# The Price Elasticity of African Elephant Poaching*

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**Abstract**

We estimate the elasticity of elephant poaching with respect to prices. To identify the supply curve, we observe that ivory is a storable commodity and hence subject to Hotelling's no-arbitrage condition. The price of gold, one of many commodities used as stores of value, is thus used as an instrument for ivory prices. The supply of illegal ivory is found to be price-inelastic with an elasticity of 0.4, with changes in consumer prices passing-through to prices faced by producers at a rate close to unity. We report the results of a number of alternative estimation approaches, all of which confirm the conclusion that supply is inelastic. We briefly discuss what such finding implies for elephant conservation policies.

*Keywords*: Elephants, poaching, price elasticity, storage, conservation

*JEL Codes*: K42, O12

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# 1 Introduction

The surge in elephant poaching in the past decade has led to a dramatic decline in the African elephant population, which now stands below 600,000 animals (Thouless et al., 2016). Conservation policies, while targeting every segment of the supply chain, have privileged a ban on the trade of elephant ivory. The Convention on International Trade in Endangered Species (CITES) enacted a ban on international trade in elephant ivory during its 7th Conference of the Parties in October 1989. More recently, following a September 2015 commitment "to enact nearly complete bans on ivory import and export (...) and to take significant and timely steps to halt the domestic commercial trade of ivory," the U.S. banned commercial ivory trade in June 2016 and China followed suit in January 2018.[1]

On the other hand, it has long been understood that optimal regulations "depend not only on the differences between the social and private values from consumption, but also on [the demand and supply] elasticities" (Becker et al., 2006). We therefore undertake the estimation of one key elasticity, the price elasticity of poached ivory supply. This elasticity is crucial for evaluating the efficacy of conservation policy. Interventions that combat trafficking and decrease consumption ultimately lead to a reduction in the (expected) price offered to poachers. The supply elasticity estimated in this paper determines how much illegal poaching decreases in response to a fall in price. This same elasticity is also informative on how poachers will react to increased anti-poaching measures.

We combine a novel dataset on ivory prices with measures of the extent of elephant poaching. With ivory price information available in both producing countries and a major consumer market – China – we estimate the supply elasticity with respect to both domestic and international prices. Our main finding is that the supply of illegal African ivory is price inelastic, with an elasticity of 0.4 with respect to prices in either African range states or in China. Accordingly, the ivory price pass-through from the consumer markets in China to the producer markets in Africa is found not to be economically or statistically different from unity.

To conduct the analysis, we assemble a unique database of ivory prices from a variety of published and unpublished sources. The resulting dataset contains 4,873 raw ivory price observations in 72 producing, consuming, and transit countries, and spans the time period 1970-2014. To our knowledge, this is the largest comprehensive global database of ivory prices

[1] Respectively, U.S. Department of the Interior ruling, citation number "81 FR 36387", https://www.gpo.gov/fdsys/pkg/FR-2016-06-06/pdf/2016-13173.pdf; China State Council announcement, index number 2016-00266, http://www.gov.cn/zhengce/content/2016-12/30/content_5155017.htm (in Chinese).

to date, and the first to enable the formal estimation of a key elasticity in the market for ivory. The price data are then combined with a panel dataset on elephant poaching, based on surveys of elephant carcasses undertaken in 30 countries since 2002.

In order to reliably estimate the price elasticity of illegal ivory supply, we must address three issues. First, the price data are collected from multiple sources and prices are recorded at various points along the supply chain. We thus partial out some of the observable covariates of prices before combining them with poaching measures. Specifically, we regress prices on variables capturing the source of data (survey, government, industry, etc.), and the location along the supply chain (poacher, middle-man, exporter, etc.), and use the residual price variation in the analysis. To further reduce the noise in the price data, we construct a country-year panel of raw ivory prices by taking the median across individual price observations in each country and year.

Second, market prices and quantities are jointly determined by the intersection of supply and demand. To identify the supply elasticity, we thus have to find a potential demand shifter. Our instrument for the price of ivory is based on the fact that ivory is storable and thus subject to the Hotelling condition (Kremer and Morcom, 2000). The behavior of ivory prices is then potentially influenced by factors that also affect other stores of value such as gold. Thus, gold prices are potential instrument for ivory prices, under the assumption that shocks to gold prices do not affect poaching other than through changes in ivory prices. We address several scenarios where that might not be the case.

Third, the Hotelling condition implies that prices and hence quantities are non-stationary. We are indeed unable to reject the hypothesis that ivory prices measured in China have a unit root. Gold prices and poaching at the aggregate level are also found to have a unit root. Non-stationarity of individual variables is not a challenge to our estimation strategy. On the contrary, Phillips and Hansen (1990) establish that IV estimates are consistent when the instrument and the variable being instrumented are both non-stationary. Furthermore, we argue that these processes are trending jointly by testing for co-integration. We reject the null of no-cointegration between gold and ivory prices and between gold prices and poaching. We fail to do so for ivory prices and poaching, possibly because of the small sample size of only 13 observations.

We then estimate the impact of ivory prices – either local ones in each range state or in China – on poaching to measure the elasticity of poaching with respect to prices. The 2SLS estimates using gold prices as instruments are larger than their OLS counterparts but still significantly below 1. Our preferred 2SLS estimates put the poaching elasticity at roughly 0.4 with respect to either local or Chinese prices. Admittedly, the elasticities calculated in the paper are identified from variation of the instrumental variable over time. The unbalanced nature of our panel data precludes us from running regressions in first differences. While our model suggests that we are dealing with unit root processes, we nonetheless add a deterministic linear or quadratic time trend to the regression specifications as a robustness check. The point estimates drop and are imprecisely measured, possibly due to the few degrees of freedom left. Yet, we always reject the null of an elastic supply (elasticity greater than unity) at the one percent level.

Across a range of estimation approaches, the substantive conclusion that supply is inelastic – quantities poached in Africa are not responsive to prices, either in Africa or in China – is remarkably robust. In fact, our preferred 2SLS coefficient of 0.4 is the highest of the elasticity estimates we report. Our finding highlights the challenges associated with interventions that act primarily to suppress demand. More generally, when the supply curve is steep – as we find in our analysis – policies that amount to inward shifts in ivory demand will need to be substantial to achieve a significant impact on poaching.

We believe our analysis is the first of its kind in the economics literature on animal conservation. The absence of sufficiently comprehensive data on prices of illegally-traded goods is a major reason why supply (and demand) elasticities are difficult to estimate. Part of our contribution is to bring much-needed data and empirical evidence to the policy discussions about elephant conservation (e.g. Wasser et al., 2010).[2]

More broadly, our paper contributes to the literature studying the markets for illegal goods (Becker et al., 2006). While the findings of the paper do not lead to any specific policy prescription — including whether trade should be legalized or not—, the paper nonetheless relates to the debate on optimal market regulation. Most earlier studies focused on the question of law enforcement of a ban versus legalization in the context of drug markets and either looked at the social costs of enforcement (Adda et al., 2014; Chimeli and Soares, 2017; Keefer et al., 2010), or estimated the elasticity of supply (Ibanez and Klasen, 2017) and demand (van Ours, 1995). Finally, our paper relates to those that use commodity price shocks to investigate the determinants of crime and violence (Angrist and Kugler, 2008; Dube

[2]One notable exception is Taylor (2011), which presents evidence consistent with a price-elastic demand in his analysis of the 19th-century collapse of the North American bison population. Although an elasticity is not explicitly estimated, the paper documents that, due to technological innovations that made bison hides a close substitute of cattle hides, the international prices for bison hides remained largely unchanged despite a sharp increase in supply, keeping incentives to slaughter the animal unchanged.

and Vargas, 2013; Berman et al., 2017; Sanchez de la Sierra, 2017).

The rest of the paper is organized as follows. Section 2 presents the policy context. In section 3, we lay out the conceptual framework and the empirical methodology. Section 4 provides a description of the data used in the analysis. Results are presented in Section 5, and section 6 discusses the robustness of the results to alternative regression specifications. Section 7 concludes.

## 2 Policy context

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is the long-standing policy-setting instrument governing commercial international trade in elephant ivory. In October 1989, a global trade ban was first agreed under CITES to curb rampant elephant poaching and ivory trafficking that affected most, but not all, parts of Africa. This ban addressed the first episode of African elephant crisis in the modern history of global ivory trade and effectively curbed uncontrolled illegal trafficking that had first commenced in the 1970s. Barbier et al. (1990) however argued the prevailing economic viewpoint of the time, stating that "the positive impact of the ban should be felt only once, and only at the outset of the ban; thereafter, this gain will be chipped away at by the illegal traders".

Indeed, in the mid-2000s, resurgent ivory demand attributed to an economically revved, outward-facing China gave rise to the second elephant crisis and continues to unfold today as an expanded regional phenomenon in Southeast Asia (Milliken et al., 2012, 2019). This time the growing penetration of resource-rich Africa by Asian actors has led to the advent of African-based transnational criminal syndicates as a dominant force in ivory trafficking (Lopes, 2015). Working through local political and economic elites, competing Asian-run syndicate groups continue to move large volumes of ivory to processing and consuming destinations in Asia (Rademeyer, 2016b,a; EIA, 2017, 2018). Facing CITES and national-level pressures for closure, Asian physical ivory markets are mostly in retreat, especially in China where a domestic trade ban took effect 31 December 2017. However, in that country and throughout the general region ivory product sales remain robust and largely insulated from effective law enforcement in the darker recesses of internet and social media trading platforms (Zhao et al., 2017).

Over the last 31 years since 1989, CITES has only twice modified its restrictive policy to allow highly conditional one-off sales of raw ivory between Botswana, Namibia, South Africa and Zimbabwe – which currently account for over 60 percent of Africas elephants (Thouless et al., 2016) – and two traditional ivory consuming countries, Japan and China. The first sale of 50 tonnes of ivory occurred in 1999, whilst the second involved 108 tonnes in 2008 and was immediately followed by the imposition of a nine-year moratorium on any further ivory sales. CITES has also allowed small numbers of hunting trophies obtained pursuant to national hunting quotas and exported as personal effects, and very limited quantities of pre-Convention and antique ivory, to be traded during this period. CITES has also moved to support demand reduction efforts, openly advocate domestic ivory market restrictions as well as complete closure, and promote ivory stockpile management including, on occasion, ivory stock destruction.

With an increasingly heightened polarisation, CITES policy choices are simplistically characterised within a binary pro-trade or anti-trade framework, with political compromise rather than strategic consideration of data and evidence typically determining outcomes. Harvey (2016) implicitly acknowledges the limits to the 1989 international trade ban to date, suggesting that new domestic trade bans, stockpile destruction and a ban in trading ivory of extinct mammoths are necessary to give full effect to the ban. However, other scholars such as t´Sas-Rolfes (2016), argue that such actions also have limits: they are costly to implement and enforce and may achieve insufficient global public support to be effective. For example, African parks agencies are argued to be chronically under-funded (James et al., 2001; McCarthy et al., 2012; Watson et al., 2014), while some have raised concerns about both the social and ultimate conservation consequences of increasingly militarised approaches to elephant protection (Duffy, 2016).

# 3 Empirical methodology

We assume a competitive market for the illegal harvesting of elephants, where poachers live for one period and have quasi-linear payoff function. Free entry in the poaching market implies that in each site and time period, poachers are price takers. When faced with price $P_{ct}$, a poacher in site $s$, country $c$, and year $t$ decides to poach quantity $Y$ to maximize his payoffs

$$U_{sct}(Y) = P_{ct}Y - C_{sct}(Y), \tag{1}$$

where $C_{sct}(.)$ denotes the cost function, assumed to take the form

$$C_{sct}(Y) = e^{-\frac{1}{\beta}\Theta_{sct}} \frac{\beta}{\beta+1} Y^{\frac{1+\beta}{\beta}}. \tag{2}$$

The parameter $\Theta_{sct}$ captures cost shifters, e.g. the density of elephants or the extent of law enforcement, which can vary across sites and over time. With lower-case letters denoting natural logs, the first-order condition of the poaching problem can be written as

$$y_{sct} = \Theta_{sct} + \beta p_{ct}. \tag{3}$$

Decomposing $\Theta_{sct}$ into a constant $\alpha$, site fixed effects $\eta_{sc}$, and observable and unobservable time-varying site characteristics $Z_{sct}$ and $\varepsilon_{sct}$, respectively, we obtain the supply equation

$$y_{sct} = \alpha + \beta p_{ct} + Z_{sct} \cdot \gamma + \eta_{sc} + \varepsilon_{sct}. \tag{4}$$

Our parameter of interest is $\beta$, the poaching elasticity with respect to price.[3] The OLS estimation of (4) faces the common challenge that prices and quantities are determined jointly at the intersection between demand and supply curves. Thus, to identify $\beta$ we need to find a demand shifter that does not simultaneously affect supply.

**Ivory storage and gold price as instrumental variable** Ivory is a storable commodity so that demand from end-consumers and supply from poachers need not equalize in every period. Rather, a model of the ivory market therefore requires considering a third category of agents, speculative traders, who not only physically bring the ivory from the poacher to the consumer but also store the ivory for speculative purposes.[4] Whether that distinct speculative function is fulfilled by agents specialized in storage or by buyers and sellers is indeterminate but irrelevant in this model.

