant ivory seizures, depending upon the specification. Together with the result in table 1, these suggest that as the Chinese become richer, they demand more elephant ivory and less mammoth ivory.

The estimated coefficient of Polity II is positive in sign and statistically significant in columns (2), (4), and (5). The Rule of Law variable in column (2) is negative in sign but is not statistically different from zero. The Conflict Index is positive in sign but is not statistically different from zero. Expenditures on Public Order and Safety is positive in sign and statistically significant in column (7). The CITES Elephant Ivory Sales variable is negative in sign and statistically significant in column (7) indicating that one tonne of permitted sales reduced elephant ivory interdictions by as much as 0.17 tonnes. The time trend variable is statistically insignificant in all specifications.

### 4.4 *Imputed elephant ivory price estimation results*

Next, we turn to the regressions on imputed permitted elephant ivory trade prices. Table 3 presents the instrumental variables results for the post-ban elephant ivory permitted trade price regressions.

The effect of Russian mammoth ivory is estimated to be negative in all specifications (except columns (1) and (5)) and is statistically significant in columns (3), (6) and (7). Thus, for each tonne of Russian mammoth ivory exports, we find that the price of elephant ivory decreases by about \$1.50 per kilogram. At the mean rate of 84 tonnes of mammoth ivory per year observed 2010–12, this implies that elephant ivory permitted trade prices would be between \$118–134 per kilogram higher had mammoth ivory not been available, or about double current prices. This is broadly supportive of the hypothesis that mammoth ivory production has reduced the incentive for poaching of elephants, and identifies the mechanism as being the reduction in the price poachers may expect.

Other notable results are that the effect of China GDP per capita is positive in all specifications except in column (5). This is consistent with demand from China driving the market, with elephant ivory prices rising by \$10–45 for each \$1,000 increase in Chinese GDP per capita.

The Conflict Index is negative and statistically significant in all specifications, suggesting that reductions in institutional quality in African result in lower elephant ivory prices. However, the Polity II index is also negative (and significant in some specifications), which is surprising since it was associated with higher interdictions in table 2. Neither Rule of Law nor Expenditures on Public Order are statistically significant in any specification. Finally, the CITES Elephant Ivory Sales variable flips signs in the two specifications but is not statistically different from zero in either.

**Table 2.** Worldwide elephant ivory seizures, instrumental regression results, 1989–2013

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory <sup>a</sup>	−0.709*** (0.156)	−1.098*** (0.209)	−0.544*** (0.160)	−0.645*** (0.140)	−1.074*** (0.237)	−0.407* (0.211)	−0.589*** (0.157)
China GDP per Capita <sup>b</sup>	10.88*** (2.921)	19.92 (11.49)	7.169* (3.860)	10.15*** (2.878)	18.57** (7.061)	6.211 (4.419)	10.97**** (4.204)
Polity II Index <sup>c</sup>	0.587 (2.379)	54.05* (26.26)	−0.333 (1.625)	−3.154* (1.766)	52.88** (21.11)	1.309 (2.178)	0.612 (1.400)
Rule of Law Index <sup>c</sup>		−174.3 (126.6)			−198.5 (204.7)		
Conflict Index <sup>c</sup>			5.436 (4.774)	0.371 (4.176)		8.046 (5.369)	0.939 (6.350)
Expenditures on Public Order <sup>c,d</sup>					4.237 (19.12)	11.84 (13.78)	10.31* (5.864)
CITES Elephant Ivory Sales <sup>d</sup>				−0.102 (0.0797)			−0.173*** (0.0311)
Time Trend	−0.0482 (1.355)	−11.92 (9.974)	0.738 (1.315)	0.827 (0.991)	−11.35 (7.554)	−0.342 (1.792)	−0.773 (0.695)
Constant	99.68 (2699.3)	23691.9 (19884.9)	−1468.5 (2618.7)	−1649.2 (1973.6)	22530.7 (14983.7)	664.8 (3560.1)	1527.8 (1385.9)
Observations	25	18	25	25	18	24	24
R <sup>2</sup>	0.399	0.496	0.536	0.555	0.513	0.644	0.723
F	15.71	30.68	65.11	42.90	57.23	46.93	111.1

Notes: Dependent variable: Worldwide Elephant Ivory Seizures (tonnes). Instrumental variable regression estimates. Newey-West standard errors in parentheses. Significance levels: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ . Units: <sup>a</sup> Tonnes, <sup>b</sup> Thousands of 2005 US\$, <sup>c</sup> African mean, <sup>d</sup> Percent of GDP.