We follow Kremer and Morcom (2000) and derive the Hotelling condition, assuming that storage levels are almost always positive, speculators are risk-neutral and the entry into the

[3] Note here that price $p_{ct}$ is country-time specific in that we do not assume that prices equalize across countries in a given year. Trade costs and other frictions might generate spatial heterogeneity.

[4] Moyle and Conrad (2014), in their analysis of ivory tusk throughput across factories in China concluded that the illegal ivory entering China is in part stored for speculative purposes.

storage market is competitive.[5] Denote by $r_t$ the interest rate in year $t$, we have

$$\mathbb{E}_{t-1}[(1-\tilde{\pi}_t)\tilde{P}_{ct}] = (1+r_t)P_{ct-1}, \tag{5}$$

where $\tilde{\pi}_t$ is the probability of seizure faced by the trader between $t-1$ and $t$. Condition (5) simply states that a trader must be indifferent between storing ivory for an additional period and selling now. By delaying the sale, traders get $\mathbb{E}_{t-1}[(1-\tilde{\pi}_t)\tilde{P}_{ct}]$ in expectation in the next period. If they instead sell today at price $P_{ct-1}$, they earn a gross rate of return $(1+r_t)$, which we assume, for simplicity, to be deterministic. Unlike perishable goods, anticipated changes in either supply or demand curves are absorbed by movements in and out of storage. Only unexpected demand or supply shocks will translate into changes in prices so that the economy moves onto an optimal storage path towards its steady state (Kremer and Morcom, 2000).

Assuming that the realization of the random variable $(1-\tilde{\pi}_t)\tilde{P}_{ct}$ is given by $(1-\pi_t)P_{ct} = \left[\mathbb{E}(1-\tilde{\pi}_t)\tilde{P}_{ct}\right] \cdot e^{-\eta_{ct}}$, we can replace in (5) and take logarithms to get

$$p_{ct} - p_{ct-1} = r_t + \pi_t + \eta_{ct}, \tag{6}$$

where $\pi_t$ are year-$t$ realizations of seizure rates. Moreover $\eta_{ct}$ aggregates unexpected shocks to ivory markets, which we can further decompose into a world demand shock for ivory $u_t$ (due to policy changes for example) and residuals $v_{ct} \equiv \eta_{ct} - u_t$.

We can then rewrite (6) as

$$p_{ct} - p_{ct-1} = r_t + \pi_t + u_t + v_{ct}, \tag{7}$$

To identify the price elasticity of ivory poaching, we need to find demand shifters that have a bearing on poaching only through ivory prices, i.e. factors that do not simultaneously affect the supply curve of elephant ivory by being correlated with $(\varepsilon_{sct} - \varepsilon_{sc(t-1)})$. In particular, other storable commodities such as gold are similarly subject to the same Hotelling condition, which we write

$$p_t^g - p_{t-1}^g = r_t - z_t, \tag{8}$$

where $z_t$ is the residual, which comprises demand shocks specific to gold markets and supply

[5] Scheinkman and Schechtman (1983) and Deaton and Laroque (1996) study storage markets when the positive-storage condition is binding with positive probability.

shocks. Plugging into (6) yields

$$p_{ct} - p_{ct-1} = p_t^g - p_{t-1}^g + u_t + \pi_t + v_{ct} + z_t. \tag{9}$$

**Exclusion restriction and threats to identification** Our exclusion restriction therefore postulates that gold prices affect poaching through ivory prices only, i.e. not through the unobserved ivory supply shocks $\varepsilon_{sct}$. We next discuss the plausibility of such assumption.

First, the economic rationale for the instrument – the Hotelling condition – holds only when storage levels are almost always positive. This condition is sufficient, but not necessary for the instrument to be relevant. We nonetheless find evidence of ivory prices being a unit root process (see below), which is consistent with prices being governed by the Hotelling condition. However, we also do not require the Hotelling condition to hold in the entire sample. If storage levels are positive in only a subset of the sample, the instrument would be relevant in that subsample. Ultimately, the strength of the first stage provides an assessment of the instrument's relevance.

Next, we need to address the possibility that shocks to gold markets $z_t$ affect poachers' incentives through channels other than ivory prices. Interest rates and global demand can indeed be correlated with the world economic conditions in general and local economic growth and social stability in particular, thereby affecting agents' opportunity cost of poaching. We address this issue by controlling for GDP growth and a measure of conflicts in our regressions. More specifically, if a surge in the price of gold and other minerals increases labor demand in mining, that would create a shortage of would-be poachers. To look into this possibility, we use data on the locations of mining extraction from Berman et al. (2017) and find that the geographical overlap between the elephant range and mines is negligible. There is only one poaching site in our data with active mining, located in South Africa (see Figure A1 in the online Appendix). Our estimates are robust to dropping that single site; results and additional details available upon request. Finally, while world interest rates could also affect ivory markets through other factors such as shipping costs or the demand for ivory, the transmission mechanism to poachers would still be through ivory prices they receive.

Finally, a prediction of the storage model is that prices are not stationary. However, non-stationarity of the instrument and the variables being instrumented is not a challenge to the estimation strategy as discussed in Phillips and Hansen (1990). We test for the stationarity of the price data using the Dickey-Fuller test with time trends. The null hypothesis of a random walk cannot be rejected. Robustness checks using Phillips-Perron tests yield similar results. We also fail to reject the null of a unit root in gold prices, consistent with Smith (2002). The model predicts that poaching data have a unit root, which we test using the global poaching data. Here also, we cannot reject that the logarithm of global poaching has a unit root. Table A3 reports the results. However, our identification admittedly hinges on our model being correctly specified. In particular, we assume that beyond prices, other variables are also stationary. Our main specification thus does not include a time trend, although we check the robustness of our results to adding such time trend.

**From global to local prices** Finally, we need to specify the relationship between global prices $p_t$ and local prices $p_{ct}$. We assume that:

$$p_{ct} = \theta p_t - \delta_{ct}. \tag{10}$$

The local price is thus a function of the global price with pass-through $\theta$, while $\delta_{ct}$ captures the iceberg trade costs from the poaching site to the global markets. This trade cost encompasses transportation costs, differential law enforcement levels across countries, or any other sources of country-level heterogeneity on the supply side. We assume that these are independent of gold prices, i.e. $Cov(p^g, \delta) = 0$.

We can then substitute for $p_{ct}$ in (4) and obtain

$$y_{sct} = \alpha + \tilde{\beta} p_t + Z_{sct} \cdot \gamma + \eta_{sc} + \tilde{\varepsilon}_{sct}, \tag{11}$$

with $\tilde{\beta} = \beta \cdot \theta$ and $\tilde{\varepsilon}_{sct} = \varepsilon_{sct} - \beta \tilde{\delta}_{ct}$, where $\tilde{\delta}_{ct}$ is the component of $\delta_{ct}$ not absorbed by site fixed-effects and parametric regressors.

Equations (4) and (11) can be estimated to assess the poaching elasticity with respect to ivory prices in Africa and China, respectively, while (10) estimates the pass-through rate. In all cases, the endogenous price is instrumented with gold price (note that the exclusion restrictions are not mutually inconsistent as we assume that gold prices affect ivory prices in China, which in turn affect ivory prices in Africa). We will also consider commodities such as silver to test the robustness of our results to alternative choices of instruments.

# 4 Data

One of the contributions of this paper is to combine for the first time price and quantity data on African elephant ivory.

### 4.1 Ivory price data

The analysis relies on a database of raw ivory prices that contains 4,873 price data points covering the time period 1970-2014 and spanning 72 countries. Details on the data collection methodology can be found in the online appendix. In a nutshell, the data are compiled from published reports and papers, websites, government and private sector proprietary data, and ivory seizure data. Prices are observed at various segments of the value chain (poachers, importers, middlemen, retailers, etc.) and are mostly for African elephants, with a few observations on Asian elephant or mammoth ivory.

To construct a country-year dataset on ivory prices from these 4,873 observations, we proceed in three steps. First, we convert the prices into U.S. dollars and deflate them so that all prices are in 2005 constant U.S. dollars. Then, since the heterogeneity in data sources induces variability in observed prices along observable dimensions, we partial out the effects of value chain, species, source and price category by regressing the logarithm of the price on these four groups of dummy variables and taking the residuals from the regressions. We conduct this exercise separately for Sub-Saharan countries and China. Lastly, for each country and year, we take the median of these residuals to form our final dataset on ivory prices.

Figure 1 plots median prices in each year in Africa and in China over time; the dotted line plots gold prices, which are discussed below. We highlight two stylized facts. First, the prices in producing (solid line) and consuming countries (dashed) closely track each other. The differences between the two, beyond measurement error, are possibly driven by shipping, smuggling costs, and the increased concentration in the ivory trafficking sector. We investigate this relationship in greater detail below.

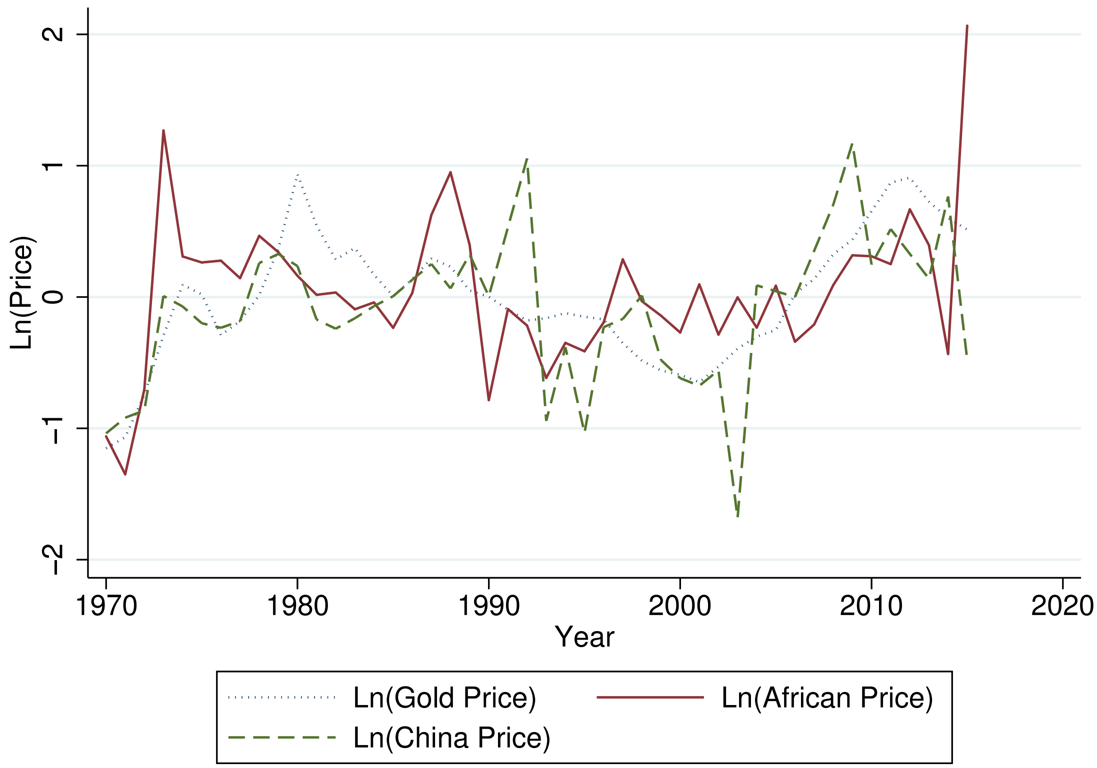


Figure 1: Gold and Ivory Prices

Note: Gold prices come from the London Bullion Market (morning prices), quoted in US dollars and deflated by US CPI published by BLS. The gold price is normalized so that the mean is zero. The ivory prices are the median of the partialled-out price.

Second, focusing on the China ivory price series, Figure 2 suggests that the price of ivory has experienced a stable average growth rate over the periods 1970-1992 at 5.03 percent per year and 1993-2014 at 5.52 percent; these two numbers are not statistically different from each other. The price of ivory experienced a sudden drop around 1992-1993, probably due to the enforcement of the 1989 CITES ban on international trade of ivory products coming into effect, at least as far as markets were concerned. The trend break is statistically significant with a $p$-value close to zero, and quantitatively large. The drop in the price between 1992 and 1993 is 1.3 log points, which corresponds to approximately 17 years' worth of price growth if compared to the pre-break price growth of 0.0503 per annum.[6] The trend break does not affect our estimation of equation (11), as our estimation sample period only starts from 2002 due to the availability of poaching data as explained below.

[6] Precisely, $(1 + 0.0503)^{17} - 1 \approx 1.3$.

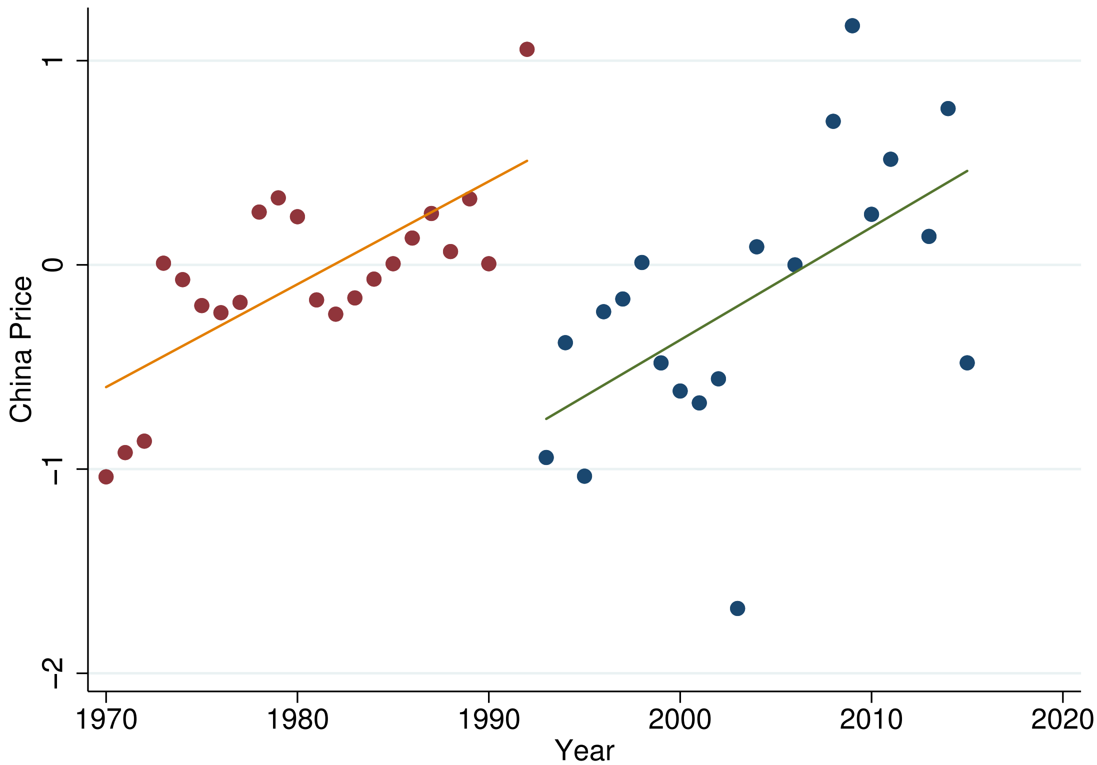


Figure 2: Prices in China over Time

Note: The figure plots the median of the filtered price of raw ivory tusks in China over time.

This pattern is in line with the theoretical predictions of a model of speculative storage of ivory (Kremer and Morcom, 2000) with a positive-storage condition that is almost never binding. The observed constant average growth rate is consistent with the Hotelling no-arbitrage condition holding for ivory prices, while the sudden drop in 1993 reflects market anticipations of lower future demand.

### 4.2 Poaching data

The Monitoring the Illegal Killing of Elephants (MIKE) Programme put in place a standardized monitoring system that relies on data from conservation area rangers in 60 sites across 30 countries dating back to 2002. "MIKE data consists of data collected by anti-poaching patrols and other sources. This patrol data includes records of elephant carcass(es) encountered – cause of death (...), and the estimated age of the carcass(es)" (Burn et al., 2011).

A commonly-used variable in the proportion of illegally killed elephants (PIKE), defined as the ratio of the number of carcasses classified as illegally killed to the total number of carcasses encountered at each site. The rationale behind using a ratio instead of say the number of illegally killed carcasses is to account for patrol efforts. (Burn et al., 2011) discuss the validity of PIKE as an unbiased measure of poaching. (Burn et al., 2011) and (CITES et al., 2013) provide a detailed description of the data and analyze the local, national, and global covariates of PIKE. The continental series indicates that PIKE has crossed the 0.5 mark in 2010 (CITES et al., 2013) and has remained above ever since (CITES, 2016). CITES considers poaching levels above that 0.5 cutoff "are cause of concern" (CITES, 2016). Given birth and natural mortality rates, Wittemyer et al. (2014) actually estimate that populations are likely to start declining when the PIKE value is above 0.54.

Since the main purpose of the analysis is to estimate a supply elasticity, our preferred specification is to use the logarithm of PIKE on the left-hand side (and the logarithm of prices on the right-hand side). We also carry estimations controlling for (the log of) the total number of carcasses (the denominator of the PIKE ratio). The rationale for this specification is to control for patrol effort more flexibly. While the variable might be potentially endogenous, it has the added benefit that the coefficient of the price variable can then be interpreted as a supply elasticity of poaching with respect to ivory prices, controlling for patrol effort among other things. Robustness checks include a host of other specifications that confirm that our finding of a positive correlation between price and poaching is robust to the functional form adopted to estimate it.

### 4.3 Stationarity and co-integration Tests

As discussed earlier, we test for the stationarity of the price data in China using the Dickey-Fuller test, allowing for time trends in both the null and the alternative hypotheses. The upper panel of Appendix Table A3 reports the results. Due to the trend break around 1992-1993, we run the test separately for the periods before and after 1993.[7] The null hypothesis of random walk cannot be rejected in either case. Robustness checks using Phillips-Perron tests, which account for potential serial correlation and heteroskedasticity in the residuals, yield similar results. Appendix Table A3 also shows that we fail to reject the null of a unit root in gold prices, consistent with Smith (2002). The model predicts that poaching data have a unit root. We test whether this is actually the case empirically. As we did for prices, we test for unit root for the global poaching and PIKE data. The results are presented in Appendix Table A3. Here also, we cannot reject that the logarithm of global PIKE has unit root.

[7] We drop 1992 and 1993 data points for the test due to extreme fluctuations around the trend break.

In addition, we test for co-integration of the variables of interest. The lower panel of Appendix Table A3 reports the results of the two-step Engel-Granger co-integration test. Given our inability to construct a complete series of poaching rates, we aggregate the poaching data at the global level and obtain a time series of 14 consecutive years. The price series on the other hand are much longer with local ivory price data going back to 1970. The data on ivory price in China however have missing information for four non-consecutive years. When testing for co-integration of gold prices with ivory prices, we reject the null of *no co-integration* at the 1 percent level. Furthermore, despite having only 13 observations to run the co-integration test, we are still able to reject the absence of co-integration between global poaching and gold prices. Gold prices are thus shown to be co-trending with ivory prices in both African range states and China and global poaching rates. However, when looking at co-integration between poaching and Africa (13 observations) and China (7 observations) prices, we fail to reject the null of *no co-integration*.

### 4.4 Other data

**Ivory seizures** We use ivory seizure data collected by the Elephant Trade Information System (ETIS) to control for the amount of ivory seized originating from a given country. Underwood et al. (2013) give a detailed description of the data and attempt to correct for reporting biases. The seizure variable, although potentially endogenous (e.g. higher seizure might be due to higher production) might capture some law enforcement intensity.

**Socio-economic data** We will use the London fix price of gold an instrument for ivory prices. We take the annual average of morning prices in the London Bullion Market denominated in current U.S. dollars, and deflate them by the consumer price index (CPI) published by the U.S. Bureau of Labor Statistics.[8] Our real GDP, population, and consumption data for all the African countries and China come from the Penn World Table (version 9.0). The number of conflicts are based on the *UCDP/PRIO Armed Conflict Dataset* (Melander et al., 2016; Gleditsch et al., 2016). We transform the original dataset from conflict-year level to country-year level by counting both major and minor conflicts a given country was involved in during a given year. We count civil wars as a single conflict within each year.

[8] We will also use silver as an alternative commodity – see the Online Appendix for details.

# 5 Results

The estimation sample is constrained by the spatial and temporal coverage of the price and poaching data. Overall we do not have continuous coverage for both sites and countries, with gaps occurring in both the poaching data and the price data. Appendix Tables A1 and A2 summarize the patterns of availability for both data sources. In the poaching data, only 9 out of 77 sites have complete coverage between 2002 and 2015, and the median site has 9 out of 14 years of data available. In the ivory price data, no country has complete coverage, but major elephant range countries such as Botswana, Kenya, and Tanzania have only one or two gap years. Overall, the sparsity in data coverage is unlikely to bias our results as the main ivory-producing countries are indeed covered continuously in both ivory and price data, especially in our estimation sample after the year 2002. Moreover, the composition of the price data stayed stable over our estimation sample as well. Around 90 percent of the price data in our Sub-Saharan African sample after year 2002 are sourced from government valuations and are local middleman prices, and the composition is stable over time.

## 5.1 Poaching elasticity with respect to domestic prices

The primary goal of this paper is to estimate the price elasticity of elephant ivory poaching as specified in equation (4). Our main outcome variable, $y_{sct}$, is measured by (the logarithm of) PIKE in site $s$, country $c$, and year $t$. The main right-hand side variable $p_{ct}$ is on the other hand measured at the country-year level, as the price data are not recorded for individual poaching sites. In addition, the regressions include a vector of controls, such as site fixed effects and characteristics of the poaching site such as the total area and the number of carcasses found at the site in a given year $t$ (see Appendix Table A4 for summary statistics of the variables used in our estimations). Finally, given that in our main specifications the instruments are global variables that only vary over time, we cluster our standard errors at the year level. In all the tables discussed in the main text, given the small number of clusters we adopt the parametric Moulton (1986) correction factor. Below we also implement alternative clustering approaches – without Moulton correction and two-way (year and country) clustering following Cameron et al. (2011)– to assess the robustness of the results.

The estimation results of (4) are shown in Table 1. The first column reports the bivariate regression, which implies an elasticity estimate of 0.12. Adding site fixed-effects increases the magnitude of the coefficient to 0.19. With supply shift controls such as a conflict variable and a country's GDP growth, column 3 shows not much difference in the estimates. Column

Table 1: Poaching Elasticity with Respect to Local Prices in Africa

| LHS = Ln(PIKE) | OLS | | | | 2SLS, IV = Gold Price | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Ln(Median Price) | 0.119 | 0.191 | 0.191 | 0.146 | 0.422 | 0.431 | 0.421 | 0.664 |
| | (0.066) | (0.052) | (0.053) | (0.111) | (0.074) | (0.082) | (0.074) | (0.151) |
| Ln(Total Carcass Found) | | | | | | -0.016 | | |
| | | | | | | (0.053) | | |
| Number of Conflicts | | | -0.140 | -0.198 | | | -0.184 | -0.388 |
| | | | (0.165) | (0.180) | | | (0.155) | (0.168) |
| GDP Growth Rate | | | -0.020 | -0.003 | | | -0.016 | 0.007 |
| | | | (0.022) | (0.022) | | | (0.018) | (0.018) |
| Total Seizure | | | | 0.031 | | | | -0.102 |
| | | | | (0.053) | | | | (0.056) |
| Constant | -0.771 | -0.739 | -0.799 | -1.061 | -0.411 | -0.360 | -0.532 | 0.383 |
| | (0.064) | (0.740) | (0.805) | (0.924) | (0.546) | (0.575) | (0.568) | (0.400) |
| | | | | | First Stage | | | |
| Ln(Gold Price) | | | | | 1.260 | 1.226 | 1.259 | 0.796 |
| | | | | | (0.256) | (0.272) | (0.255) | (0.139) |
| N | 151 | 151 | 151 | 114 | 151 | 151 | 151 | 114 |
| First Stage F statistic | | | | | 67.768 | 55.455 | 67.083 | 49.034 |
| p-val ($H_0 : \beta == 1$) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.029 |
| Site FE | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Mean, Ln(PIKE) | -0.759 | -0.759 | -0.759 | -0.852 | -0.759 | -0.759 | -0.759 | -0.852 |
| SD, Ln(PIKE) | 0.789 | 0.789 | 0.789 | 0.795 | 0.789 | 0.789 | 0.789 | 0.795 |

Note: Standard errors clustered at the year level with Moulton correction in parentheses. This table reports the results of estimating equation (4) with OLS and 2SLS. The dependent variable is the log of PIKE at the site level. "Ln(Median Price)" refers to the price in Africa. Variable definitions and sources are described in detail in the text.

4 adds a variable measuring the total amount of ivory seized coming out of the country in a given year. We lose a lot of observations due to the scarcity of the data on ivory seizures. The point estimate drops slightly but is imprecisely measured. However, in each of these specifications, we reject unit-elasticity at the 1 percent level.

Admittedly, OLS might be biased as prices are endogenous. If, for example, law enforcement has been more and more stringent over time, then increases in prices will not translate into commensurate increases in poaching. Conversely, reverse causation implies that our estimates are over-estimates of the true elasticity, in which case the supply elasticity with respect to prices would be even lower than the one estimated here. To address the joint determination of poaching levels and ivory prices, we next estimate equation (4) using 2SLS with gold prices as an instrument for ivory prices. First, looking at the reduced form, Figure 3 shows the correlation between gold prices and yearly aggregate poaching; the scatterplot suggests a very strong association. Furthermore, Figure 1 already hinted at a high degree of co-movement between ivory prices, both in Africa and China, and gold prices, suggesting strong first stages.

Quantitatively, the first stage results are displayed in the lower panel of Table 1 columns 5-8 and consistently indicate that the instrument is particularly strong with a partial F-statistic always above 50. The upper panel reports the second stage estimates in columns 5-8.