**Table 3.** Permitted elephant ivory price, instrumental variable regression results, 1989–2013

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory <sup>a</sup>	0.471 (0.643)	-0.0324 (0.892)	-1.455*** (0.469)	-0.982 (0.700)	0.738 (1.255)	-1.562** (0.551)	-1.580* (0.815)
China GDP per Capita <sup>b</sup>	3.561 (7.642)	9.718** (3.669)	46.51** (17.53)	32.57** (12.30)	-89.36 (265.5)	44.16*** (7.622)	44.43*** (11.98)
Polity II Index <sup>c</sup>	-46.87*** (8.693)	-19.91 (25.31)	-36.24*** (7.365)	-22.96* (11.94)	-167.3 (414.3)	-3.999 (4.429)	-4.091 (3.863)
Rule of Law Index <sup>c</sup>		191.5 (294.9)			-173.9 (442.0)		
Conflict Index <sup>c</sup>			-63.06*** (21.30)	-39.33** (17.24)		-51.44*** (9.846)	-51.93** (17.89)
Expenditures on Public Order <sup>c,d</sup>					124.1 (168.5)	-14.34 (21.18)	-14.70 (24.11)
CITES Elephant Ivory Sales <sup>a</sup>				0.477 (0.472)			-0.0166 (0.249)
Time Trend	7.901 (4.797)	2.688 (2.933)	-1.164 (5.586)	-1.600 (3.767)	65.45 (183.6)	-5.552* (3.031)	-5.511* (2.875)
Constant	-15793.6 (9564.8)	-5237.4 (5810.2)	2297.8 (11131.5)	3176.9 (7505.7)	-130940.0 (366709.7)	11102.2* (6012.3)	11022.8* (5706.8)
Observations	25	18	25	25	18	24	24
R <sup>2</sup>	0.561	0.377	0.603	0.740		0.489	0.485
F	23.58	9.791	19.65	31.60	8.364	43.37	41.69

Notes: Dependent variable: Legally traded elephant ivory prices (nominal U.S. dollars per kilogram). Instrumental variable regression estimates. Newey-West standard errors in parentheses. Significance levels: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ . Units: <sup>a</sup> Tonnes. <sup>b</sup> Thousands of 2005 U.S. Dollars. <sup>c</sup> African mean. <sup>d</sup> Percent of GDP.

#### 4.5 Panel data estimation results

Because the results just reported are based on a sample of only 25 years of aggregated data, we turn now to an analysis of the effect of Russian mammoth ivory exports using a more detailed panel data set on interdictions of illegal elephant ivory. This panel has the advantage that it utilizes interdictions from 106 countries. It has the disadvantages that both the main variable of interest, Russian mammoth ivory exports, and the instrumental variable, Russian mineral rents, vary only across time, not across countries, and that elephant ivory interdictions data is available only until 2010.<sup>26</sup> In each panel estimation, we use the same specifications as in (12), although the models are estimated using a panel fixed-effects (by countries) instrumental variables estimator, with errors clustered by countries.