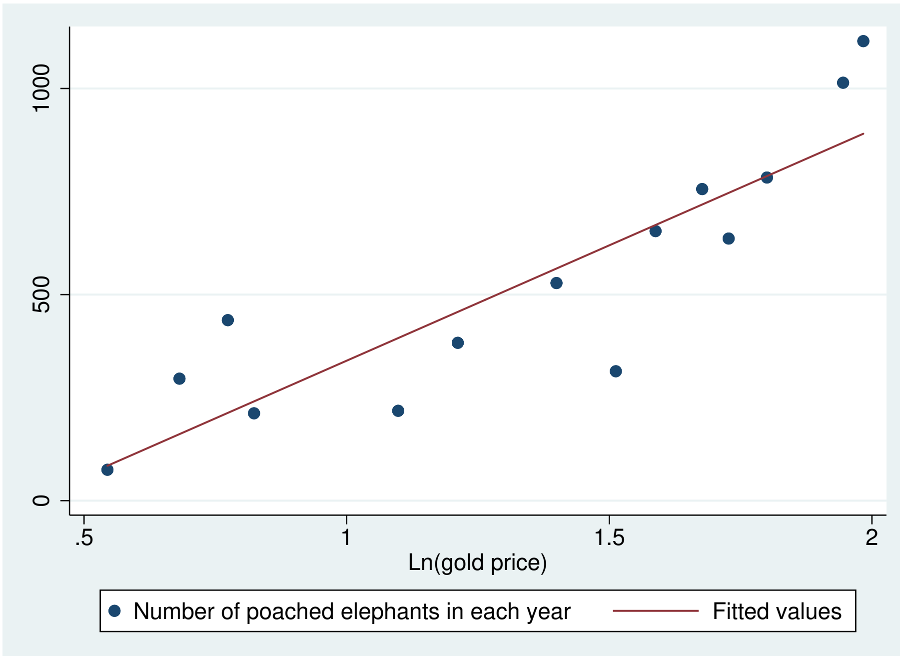


Figure 3: Gold prices and elephant poaching

In column 5, the 2SLS estimate suggests a PIKE elasticity with respect to price of around 0.42. The estimate is statistically significant at the 1 percent level. The 2SLS coefficient is markedly higher than the OLS one, which might be due to measurement error in price data (either due to the inherent noise in the data or to the model errors following partialling out of the data) but also OLS being potentially biased downward as discussed above. In column 6, we control for the logarithm of the total number of carcasses found at site $s$ in year $t$, i.e. the denominator of PIKE. As discussed earlier, the objective is twofold: first, to account more flexibly for patrol effort, and second, the coefficient of the price variable can now be interpreted as the elasticity of illegal ivory supply with respect to prices. The coefficient in column 6 is almost identical to the one in column 5 at 0.43, alleviating concerns that the variable "Total Carcass Count" itself is endogenous. Controlling for the number of conflicts and GDP growth rate in column 7 and ivory seizures in column 8 does not change the qualitative result much: the elasticity is always statistically significantly below one.

A 0.42−0.43 elasticity is evidence of an inelastic supply of ivory: a 10 percent decrease in the price of ivory in a given range state in Africa implies a 4.2−4.3 percent decrease in poaching. A more concrete way to interpret this elasticity would be to consider an increase in law enforcement intensity. Let's do the following thought-experiment. Suppose that from the current situation, we could double the probability that poachers are apprehended by law enforcement. For simplicity's sake, assume that poachers are risk-neutral and the only punishment when they are caught is a confiscation of their loot. As a result, if their expected profits were $\pi \times p$ (i.e. the initial apprehension probability multiplied by the price of the tusk), their expected profits after doubling apprehension probability is now $(1/2\pi)\times p$, or equivalently $\pi \times (1/2p)$. In other words, in this stylized environment, doubling the apprehension probability is akin to halving the price, everything else remaining constant. In particular, we acknowledge that this analysis is "partial equilibrium" in that a higher rate of apprehension might lead to higher prices, which we ignore here. A $0.42-0.43$ poaching elasticity with respect to price implies that poaching will drop by 26 percent as a result of that hypothetical policy. Starting from a 63 percent rate in 2014, such law enforcement effort would bring poaching rates down to 46 percent. Admittedly, it is unclear what it would take for *every* range state to double the probability of apprehension of poachers, as efforts limited to a few countries might lead to crime displacement to the more vulnerable ones.

### 5.2 Price pass-through and the poaching elasticity with respect to global prices

While the previous section allows us to identify poachers' responses to changes in local prices, those results are not yet informative on the impact of policies in consumer countries on poaching. In particular, it is not clear how much demand reduction interventions in ivory consuming countries affect prices in the countries where poaching actually takes place. This question is important, as policymakers have high expectations for policies that act primarily in the consuming countries, such as the announced bans on domestic ivory markets in the U.S. and China.

With data on prices in both China and Africa, we can measure the price pass-through rate $\theta$ by estimating equation (10). Table 2 reports the results. The first part of the table (columns 1-5) looks at the entire time period for which we have price data. Column 1 shows the OLS bivariate relationship and captures the raw correlation between these two variables. Column 2 adds country fixed effects and suggests a roughly 35 percent pass-through rate. Since the relationship between Africa and China prices goes both ways, we instrument the latter with gold prices. The first stage is similar to the earlier IV estimation with a close-to-unit elasticity and a large partial F-statistic. Whether we look at the whole period since

Table 2: Price pass-through rates

| LHS = Ln(Median Price), Africa | OLS | | 2SLS, IV = Gold Price | | | |
|---|---|---|---|---|---|---|
| | (1) All Years | (2) All Years | (3) All Years | (4) Pre-1993 | (5) Post-1993 | (6) Post-2002 |
| Ln(Median Price), China | 0.284 | 0.349 | 1.000 | 1.992 | 0.955 | 0.900 |
| | (0.121) | (0.120) | (0.168) | (0.589) | (0.158) | (0.183) |
| Ln(Total Carcass Found) | | | | | | 0.206 |
| | | | | | | (0.063) |
| Constant | 0.002 | -0.823 | -1.321 | -0.941 | -1.287 | 2.195 |
| | (0.071) | (1.396) | (1.171) | (0.915) | (1.177) | (1.239) |
| | | | First Stage | | | |
| Ln(Gold Price) | | | 0.740 | 0.266 | 0.955 | 1.107 |
| | | | (0.186) | (0.143) | (0.264) | (0.353) |
| N | 432 | 432 | 432 | 166 | 266 | 188 |
| First Stage F statistic | | | 174.349 | 14.956 | 154.138 | 90.728 |
| Fixed Effects | None | Country | Country | Country | Country | Site |

Note: Standard errors clustered at the year level with Moulton correction in parentheses. This table reports the results of estimating equation 10 with OLS and 2SLS. The dependent variable is the log of median price in Africa at the country level. Variable definitions and sources are described in detail in the text.

1970 for which we have data on prices (column 3), the time period after the trend-break year 1993 (column 5), or look at post-2002 data that have common support with the poaching data (column 6), the 2SLS estimates indicate a pass-through rate quite close to unity.[9] This finding is consistent with the "iceberg" trade cost assumption in the large majority of trade models. It is consistent with marginal cost pricing or constant markups, and would obtain more generally whenever there is no arbitrage in shipping ivory internationally.[10]

We now turn to the estimation of the poaching elasticity with respect to ivory prices in China. For symmetry, we use the same set of specifications as in Table 1. Table 3 presents the 2SLS results. Not surprisingly in light of the nearly complete pass-through, the patterns are quite similar to the estimates using local prices. The OLS specifications (columns 1-4) show similar patterns as in the domestic price analysis with an elasticity of 0.13. Similarly accounting for the potential endogeneity of ivory prices, our preferred specifications (columns 5-6) estimate an elasticity of roughly 0.40 and significant at the 1 percent level. Here again, in all specifications, we can reject unit elasticity at the 1 percent level. As expected, the poaching elasticity with respect to global prices is quite close to the product of the elasticity with respect to local prices and the pass-through rate between global and local prices. Multiplying our preferred local price coefficient (Table 1, column 6) with the post-2002 pass-through coefficient

[9] In the pre-1993 sample the pass-through coefficient is about 2.

[10] We unfortunately do not have enough poacher-level observations (169 in total) to compute a pass-through rate from retailers to poachers.

Table 3: Poaching Elasticity with Respect to Prices in China

| LHS = Ln(PIKE) | OLS | | | | 2SLS, IV = Gold Price | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Ln(Median Price), China | 0.118 | 0.132 | 0.132 | 0.163 | 0.402 | 0.395 | 0.407 | 0.347 |
| | (0.061) | (0.053) | (0.053) | (0.057) | (0.066) | (0.066) | (0.066) | (0.067) |
| Ln(Total Carcass Found) | | | | | | 0.010 | | |
| | | | | | | (0.028) | | |
| Number of Conflicts | | | 0.024 | -0.052 | | | -0.003 | -0.110 |
| | | | (0.069) | (0.105) | | | (0.067) | (0.104) |
| GDP Growth Rate | | | -0.003 | 0.009 | | | -0.005 | 0.007 |
| | | | (0.005) | (0.008) | | | (0.005) | (0.008) |
| Total Seizure | | | | 0.028 | | | | -0.007 |
| | | | | (0.047) | | | | (0.046) |
| Constant | -0.626 | 0.970 | 1.077 | -0.299 | 0.629 | 0.678 | 0.628 | -0.229 |
| | (0.043) | (2.187) | (2.229) | (0.541) | (1.430) | (1.437) | (1.460) | (0.395) |
| | | | | | First Stage | | | |
| Ln(Gold Price) | | | | | 0.869 | 0.911 | 0.873 | 1.145 |
| | | | | | (0.332) | (0.345) | (0.335) | (0.429) |
| N | 422 | 422 | 422 | 248 | 422 | 422 | 422 | 248 |
| First Stage F statistic | | | | | 153.899 | 155.102 | 150.511 | 140.367 |
| p-val ($H_0 : \beta == 1$) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Site FE | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Mean, Ln(PIKE) | -0.603 | -0.603 | -0.603 | -0.696 | -0.603 | -0.603 | -0.603 | -0.696 |
| SD, Ln(PIKE) | 0.715 | 0.715 | 0.715 | 0.739 | 0.715 | 0.715 | 0.715 | 0.739 |

Note: Standard errors clustered at the year level with Moulton correction in parentheses. This table reports the results of estimating equation 11 with OLS and 2SLS. The dependent variable variable is the log of PIKE at the site level. "Ln(Median Price)" refers to the price in China. Variable definitions and sources are described in detail in the text.

(Table 2, column 6) we get $0.431 \times 0.900 = 0.39$, roughly equal to the measured elasticity with respect to global prices.

How informative are our estimates about the impact of policies in consuming countries such as China? In particular, China's recent decision to ban its domestic market for ivory is considered the single most significant step towards the conservation of elephants since the 1989 CITES ban on the international trade of elephant specimens. Vigne and Martin (2017) document a drop in raw ivory prices in China from US$2,100 per kg in early 2014 down to US$730 per kg in early 2017, i.e. a price drop of as much as 65.2 percent. The estimated elasticities imply that poaching is expected to fall by an average of 34.3 percent. A 0.63 PIKE that prevailed in 2014 suggests a fall in PIKE to 0.41 in 2017.[11]

[11] The number of elephants poached declines by $1-(1-0.652)^{0.398} \approx 34.3$ percent, where 0.398 is the supply elasticity from column 6, Table 3. To infer the changes in PIKE from the number of elephants poached, we assume a constant total number of carcasses found within a short-span of time. This implies that PIKE will decline by 34.3 percent as well, and thus $0.63 \times (1-0.343) \approx 0.41$.

## 6 Robustness

In this section, we look at the robustness of the results presented in Tables 1 and 3 to alternative specifications and estimation samples. Appendix Tables A5 and A6 assess the robustness of the results on the elasticity of PIKE with respect to domestic prices (Table 1).

In Table A5, we first repeat the estimation while restricting the sample to "large" sites, i.e. the sites that report at least 8 or 16 carcasses on average across the years. We show the regression results for our preferred specifications (with site fixed effects – columns 2-3 and 5-6 in Table 1) but restrict the sample to sites with an average of at least 8 carcasses found (column 1-2) or 16 carcasses found (columns 3-4). The estimated elasticities are virtually identical. We next adopt alternative approaches to compute our standard errors. Our main specifications include site fixed effects and cluster standard errors at the year level with Moulton correction. In columns 5-6, we show the same results without correction and in columns 7-8, we adopt two-way clustering instead following Cameron et al. (2011). While each method produces different standard errors, the elasticities remain precisely measured. We then use silver prices as an alternative instrument in addition to gold prices. Columns 9-10 of Appendix Table A5 use silver prices as the single instrument and columns 11-12 use both silver and gold prices as instruments.

Table A6 assesses the robustness with respect to the functional form adopted for the estimation. In the baseline model, we use the logarithm of PIKE as the LHS which suffers the downside of omitting the observations that equal to zero. To remedy this, the first two columns of the table use the levels of PIKE, and the next two columns use the inverse hyperbolic sine transformation of PIKE following Burbidge et al. (1988), both of which allow for zeros on the LHS. Column 5 and 6 use the logarithm of poaching at the site level on the left-hand side and control for the number of total carcasses on the right hand side. In these cases, the coefficients on the price variable can be directly interpreted as supply elasticity.[12] Column 7-10 again employ the level of poaching and the inverse hyperbolic sine transformation of poaching to include the observations with zero poaching into the estimation sample. The results are essentially the same as compared to the baseline results in Table 1. In particular, in columns 1 and 2 the coefficient estimates now represent the change in the level of PIKE in response to a log change in price, they must be divided by the level of PIKE to obtain

[12]The coefficient on the price variable in column 6 is the same as in column 6 in Table 1, although the two regressions have different dependent variables on the LHS. This is because PIKE is defined as the ratio of poached elephants to total number of carcasses found. After controlling for the number of carcasses and taking logs, the two specifications are mathematically identical.

the elasticity. From Table A4, the mean level of PIKE across site-year observations is 0.577, implying a PIKE elasticity of 0.29 to 0.35 at the mean site, close to the estimate of 0.42 in Table 1. Similarly, in columns 9 and 10 the implied poaching supply elasticity in the mean site is around 0.5 based on the average level of poaching reported in Table A4. In all these cases also, we reject at the 1 percent level the hypothesis that the measured elasticity is equal to 1.

Next, Appendix Table A7 and A8 check the robustness of the results presented in Table 11 in a similar fashion as we did for the estimation of the elasticity with respect to domestic prices. We follow the same sequence as above and here again, the results suggest that our main finding of a low elasticity with respect to global prices are robust to the specifications and samples considered herein.

Finally, Appendix Table A9 looks at the regression results after adding time controls in the form of either a linear or quadratic time trend. As discussed above, the identification of the price elasticity is obtained through price variation over time especially since the instrument does not vary in the cross-section. Moreover and as predicted by theory, we cannot reject the null hypothesis of unit-root. A highly unbalanced panel (see Appendix Tables A1 and A2) also prevents us from running regressions in first differences as that would lead to too many missing observations. While non-stationarity does not invalidate the 2SLS results, we check the robustness of our findings when controlling for a deterministic linear or quadratic time trend. Our theory privileges unit root processes; yet, empirically, it is well-understood that in finite samples, it is difficult to distinguish a unit root process from a deterministic trend (Campbell and Perron, 1991). Since the time series of our estimation sample only has 13 years, controlling for a deterministic trend removes much of the time variation in the instrument and thus is a very demanding control in our setting. As Appendix Table A9 shows, the estimated elasticities vary substantially depending on the functional form adopted for the time trend and is never statistically significantly different from 0. Nonetheless, across all specifications, we consistently reject at the one percent level that the elasticity is greater than or equal to 1.[13]

[13] We also provide robustness to the way the price variable was constructed. We re-run our regressions using mean prices rather than median prices and find that results are almost identical. Results available upon request.

## 7 Conclusion

This paper estimates the price elasticity of African elephant poaching using gold prices as instruments of ivory prices. A low poaching elasticity with respect to price may partly explain why the African elephant did not experience the fate of the 19th century American bison, despite sharp increases in ivory prices. On the other hand, the low elasticity also means that the challenge of medium- to long-term conservation of African elephants remains largely unresolved.

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# Appendix

# A Ivory Price Data

The dataset on ivory prices has been compiled by TRAFFIC, a non-governmental organization "working globally on trade in wild animals and plants in the context of both biodiversity conservation and sustainable development."[14] The database collates a total of 132 published ivory trade reports and articles, 343 contemporary websites, all records from the Elephant Trade Information System (ETIS) through February 2015, Customs statistics from various countries, certain proprietary industry or government-held datasets, and unpublished TRAFFIC market monitoring survey data. Members of the IUCN/SSC African Elephant Specialist Group were also asked for data and a few data points were obtained from that source. The data were entered into a unique dataset with fields such as price, date (year), country, place in the value chain, type of ivory, etc. This database constitutes the largest collection of ivory price data to date.

The complete dataset contains 21,395 observations of both raw and carved ivory. For consistency, we conduct our analysis using 4,873 observations on raw ivory prices only, given that carved ivory items are not easily comparable. All prices are measured in 2005 constant U.S. dollars per kilogram of ivory. Table A10 breaks down our sample along several dimensions. Around 91 percent of the data pertain to African elephants, followed by Asian elephants (5 percent), and mammoth (2 percent); around 2 percent of the entries do not have information on the species associated with the tusks.

The data are concentrated at the middle segment of the value chain — the importers (33 percent), and the middlemen in the country of production (27 percent). The price data are mainly collected from three sources: customs or tax declarations (32 percent), government valuation of seized illegal ivory (27 percent), and market/field surveys (25 percent). Around 40 percent of the price data are the "average price" over a batch of products, followed by "other price" (28 percent), and "final price" (15 percent). The latter is the last price recorded when a transaction is associated with bargaining between seller and buyer. Table A11 summarizes the distribution of the data over time and location. Over 40 percent of the data are collected pre-1989; post-1989, we have between 17 and 346 observations in each year. Around 48 percent of the data come from African countries, followed by 38 percent from Asian countries, and another 12.5 percent from European countries.

[14] `http://www.traffic.org/overview/`.

**Partialling out** Even when restricting the analysis to raw ivory, prices still exhibit a great deal of variation along the above-mentioned observable characteristics. Figure A2 presents the distribution of raw prices within year groups. The variation of the price data comes from many potential sources, such as the country of origin, the position in the value chain, or the source of the data (market survey, government valuation, etc). Table A12 provides a first glance into this variation by regressing the logarithm of the price on the various characteristics described above. The first two columns use all the available data points. The first column regresses log price on observables, and the second column adds a time trend. The third and the fourth columns split the sample at 1989. Columns (5)-(8) add the weight of the tusk as a control. Because this variable has much less complete coverage, adding the weight control variable reduces the sample size to around one-third of the full sample.

The real price of ivory has been steadily increasing at around 1.5 - 5 percent per year throughout our entire sample. On average the prices collected upstream (the poachers and local middleman) are lower than those downstream, which is consistent with increasing added value along the value chain. The source of information also matters: government valuations usually produce lower prices, while customs declarations are lower pre-1989 and higher post-1989. Between the three elephant species, Asian elephant tusks command higher prices than African ones, especially after the weight of the tusk has been taken into consideration, while mammoth tusks are relatively cheaper. Larger and heavier tusks command an increasing premium: the estimated price elasticity of weight per tusk increases from 5.4 percent pre-1989 to 13.4 percent post-1989, perhaps due to the increasing rarity of large tusks over time.

To reduce the noise in the price data, we partial out the effects of value chain, species, source of price, and types of price by regressing the logarithm of the price on these four groups of dummy variables, and taking the residuals from the regression.[15] In other words, a price in our database is a price $\hat{P}_{ectlim}$ of ivory from species $e$ (i.e. African elephant, Asian elephant, mammoth, or unknwon) in country $c$ and year $t$, at a location $l$ along the supply chain (e.g. poacher, middleman, retailer, etc.), obtained from source of information $i$ (e.g. Customs declaration, informant, internet, etc.), and following method $m$ (e.g. average price, fixed price, final price, etc.). We moreover assume that $\hat{P}_{ectlim}$ is a noisy signal of a market price $P_{ct}$ and

$$\hat{P}_{ectlim} = E_e \cdot L_l \cdot I_i \cdot M_m \cdot U_{ectlim} \cdot P_{ct} \tag{12}$$

[15]We run the regression after dropping the top and bottom 1 percent of the prices to reduce the influence of outliers.

where $E_e$, $I_i$, $M_m$ are, respectively, species-specific, source-of-information-specific and price-collection-method-specific measurement errors, $L_l$ captures the markup associated with supply chain location $l$, and $U_{ectlim}$ captures other sources of measurement errors for which we impose $\mathbb{E}U_{ectlim} = 1$.

To construct our price series, we take the logarithm of equation (12), and then regress the log price on a set of dummy variables for species, information source, supply chain location, and method of price collection and take the residuals. If differences in reported prices across countries or over time are driven by changes in the composition of price observations along these dimensions, our partialling-out exercise removes these compositional biases. We carry out the partialling-out exercise separately on samples from Sub-Saharan countries and China, and label the residuals from the Sub-Saharan sample as "African prices" or "local prices", which we denote denoted $p_ct$, and those from the Chinese sample as "China prices" or "international prices", which we denote $p_t$. Columns 9-10 in Table A12 report the regressions on which the partialling-out procedure is based.

# B Additional Figures and Tables

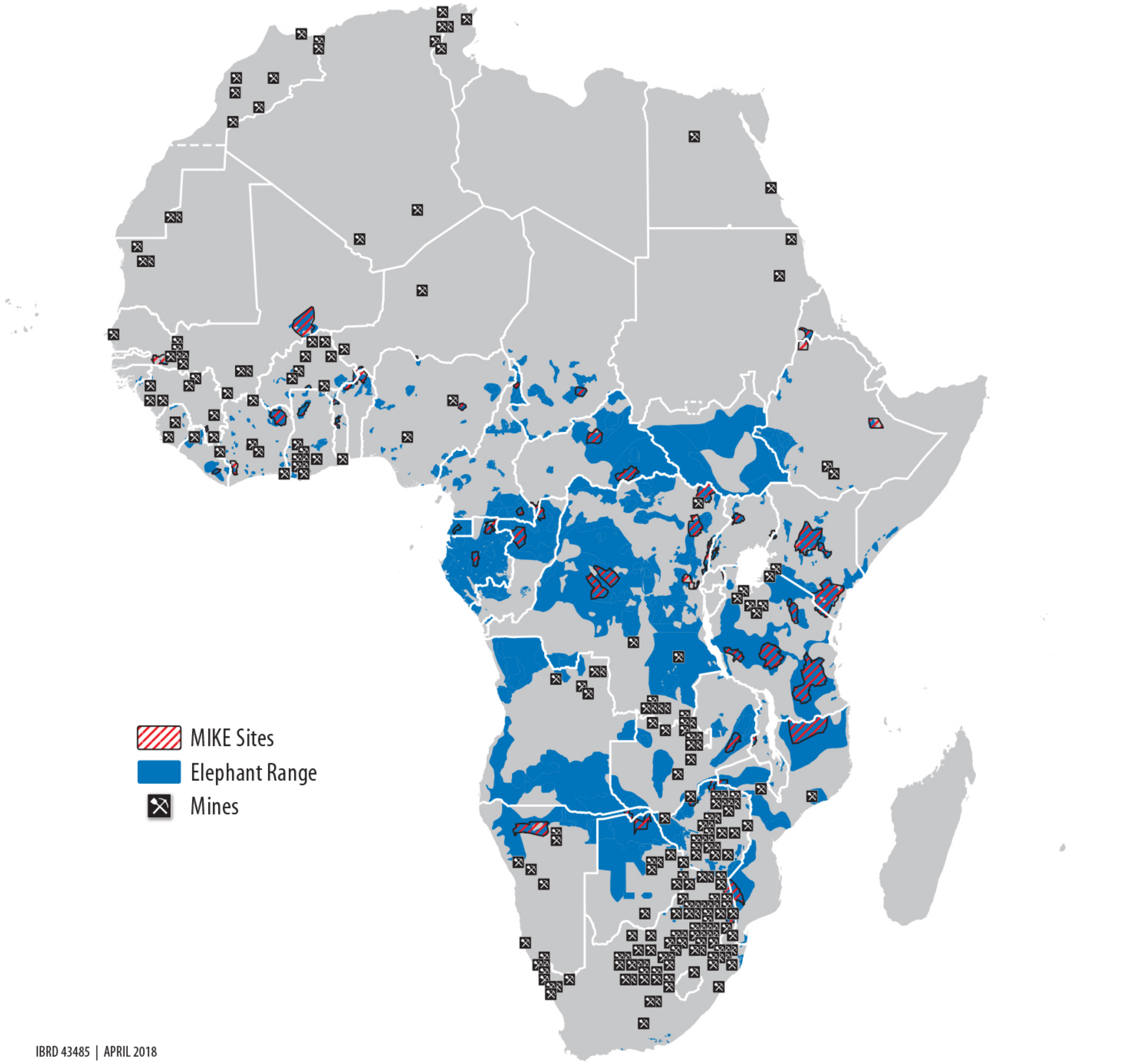


Figure A1: Elephant range (known, probable, and doubtful), MIKE sites, and mining sites in Africa

Source: African Elephant Specialist Group (Thouless et al., 2016), MIKE Programme, and Berman et al. (2017), respectively. The elephant range includes "known", "possible" and "doubtful" ranges as defined by AESG.