Table 4 reports the instrumental variables panel fixed-effects regression results for the number of elephant ivory interdictions, using data from all countries for which interdictions have been reported in the ETIS data between 1989 and 2010. All specifications show that an increase in Russian mammoth ivory exports decreases the number of elephant ivory interdictions, with all coefficients statistically significant in all but columns (2) and (5). Other results include positive and significant effects on the number of interdictions from increases in China GDP per capita, positive and significant effects from an increase in the Polity II Index, and negative and significant effects from the CITES permitted African elephant ivory sales. The difference in the Polity II Index relative to the other panels is likely due to the fact that this panel includes many developed countries, where as the other two panels only include the lesser developed African and Asian countries. The first-stage results of these panel estimates are reported in the online appendix. Also reported there are estimates using only African countries. These estimates are qualitatively similar to those in table 4.

In the online appendix, we report a panel on interdictions only in African countries, and two additional panels using data from the MIKE carcass surveys. The MIKE data, however, is only available from 2002 forward, and is based upon surveys of varying quality.

#### 5. Effect of mammoth ivory on poaching

Finally, we use our estimates to determine the effect that mammoth ivory has had upon elephant poaching. Our approach is to take the estimate of Wittemyer *et al.* (2014), that on average 33,600 elephants were illegally poached every year between 2010 and 2012, and to compare that with the counterfactual of the change in the number of elephants that would have been poached had there been no mammoth ivory exports from Russia.

For the seizures time series, where the econometric model was of the form  $Y = a + bM$ , with  $Y$  the dependent variable and  $M$  mammoth ivory, and where  $a$  represents the mean estimated effect of all other exogenous causes, and  $b$  the estimated effect of one tonne of mammoth ivory upon  $Y$ , the marginal effect is  $dY = b dM$ . To get the change in the number of animals poached, we multiply  $dY$  by  $33,600/\bar{Y}$ , where  $\bar{Y}$  is the mean of the dependent variable over 2010–2012. For the interdictions panel where the estimation was of the form  $\ln(Y + 1) = a + bM$ , the marginal effect upon the dependent

<sup>26</sup>We built this panel based on tables in CITES (2011). Data for 2011 were reported by ETIS, but were apparently for only the first part of the year. More recent ETIS reports (e.g., see Milliken *et al.*, 2016, figure 7 and table 3, pp. 12–13) do not make it possible to determine when and where interdictions occurred. Requests to Mr. Milliken for data for later years have not received a response.

**Table 4.** Number of elephant ivory interdictions by country, by year, panel fixed-effects instrumental variable regression results, 1989–2010

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory <sup>a</sup>	−0.00603* (0.00332)	0.000217 (0.00181)	−0.00597* (0.00333)	−0.00799* (0.00434)	0.000588 (0.00221)	−0.00695* (0.00401)	−0.00956* (0.00518)
China GDP per Capita <sup>b</sup>	0.0843* (0.0471)	−0.0341 (0.0265)	0.0813* (0.0475)	0.123* (0.0671)	−0.0594* (0.0310)	0.0770 (0.0553)	0.131* (0.0786)
Polity II Index <sup>c</sup>	0.0172 (0.0137)	0.0369*** (0.0127)	0.0177 (0.0146)	0.0169 (0.0146)	0.0375** (0.0146)	0.0318** (0.0133)	0.0314** (0.0131)
Rule of Law Index <sup>c</sup>		0.0837 (0.117)			0.112 (0.153)		
Conflict Index <sup>c</sup>			−0.0235 (0.0209)	−0.0227 (0.0205)		−0.0294 (0.0297)	−0.0278 (0.0293)
Expenditures on Public Order <sup>c,d</sup>					0.156 (0.106)	0.170 (0.110)	0.167 (0.109)
CITES Elephant Ivory Sales <sup>a</sup>				−0.00224* (0.00121)			−0.00289** (0.00139)
Observations	1942	1395	1912	1912	1080	1474	1474
R <sup>2</sup>	−0.028	0.014	−0.026	−0.031	0.025	−0.030	−0.038
Countries	93	93	92	92	72	71	71
Anderson	358.3	719.5	356.6	355.3	557.9	280.5	280.0
LR Test $\chi^2(1)$							

Notes: Dependent variable: log(Number of elephant ivory interdictions+1) by country, by year. Fixed-effects Instrumental Variables Panel Regression. Standard errors (clustered by Country) in parentheses. Significance levels: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ . Units: <sup>a</sup> Tonnes. <sup>b</sup> Thousands of 2005 US\$. <sup>c</sup> Country-Specific. <sup>d</sup> Percent of GDP.