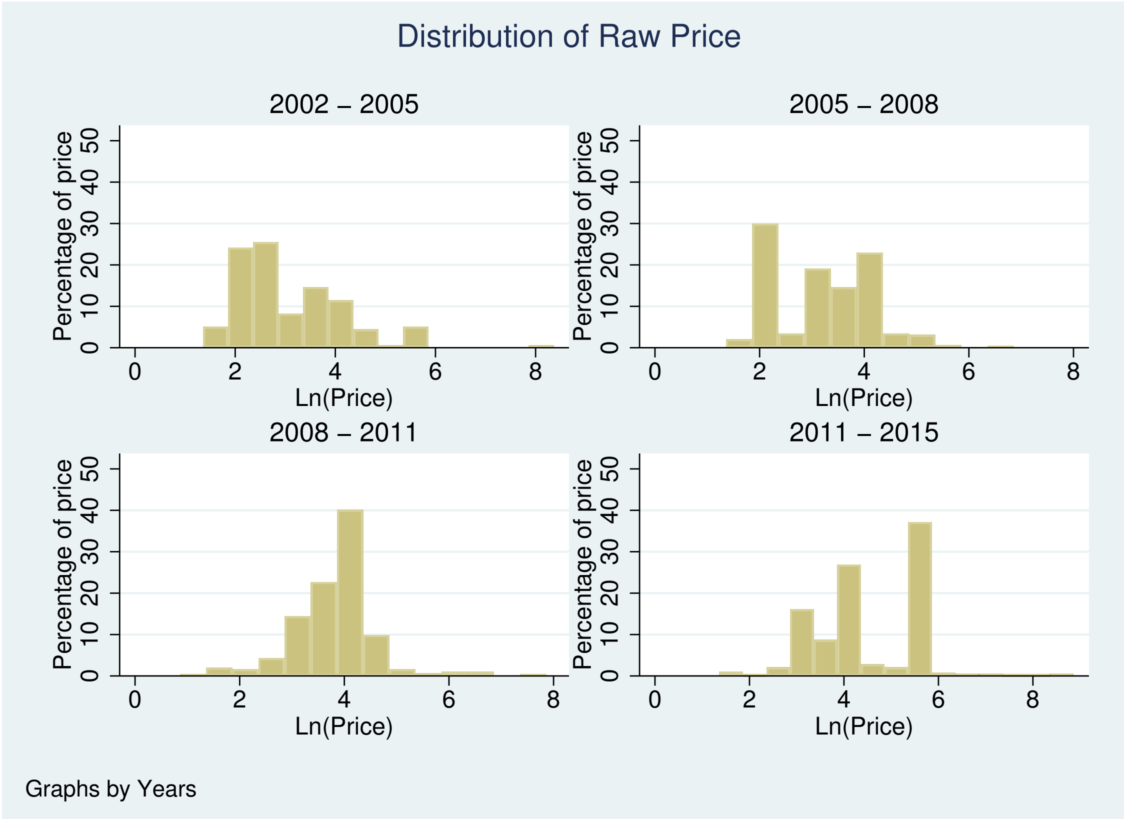


Figure A2: Distribution of Price

Note: The histogram of Ln(price) in the African Sample by year-group. The unit of observation is the unfiltered prices.

Table A1: Data availability: poaching

| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
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| SVK | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ | □ |
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| CHU | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | □ | □ | ■ | ■ | □ | □ |
| DEO | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ | □ | □ |
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| KSH | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | ■ |
| MAR | □ | □ | □ | □ | □ | ■ | ■ | ■ | □ | □ | □ | ■ | □ | □ |
| MKZ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | □ | ■ |
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| ALW | □ | □ | □ | □ | ■ | □ | □ | ■ | □ | □ | ■ | □ | □ | □ |
| KSG | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ |
| MKR | □ | □ | □ | □ | ■ | □ | □ | □ | ■ | □ | □ | ■ | □ | □ |
| NAK | □ | ■ | □ | □ | □ | ■ | □ | □ | □ | ■ | □ | □ | □ | □ |
| WYD | □ | □ | ■ | ■ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| FAZ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ |
| NKK | □ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |

Note: The column header is the site ID in the MIKE programme and the row header is year. Solid square means data are available, and hollowed square indicates missing data.

Table A2: Data availability: African prices

| | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 |
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| BWA | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ | □ | □ | □ |
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| CIV | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ | □ | ■ | □ | ■ | □ |
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| COG | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | ■ | □ | ■ | □ |
| ETH | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| GAB | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | □ | □ | □ |
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| NGA | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ |
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| CMR | ■ | ■ | □ | □ | □ | ■ | ■ | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ | ■ | □ | □ |
| COD | □ | □ | □ | ■ | ■ | □ | ■ | ■ | □ | □ | ■ | ■ | ■ | □ | ■ | □ | ■ | ■ | □ | □ | □ | □ | □ |
| COG | □ | □ | ■ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | ■ | ■ | □ | □ | □ | □ | □ |
| ETH | ■ | □ | ■ | □ | □ | ■ | ■ | □ | □ | □ | □ | □ | ■ | □ | □ | ■ | □ | □ | □ | □ | □ | □ | □ |
| GAB | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | □ | □ | □ | □ | □ | □ |
| KEN | □ | □ | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ |
| LBR | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| MOZ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| MWI | □ | □ | ■ | □ | ■ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ |
| NAM | □ | □ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ | ■ | ■ | ■ | □ |
| NGA | □ | ■ | ■ | □ | □ | ■ | ■ | □ | □ | ■ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ |
| REU | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| SDN | □ | □ | □ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| SEN | □ | □ | □ | □ | □ | □ | ■ | □ | ■ | ■ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| SWZ | □ | □ | □ | □ | □ | ■ | □ | □ | ■ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| TCD | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| TGO | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ |
| TZA | □ | ■ | ■ | ■ | ■ | ■ | □ | ■ | ■ | ■ | ■ | □ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| UGA | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ |
| ZAF | □ | ■ | □ | □ | ■ | ■ | ■ | □ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | □ | □ | □ | □ | □ | □ |
| ZMB | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | ■ | □ | □ | □ | □ | □ |
| ZWE | □ | □ | □ | □ | □ | ■ | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |

Note: The column header is the country ISO code and the row header is year. Solid square means data are available, and hollowed square indicates missing data.

Table A3: Unit root tests

| | | Unit root tests | | | | |
|---|---|---|---|---|---|---|
| | | Dickey-Fuller | | Phillips-Perron | | |
| Variable | Nobs. | Z-stat | p-value | Z-stat | p-value | lags |
| Global ivory price, pre-1992 | 20 | -2.5069 | 0.3245 | -2.4157 | 0.3713 | 2 |
| Global ivory price, post-1993 | 16 | -2.9567 | 0.1446 | -2.9094 | 0.1592 | 2 |
| Gold price, all years | 45 | -2.1354 | 0.5262 | -2.3245 | 0.4205 | 3 |
| Gold price, post-1993 | 22 | -1.5330 | 0.8176 | -1.7115 | 0.7458 | 2 |
| Gold price, post-2002 | 14 | 0.6777 | 0.9970 | 0.1422 | 0.9954 | 2 |
| Global PIKE | 13 | -2.4950 | 0.3305 | -2.4258 | 0.3660 | 2 |

Note: The table reports univariate stationarity tests. Global ivory price is the median price across all observations in a given year. Both tests assume a linear trend in the associated regressions. Due to the trend break around 1992-1993, we run the test separately for the periods before and after 1993. We drop 1992 and 1993 data points for the test due to extreme fluctuations around the trend break.

Table A4: Summary statistics of variables in IV regressions

| | Mean | SD | Min | Max |
|---|---|---|---|---|
| Poaching | 25.424 | 38.306 | 1.000 | 225.000 |
| PIKE | 0.577 | 0.291 | 0.013 | 1.000 |
| Median Price, Africa | 1.846 | 2.233 | 0.239 | 13.903 |
| Median Price, China | 1.509 | 0.835 | 0.186 | 3.226 |
| Gold Price | 4.416 | 1.743 | 1.724 | 7.269 |
| Area of Poaching Site | 16933.649 | 21505.286 | 169.000 | 81046.000 |
| Total Carcass Found | 53.662 | 73.078 | 1.000 | 329.000 |
| Number of Conflicts | 0.060 | 0.288 | 0.000 | 2.000 |
| GDP Growth Rate | 2.436 | 2.418 | -9.463 | 7.655 |
| N | 151 | | | |
| Number of Countries | 15 | | | |
| Number of Years | 14 | | | |

Note: This table reports the summary statistics for the main variables in the estimation samples underlying Table 1.

Table A5: Robustness: Poaching Elasticity with Respect to Local Prices in Africa

| LHS = Ln(PIKE) | Large Sites (8) | | Large Sites (16) | | One-way Clustering | | Two-way Clustering | | Silver as IV | | Silver and Gold | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| Ln(Median Price) | 0.516 | 0.501 | 0.576 | 0.584 | 0.422 | 0.431 | 0.422 | 0.431 | 0.581 | 0.555 | 0.334 | 0.326 |
| | (0.100) | (0.088) | (0.122) | (0.113) | (0.115) | (0.111) | (0.124) | (0.133) | (0.134) | (0.115) | (0.073) | (0.071) |
| Ln(Total Carcass Found) | -0.027 | | -0.010 | | | -0.016 | | -0.016 | -0.057 | | 0.011 | |
| | (0.060) | | (0.069) | | | (0.065) | | (0.092) | (0.061) | | (0.052) | |
| Number of Conflicts | | -0.275 | | -0.453 | | | | | | -0.210 | | -0.166 |
| | | (0.169) | | (0.267) | | | | | | (0.160) | | (0.160) |
| GDP Growth Rate | | -0.016 | | -0.018 | | | | | | -0.013 | | -0.018 |
| | | (0.020) | | (0.022) | | | | | | (0.019) | | (0.020) |
| Constant | -0.524 | -1.961 | -0.506 | -0.541 | 19.804 | 19.655 | 19.804 | 19.655 | -0.049 | -0.377 | -0.562 | -0.642 |
| | (0.493) | (1.103) | (0.581) | (0.497) | (3.985) | (3.797) | (3.898) | (3.883) | (0.632) | (0.633) | (0.627) | (0.677) |
| | First Stage | | | | | | | | | | | |
| Ln(Gold Price) | 1.168 | 1.227 | 1.181 | 1.196 | 1.260 | 1.226 | 1.260 | 1.226 | | | 2.803 | 2.872 |
| | (0.289) | (0.275) | (0.261) | (0.248) | (0.237) | (0.220) | (0.261) | (0.256) | | | (0.533) | (0.519) |
| Ln(Silver Price) | | | | | | | | | 0.669 | 0.765 | -1.517 | -1.588 |
| | | | | | | | | | (0.287) | (0.287) | (0.469) | (0.473) |
| N | 117 | 117 | 80 | 80 | 151 | 151 | 151 | 151 | 151 | 151 | 151 | 151 |
| First Stage F statistic | 36.586 | 46.232 | 28.702 | 32.825 | 67.768 | 55.455 | 67.768 | 55.455 | 17.195 | 23.454 | 46.473 | 54.526 |
| p-val ($H_0 : \beta == 1$) | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 |
| Site FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Note: The dependent variable is the log of PIKE at the site level. The first four columns restrict the sample to sites with average number of carcass above 8 or 16. Standard errors clustered at the year level with Moulton correction in parentheses for the first four columns. Columns 5 and 6 cluster the standard errors at the year level without using the Moulton correction. Columns 7 and 8 adopt two-way clustering at the site and year level following Cameron et al. (2011). Columns 9 and 10 use silver prices as IV and columns 11 and 12 use both gold and silver prices as IV. Silver prices come from the London Bullion Market. Variable definitions and sources are described in detail in the text.

Table A6: Robustness II: Poaching Elasticity with Respect to Local Prices in Africa

| | PIKE | | $\sinh^{-1}$(PIKE) | | Ln(Poaching) | | $\sinh^{-1}$(Poaching) | | Poaching | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Ln(Median Price) | 0.166 | 0.201 | 0.147 | 0.181 | 0.431 | 0.436 | 0.575 | 0.583 | 12.653 | 12.882 |
| | (0.045) | (0.041) | (0.040) | (0.037) | (0.082) | (0.082) | (0.138) | (0.133) | (4.831) | (4.838) |
| Ln(Total Carcass Found) | 0.049 | | 0.047 | | 0.984 | 0.973 | 0.805 | 0.789 | 11.980 | 11.660 |
| | (0.022) | | (0.019) | | (0.053) | (0.053) | (0.065) | (0.064) | (2.325) | (2.349) |
| Number of Conflicts | | -0.163 | | -0.146 | | -0.196 | | -0.577 | | -12.180 |
| | | (0.067) | | (0.059) | | (0.157) | | (0.191) | | (6.974) |
| GDP Growth Rate | | 0.001 | | 0.001 | | -0.016 | | -0.011 | | 0.006 |
| | | (0.008) | | (0.007) | | (0.018) | | (0.022) | | (0.816) |
| Constant | 0.293 | 0.286 | 0.316 | 0.321 | -0.360 | -0.457 | 1.069 | 0.597 | 3.029 | -7.897 |
| | (0.300) | (0.324) | (0.272) | (0.296) | (0.575) | (0.591) | (0.977) | (0.935) | (33.189) | (33.787) |
| | First Stage | | | | | | | | | |
| Ln(Gold Price) | 0.996 | 1.076 | 0.996 | 1.076 | 1.226 | 1.222 | 0.996 | 0.994 | 0.996 | 0.994 |
| | (0.210) | (0.205) | (0.210) | (0.205) | (0.272) | (0.269) | (0.210) | (0.212) | (0.210) | (0.212) |
| N | 188 | 188 | 188 | 188 | 151 | 151 | 188 | 188 | 188 | 188 |
| First Stage F statistic | 49.078 | 64.176 | 49.078 | 64.176 | 55.455 | 54.542 | 49.078 | 48.462 | 49.078 | 48.462 |
| p-val ($H_0 : \beta == 1$) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | | |
| Site FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Note: Standard errors clustered at the year level with Moulton correction in parentheses in all columns. Column 1 and 2 use the level of PIKE, instead of log of PIKE, as the LHS variable. Column 3 and 4 use the inverse hyperbolic sine transformation of PIKE as the LHS. Column 5 and 6 use the log of, and column 7 and 8 use the inverse hyperbolic sine of the number of poached elephants at the site level as the LHS. The last two columns, column 9 and 10, use the level of poaching at the site level as the LHS. All the specifications, except for column 5 and 6, allow for zeros in PIKE or poaching to be included in the estimation. Variable definitions and sources are described in detail in the text.

Table A7: Robustness: Poaching Elasticity with Respect to Prices in China

| LHS = Ln(PIKE) | Large Sites (8) | | Large Sites (16) | | One-way Clustering | | Two-way Clustering | | Silver as IV | | Silver and Gold | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| Ln(Median Price), China | 0.484 | 0.549 | 0.644 | 0.716 | 0.402 | 0.395 | 0.402 | 0.395 | 0.339 | 0.355 | 0.380 | 0.393 |
| | (0.090) | (0.089) | (0.127) | (0.128) | (0.150) | (0.136) | (0.157) | (0.144) | (0.081) | (0.081) | (0.065) | (0.066) |
| Ln(Total Carcass Found) | 0.037 | | 0.056 | | | 0.010 | | 0.010 | 0.013 | | 0.011 | |
| | (0.034) | | (0.044) | | | (0.031) | | (0.039) | (0.029) | | (0.028) | |
| Number of Conflicts | | -0.080 | | -0.034 | | | | | | 0.002 | | -0.002 |
| | | (0.075) | | (0.118) | | | | | | (0.068) | | (0.067) |
| GDP Growth Rate | | -0.007 | | -0.004 | | | | | | -0.005 | | -0.005 |
| | | (0.006) | | (0.009) | | | | | | (0.005) | | (0.005) |
| Constant | -1.394 | -1.329 | -1.539 | -1.451 | 94.389 | 95.193 | 94.389 | 95.193 | 0.765 | 0.714 | 0.700 | 0.652 |
| | (0.459) | (0.455) | (0.504) | (0.499) | (40.921) | (41.974) | (18.690) | (20.535) | (1.729) | (1.754) | (1.441) | (1.464) |
| First Stage | | | | | | | | | | | | |
| Ln(Gold Price) | 0.833 | 0.799 | 0.805 | 0.775 | 0.869 | 0.911 | 0.869 | 0.911 | | | 0.688 | 0.647 |
| | (0.342) | (0.325) | (0.331) | (0.321) | (0.454) | (0.471) | (0.448) | (0.465) | | | (0.712) | (0.721) |
| Ln(Silver Price) | | | | | | | | | 0.774 | 0.759 | 0.230 | 0.233 |
| | | | | | | | | | (0.325) | (0.319) | (0.651) | (0.670) |
| N | 281 | 281 | 176 | 176 | 422 | 422 | 422 | 422 | 422 | 422 | 422 | 422 |
| First Stage F statistic | 90.327 | 91.510 | 54.732 | 53.369 | 153.899 | 155.102 | 153.899 | 155.102 | 131.036 | 130.142 | 79.349 | 76.989 |
| p-val ($H_0 : \beta == 1$) | 0.000 | 0.000 | 0.006 | 0.028 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Site FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Note: The dependent variable is the log of PIKE at the site level. The first four columns restrict the sample to sites with average number of carcass above 8 or 16. Standard errors clustered at the year level with Moulton correction in parentheses for the first four columns. Columns 5 and 6 cluster the standard errors at the year level without using the Moulton correction. Columns 7 and 8 adopt two-way clustering at the site and year level following Cameron et al. (2011). Columns 9 and 10 use silver prices as IV and columns 11 and 12 use both gold and silver prices as IV. Silver prices come from the London Bullion Market. Variable definitions and sources are described in detail in the text.

Table A8: Robustness II: Poaching Elasticity with Respect to Prices in China

| | PIKE | | $\sinh^{-1}$(PIKE) | | Ln(Poaching) | | $\sinh^{-1}$(Poaching) | | Poaching | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Ln(Median Price), China | 0.217 | 0.268 | 0.190 | 0.239 | 0.395 | 0.398 | 0.550 | 0.556 | 4.945 | 5.570 |
| | (0.033) | (0.034) | (0.029) | (0.030) | (0.066) | (0.066) | (0.086) | (0.087) | (2.160) | (2.188) |
| Ln(Total Carcass Found) | 0.062 | | 0.059 | | 1.010 | 1.012 | 0.900 | 0.903 | 11.481 | 11.553 |
| | (0.013) | | (0.012) | | (0.028) | (0.029) | (0.033) | (0.033) | (0.852) | (0.856) |
| Number of Conflicts | | 0.049 | | 0.044 | | 0.000 | | 0.042 | | -2.991 |
| | | (0.033) | | (0.029) | | (0.067) | | (0.082) | | (2.102) |
| GDP Growth Rate | | -0.002 | | -0.002 | | -0.005 | | -0.006 | | -0.303 |
| | | (0.003) | | (0.002) | | (0.005) | | (0.007) | | (0.177) |
| Constant | 0.617 | 1.227 | 0.573 | 1.031 | 0.678 | 0.703 | 0.290 | 0.290 | -35.277 | -34.584 |
| | (0.159) | (0.664) | (0.141) | (0.604) | (1.437) | (1.470) | (0.418) | (0.416) | (10.345) | (10.346) |
| | First Stage | | | | | | | | | |
| Ln(Gold Price) | 0.858 | 0.828 | 0.858 | 0.828 | 0.911 | 0.922 | 0.858 | 0.867 | 0.858 | 0.867 |
| | (0.327) | (0.317) | (0.327) | (0.317) | (0.345) | (0.349) | (0.327) | (0.334) | (0.327) | (0.334) |
| N | 531 | 528 | 531 | 528 | 422 | 422 | 531 | 528 | 531 | 528 |
| First Stage F statistic | 200.855 | 198.669 | 200.855 | 198.669 | 155.102 | 152.438 | 200.855 | 194.060 | 200.855 | 194.060 |
| p-val ($H_0 : \beta == 1$) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | | |
| Site FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Note: Standard errors clustered at the year level with Moulton correction in parentheses in all columns. Column 1 and 2 use the level of PIKE, instead of log of PIKE, as the LHS variable. Column 3 and 4 use the inverse hyperbolic sine transformation of PIKE as the LHS. Column 5 and 6 use the log of, and column 7 and 8 use the inverse hyperbolic sine of the number of poached elephants at the site level as the LHS. The last two columns, column 9 and 10, use the level of poaching at the site level as the LHS. All the specifications, except for column 5 and 6, allow for zeros in PIKE or poaching to be included in the estimation. Variable definitions and sources are described in detail in the text.

Table A9: Robustness Checks: Time Controls

| LHS = Ln(PIKE) | Africa Price | | | | | | China Price | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| Ln(Median Price) | -0.331 | -0.299 | -0.332 | -0.299 | -1.303 | -0.994 | 0.219 | 0.222 | 0.219 | 0.222 | -0.302 | -0.289 |
| | (0.198) | (0.191) | (0.199) | (0.192) | (0.641) | (0.518) | (0.084) | (0.085) | (0.084) | (0.085) | (0.154) | (0.154) |
| Ln(Total Carcass Found) | -0.010 | | -0.011 | | -0.130 | | -0.006 | | -0.006 | | -0.016 | |
| | (0.052) | | (0.052) | | (0.087) | | (0.029) | | (0.029) | | (0.029) | |
| Number of Conflicts | | -0.049 | | -0.049 | | 0.158 | | -0.023 | | -0.023 | | -0.033 |
| | | (0.158) | | (0.158) | | (0.209) | | (0.068) | | (0.068) | | (0.068) |
| GDP Growth Rate | | -0.034 | | -0.034 | | -0.064 | | -0.004 | | -0.004 | | -0.003 |
| | | (0.019) | | (0.019) | | (0.027) | | (0.005) | | (0.005) | | (0.005) |
| Year | 0.136 | 0.129 | | | -92.253 | -69.707 | 0.022 | 0.022 | | | 56.854 | 55.392 |
| | (0.044) | (0.042) | | | (50.788) | (41.329) | (0.009) | (0.009) | | | (23.271) | (23.324) |
| Year$^2$ | | | 0.000 | 0.000 | 0.023 | 0.017 | | | 0.000 | 0.000 | -0.014 | -0.014 |
| | | | (0.000) | (0.000) | (0.013) | (0.010) | | | (0.000) | (0.000) | (0.006) | (0.006) |
| Constant | -275.416 | -260.772 | -138.591 | -131.176 | 92285.413 | 69721.267 | -42.943 | -43.022 | -21.159 | -21.227 | -57164.310 | -55695.190 |
| | (88.578) | (83.838) | (44.468) | (42.070) | (50865.449) | (41399.467) | (18.434) | (18.119) | (9.303) | (9.153) | (23384.532) | (23437.319) |
| | First Stage | | | | | | First Stage | | | | | |
| Ln(Gold Price) | -1.134 | -1.172 | -1.131 | -1.169 | -0.539 | -0.634 | 1.347 | 1.321 | 1.348 | 1.322 | -1.266 | -1.244 |
| | (0.339) | (0.319) | (0.338) | (0.318) | (0.498) | (0.431) | (0.637) | (0.638) | (0.636) | (0.638) | (0.720) | (0.708) |
| N | 151 | 151 | 151 | 151 | 151 | 151 | 422 | 422 | 422 | 422 | 422 | 422 |
| First Stage F statistic | 16.309 | 17.624 | 16.260 | 17.577 | 1.584 | 2.447 | 99.587 | 95.268 | 99.982 | 95.657 | 61.253 | 60.925 |
| p-val ($H_0 : \beta == 1$) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Site FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Note: Standard errors clustered at the year level with Moulton correction in parentheses in all columns. Column 1 - 6 use African prices and Columns 7 - 12 use Chinese prices. Variable definitions and sources are described in detail in the text.

Table A10: Distribution of price data over various characteristics

| | No. | % |
|---|---|---|
| **ANIMAL SPECIES** | | |
| African Elephant | 4,416 | 90.6% |
| Asian Elephant | 241 | 4.9% |
| Unknown | 116 | 2.4% |
| Mammoth | 100 | 2.1% |
| **Total** | 4,873 | 100.0% |
| **PLACE IN VALUE CHAIN** | | |
| Importer | 1,610 | 33.0% |
| Middleman - Local | 1,318 | 27.0% |
| Exporter | 351 | 7.2% |
| Carver - Consumer | 347 | 7.1% |
| Carver - Local | 320 | 6.6% |
| Retailer | 312 | 6.4% |
| Wholesaler | 189 | 3.9% |
| Government Sale/Auction | 170 | 3.5% |
| Poacher | 144 | 3.0% |
| Middleman - Consumer | 106 | 2.2% |
| Unknown | 6 | 0.1% |
| **Total** | 4,873 | 100.0% |
| **SOURCE OF INFORMATION** | | |
| Customs or Tax Declaration | 1,581 | 32.4% |
| Government Valuation | 1,315 | 27.0% |
| Market/Field Survey Price | 1,239 | 25.4% |
| Actual Transaction | 397 | 8.1% |
| Expert Opinion | 202 | 4.1% |
| Informant | 90 | 1.8% |
| Internet | 45 | 0.9% |
| Unknown | 4 | 0.1% |
| **Total** | 4,873 | 100.0% |
| **TYPE OR NATURE OF THE PRICE** | | |
| Average price | 1,978 | 40.6% |
| Other price | 1,377 | 28.3% |
| Final price | 752 | 15.4% |
| Minimum price | 287 | 5.9% |
| Maximum price | 281 | 5.8% |
| Fixed price | 81 | 1.7% |
| Starting price | 55 | 1.1% |
| Observed price | 35 | 0.7% |
| Unknown | 27 | 0.6% |
| **Total** | 4,873 | 100.0% |

Source: TRAFFIC and World Bank.