**Table 5.** Implied effect of mammoth ivory on the number of poached African elephants

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Mean (1)–(7)
1. Seizures Time-Series	−50,774	−84,575	−38,958	−46,119	−92,811	−29,075	−42,180	−54,927
2. Interdictions Panel	−18,381	6,615	−18,198	−24,355	1,792	−21,185	−29,141	−14,693

Notes: The numbers represent the regression model estimate of the change in the number of elephants poached per annum 2010–2012, relative to the counterfactual of having had no mammoth ivory exports from Russia. A negative number implies that mammoth ivory reduced elephant poaching; a positive number implies that mammoth ivory increased elephant poaching.

variable was calculated as  $dY = be^{a+bM}dM = b(\bar{Y} + 1)dM$ . The resulting estimates are presented in table 5, with each column corresponding to the regression coefficient from columns (1)–(7) of the models reported in tables 2 and 4, respectively.<sup>27</sup>

The implied change in number of elephants poached per year for the time series estimates from table 2 (row 1) show that the 83.9 tonnes of mammoth ivory exports per year reduced poaching by 29,000–85,000 elephants, depending upon the specification. On average the time series point estimates imply each year that 54,927 fewer elephants were poached because of the Russian mammoth ivory exports. Row 2 shows the estimates on the change in number of elephants poached from the panel on interdictions by country from table 4. These estimates range from an additional 6,600 elephants poached per year (column (2)) to 29,100 fewer elephants poached (column (7)), with a mean of 14,700 fewer elephants poached. Thus, the seizures time-series (row 1) show mean reductions in poaching, which if absent, would have more than doubled current poaching rates. The interdictions panel estimates (row 2) mean reductions in poaching, which if absent, would have increased poaching by about 50 per cent.

Thus, the presence of mammoth ivory substitute may have had a sizeable positive effect upon reducing the number of elephants poached. Absent these effects, the situation concerning elephants would certainly be much more dire. It should not be a surprise that the development of a market in mammoth ivory could yield large effects upon elephant poaching, since a \$100 per kilogram reduction in the legal price corresponds to a reduction in around \$1,000 per animal poached.

### 6. Discussion and conclusions

This paper studies the effect that Russian exports of mammoth ivory has had upon the poaching of African elephants. The CITES ban on elephant ivory trade initially showed an increasing elephant population and falling ivory prices, but over the past decade has seen falling elephant populations, rising poaching, rising interdictions of illegal elephant ivory and rising ivory prices. Our theory shows that the early successes were due in part to the presence of reduced costs of producing the mammoth ivory substitute. We also show that the subsequent rise in poaching is due to rising Chinese demand.

Our empirical analysis of worldwide elephant ivory seizures finds that at the current production levels of over 80 tonnes of Russian mammoth ivory exports per year, mammoth ivory production may have reduced poaching by as many as 55,000 African elephants per year. Our empirical analysis based on panels of observed illegal kills and

<sup>27</sup>The 2010–2012 sample means (the  $\bar{Y}$ 's) were 39.4 tonnes of elephant ivory seized per year, and the 2010 number of interdictions per country per year were 12.45 interdictions.

numbers of interdictions of illegal elephant ivory finds a reduction of between 15,000 and 35,000 in the number of elephants being poached per year. At current poaching rates of 34,000 elephants per year, these estimates imply that absent the mammoth ivory trade, the poaching could increase by between 50–200 per cent, which would endanger elephants. We also find that absent mammoth ivory exports, raw elephant ivory prices would be nearly double their current rates, which is likely the mechanism behind the reductions in poaching.

**Supplementary material.** The supplementary material for this article can be found at <https://doi.org/10.1017/S1355770X18000554>.

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