Table A11: Distribution of price data over continents and time

| Year | Location, Continents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Africa** | | **Asia** | | **Europe** | | **North America** | | **Other** | | **Total** | |
| | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % |
| pre 1989 | 476 | 20.5% | 1,183 | 64.0% | 286 | 47.0% | 16 | 20.3% | 14 | 70.0% | 1,975 | 40.5% |
| 1989 | 82 | 3.5% | 72 | 3.9% | 12 | 2.0% | 2 | 2.5% | 1 | 5.0% | 169 | 3.5% |
| 1990 | 10 | 0.4% | 25 | 1.4% | 0 | 0.0% | 6 | 7.6% | 0 | 0.0% | 41 | 0.8% |
| 1991 | 29 | 1.3% | 11 | 0.6% | 4 | 0.7% | 0 | 0.0% | 0 | 0.0% | 44 | 0.9% |
| 1992 | 3 | 0.1% | 16 | 0.9% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 19 | 0.4% |
| 1993 | 15 | 0.6% | 11 | 0.6% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 26 | 0.5% |
| 1994 | 20 | 0.9% | 16 | 0.9% | 1 | 0.2% | 0 | 0.0% | 0 | 0.0% | 37 | 0.8% |
| 1995 | 26 | 1.1% | 15 | 0.8% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 41 | 0.8% |
| 1996 | 7 | 0.3% | 9 | 0.5% | 0 | 0.0% | 1 | 1.3% | 0 | 0.0% | 17 | 0.3% |
| 1997 | 49 | 2.1% | 6 | 0.3% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 55 | 1.1% |
| 1998 | 59 | 2.5% | 17 | 0.9% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 76 | 1.6% |
| 1999 | 320 | 13.8% | 14 | 0.8% | 10 | 1.6% | 0 | 0.0% | 2 | 10.0% | 346 | 7.1% |
| 2000 | 42 | 1.8% | 32 | 1.7% | 11 | 1.8% | 4 | 5.1% | 0 | 0.0% | 89 | 1.8% |
| 2001 | 40 | 1.7% | 145 | 7.9% | 12 | 2.0% | 0 | 0.0% | 0 | 0.0% | 197 | 4.0% |
| 2002 | 60 | 2.6% | 84 | 4.5% | 4 | 0.7% | 4 | 5.1% | 0 | 0.0% | 152 | 3.1% |
| 2003 | 54 | 2.3% | 14 | 0.8% | 15 | 2.5% | 0 | 0.0% | 0 | 0.0% | 83 | 1.7% |
| 2004 | 43 | 1.9% | 10 | 0.5% | 33 | 5.4% | 3 | 3.8% | 0 | 0.0% | 89 | 1.8% |
| 2005 | 90 | 3.9% | 0 | 0.0% | 18 | 3.0% | 4 | 5.1% | 0 | 0.0% | 112 | 2.3% |
| 2006 | 122 | 5.3% | 10 | 0.5% | 15 | 2.5% | 38 | 48.1% | 0 | 0.0% | 185 | 3.8% |
| 2007 | 75 | 3.2% | 5 | 0.3% | 9 | 1.5% | 0 | 0.0% | 0 | 0.0% | 89 | 1.8% |
| 2008 | 68 | 2.9% | 35 | 1.9% | 1 | 0.2% | 0 | 0.0% | 1 | 5.0% | 105 | 2.2% |
| 2009 | 134 | 5.8% | 11 | 0.6% | 5 | 0.8% | 0 | 0.0% | 0 | 0.0% | 150 | 3.1% |
| 2010 | 102 | 4.4% | 34 | 1.8% | 3 | 0.5% | 0 | 0.0% | 0 | 0.0% | 139 | 2.9% |
| 2011 | 81 | 3.5% | 15 | 0.8% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 96 | 2.0% |
| 2012 | 143 | 6.2% | 6 | 0.3% | 23 | 3.8% | 0 | 0.0% | 0 | 0.0% | 172 | 3.5% |
| 2013 | 128 | 5.5% | 8 | 0.4% | 14 | 2.3% | 0 | 0.0% | 0 | 0.0% | 150 | 3.1% |
| 2014 | 38 | 1.6% | 40 | 2.2% | 107 | 17.6% | 0 | 0.0% | 0 | 0.0% | 185 | 3.8% |
| 2015 | 3 | 0.1% | 3 | 0.2% | 25 | 4.1% | 1 | 1.3% | 2 | 10.0% | 34 | 0.7% |
| **Total** | 2,319 | 100.0% | 1,847 | 100.0% | 608 | 100.0% | 79 | 100.0% | 20 | 100.0% | 4,873 | 100.0% |

Source: TRAFFIC and World Bank.

## Table A12: Basic analysis of prices, all data

| | Full Sample | | | | With Weight | | | | SSA | China |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) All Years | (2) All Years | (3) Pre-1989 | (4) Post-1989 | (5) All Years | (6) All Years | (7) Pre-1989 | (8) Post-1989 | (9) All Years | (10) All Years |
| Year | | 0.031 | 0.038 | 0.040 | | 0.015 | 0.050 | 0.029 | | |
| | | (0.00) | (0.01) | (0.00) | | (0.00) | (0.01) | (0.00) | | |
| Weight | | | | | 0.090 | 0.096 | 0.054 | 0.134 | | |
| | | | | | (0.02) | (0.02) | (0.02) | (0.02) | | |
| **Value Chain** | | | | | | | | | | |
| Carver - Local | -0.241 | -0.222 | 0.207 | -0.182 | -0.096 | -0.074 | 0.489 | -0.093 | 0.002 | |
| | (0.08) | (0.08) | (0.20) | (0.09) | (0.07) | (0.07) | (0.29) | (0.07) | (0.18) | |
| Exporter | 0.010 | 0.241 | 0.570 | 0.051 | 0.398 | 0.453 | 1.361 | 0.114 | 0.573 | -0.840 |
| | (0.09) | (0.10) | (0.17) | (0.12) | (0.18) | (0.19) | (0.31) | (0.24) | (0.21) | (0.21) |
| Government Sale/Auction | 0.107 | 0.068 | 0.520 | -0.265 | -0.185 | -0.202 | 0.742 | -0.511 | 0.523 | |
| | (0.11) | (0.10) | (0.23) | (0.17) | (0.22) | (0.22) | (0.36) | (0.26) | (0.25) | |
| Importer | -0.220 | 0.027 | 0.105 | -0.045 | -0.810 | -0.649 | -0.176 | -0.684 | 0.290 | -0.914 |
| | (0.08) | (0.08) | (0.15) | (0.13) | (0.12) | (0.11) | (0.21) | (0.16) | (0.23) | (0.16) |
| Middleman - Consumer | -0.165 | -0.245 | -0.911 | -0.207 | 0.288 | 0.239 | -1.935 | 0.134 | | 0.118 |
| | (0.12) | (0.12) | (0.33) | (0.13) | (0.11) | (0.11) | (0.36) | (0.12) | | (0.18) |
| Middleman - Local | -0.331 | -0.386 | 0.549 | -0.396 | -0.057 | -0.062 | 0.489 | -0.081 | -0.040 | 0.861 |
| | (0.09) | (0.10) | (0.17) | (0.12) | (0.09) | (0.09) | (0.44) | (0.08) | (0.18) | (1.00) |
| Poacher | -1.067 | -1.095 | -0.536 | -0.975 | -1.066 | -1.186 | | -1.206 | -0.879 | |
| | (0.10) | (0.11) | (0.28) | (0.12) | (0.13) | (0.12) | | (0.12) | (0.19) | |
| Retailer | 0.015 | -0.249 | 0.438 | 0.053 | 0.272 | 0.079 | | 0.024 | 0.365 | 0.361 |
| | (0.10) | (0.10) | (0.29) | (0.09) | (0.10) | (0.11) | | (0.11) | (0.22) | (0.27) |
| Unknown | 0.097 | 0.056 | -0.755 | 1.210 | 0.435 | 0.379 | 0.000 | 0.275 | 0.094 | |
| | (0.48) | (0.40) | (0.53) | (0.36) | (0.16) | (0.15) | (.) | (0.16) | (0.51) | |
| Wholesaler | 0.011 | -0.114 | 0.541 | -0.146 | 0.283 | 0.225 | -1.354 | 0.151 | -0.004 | 0.115 |
| | (0.09) | (0.09) | (0.24) | (0.10) | (0.08) | (0.08) | (0.34) | (0.08) | (0.31) | (0.17) |
| **Source of Info.** | | | | | | | | | | |
| Customs or Tax Declaration | -0.205 | -0.160 | -0.242 | 0.440 | -0.141 | -0.171 | -0.059 | 0.855 | -0.356 | -0.553 |
| | (0.08) | (0.07) | (0.09) | (0.14) | (0.11) | (0.11) | (0.20) | (0.23) | (0.12) | (0.24) |
| Expert Opinion | 0.501 | 0.701 | 0.681 | -0.153 | | | | | 0.257 | 0.131 |
| | (0.11) | (0.12) | (0.13) | (0.31) | | | | | (0.16) | (0.56) |
| Government Valuation | 0.201 | 0.051 | -0.435 | -0.982 | 0.075 | 0.027 | -0.157 | -0.132 | 0.288 | 1.599 |
| | (0.13) | (0.13) | (0.14) | (0.22) | (0.25) | (0.26) | (0.22) | (0.37) | (0.19) | (0.34) |
| Informant | 0.037 | 0.050 | 0.411 | -0.456 | -0.165 | -0.228 | 0.837 | -0.558 | 0.280 | -0.235 |
| | (0.18) | (0.18) | (0.24) | (0.29) | (0.20) | (0.20) | (0.33) | (0.15) | (0.20) | (0.42) |
| Internet | 0.986 | 0.758 | | 0.446 | 0.605 | 0.477 | | 0.172 | | 0.620 |
| | (0.28) | (0.30) | | (0.29) | (0.24) | (0.24) | | (0.21) | | (0.39) |
| Market/Field Survey Price | 0.022 | -0.011 | 0.069 | -0.270 | -0.196 | -0.242 | 0.833 | -0.484 | -0.241 | -0.522 |
| | (0.09) | (0.09) | (0.17) | (0.12) | (0.16) | (0.16) | (0.27) | (0.14) | (0.16) | (0.23) |
| **Price Type** | | | | | | | | | | |
| Final price | 0.276 | 0.122 | 0.311 | -0.108 | 0.589 | 0.489 | 0.760 | 0.159 | 0.263 | 0.417 |
| | (0.04) | (0.04) | (0.04) | (0.12) | (0.16) | (0.16) | (0.20) | (0.16) | (0.16) | (0.13) |
| Fixed price | -0.064 | -0.028 | 0.283 | -0.030 | -0.034 | -0.008 | 0.148 | -0.137 | -0.444 | 1.574 |
| | (0.12) | (0.13) | (0.13) | (0.17) | (0.15) | (0.15) | (0.15) | (0.16) | (0.18) | (0.42) |
| Maximum price | 0.210 | 0.136 | -0.552 | 0.141 | 0.154 | 0.118 | -0.192 | 0.088 | 0.207 | 0.256 |
| | (0.05) | (0.05) | (0.16) | (0.06) | (0.06) | (0.06) | (0.16) | (0.05) | (0.10) | (0.15) |
| Minimum price | -0.237 | -0.305 | -0.869 | -0.308 | -0.241 | -0.278 | -0.447 | -0.312 | -0.152 | -0.218 |
| | (0.06) | (0.06) | (0.17) | (0.06) | (0.07) | (0.06) | (0.14) | (0.06) | (0.10) | (0.15) |
| Observed price | -0.260 | -0.428 | | -0.460 | 0.728 | 0.673 | | 0.593 | | |
| | (0.47) | (0.49) | | (0.51) | (0.23) | (0.24) | | (0.24) | | |
| Other price | 0.300 | 0.087 | -0.421 | 1.106 | 0.656 | 0.564 | | 0.311 | 0.009 | 0.000 |
| | (0.10) | (0.10) | (0.11) | (0.18) | (0.19) | (0.20) | | (0.36) | (0.14) | (.) |
| Starting price | 0.287 | 0.123 | 0.361 | 0.077 | 0.020 | -0.017 | | -0.113 | 0.180 | 0.982 |
| | (0.15) | (0.15) | (0.22) | (0.16) | (0.12) | (0.12) | | (0.12) | (0.28) | (0.21) |
| **Species** | | | | | | | | | | |
| Asian Elephant | 0.547 | 0.401 | 0.043 | 0.336 | 0.666 | 0.580 | 0.000 | 0.603 | | -0.055 |
| | (0.12) | (0.12) | (0.21) | (0.15) | (0.16) | (0.15) | (.) | (0.15) | | (0.82) |
| Mammoth | -0.382 | -0.626 | -2.290 | -0.338 | 0.541 | 0.367 | | 0.086 | | -0.368 |
| | (0.14) | (0.13) | (0.66) | (0.16) | (0.72) | (0.69) | | (0.64) | | (0.14) |
| African Elephant | | | | | | | | | 0.000 | |
| | | | | | | | | | (.) | |
| Constant | 4.126 | -58.566 | -70.465 | -75.217 | 4.127 | -25.052 | -96.344 | -54.750 | 3.483 | 5.505 |
| | (0.08) | (5.18) | (11.64) | (7.87) | (0.15) | (6.12) | (24.75) | (7.74) | (0.23) | (0.25) |
| N | 4707 | 4707 | 1943 | 2764 | 1476 | 1476 | 459 | 1017 | 2250 | 472 |
| R-squared | 0.481 | 0.501 | 0.360 | 0.624 | 0.723 | 0.730 | 0.631 | 0.812 | 0.137 | 0.470 |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No |

Note: Robust standard errors in parentheses. The dependent variable is the observed price of raw ivory tusks, deflated by CPI.