The Price Elasticity of African Elephant Poaching*

Quy-Toan Do, Andrei A. Levchenko, Lin Ma,
Julian Blanc and Tom Milliken†

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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 briefly discuss what an inelastic supply implies for elephant conservation policies.

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

JEL Codes: K42, O12

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†Do: Research Department, World Bank (e-mail: qdo@worldbank.org); Levchenko: Economics Department, University of Michigan, NBER and CEPR (e-mail: alev@umich.edu); Ma: Economics Department, National University of Singapore (e-mail: ecsml@nus.edu.sg); Blanc: UNEP (e-mail: Julian.Blanc@unep.org); Milliken: TRAFFIC (e-mail: tom.milliken@traffic.org)

1 Introduction

The surge in elephant poaching in the past decade has led to a dramatic decline in 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). To inform the debate on conservation policy, we therefore undertake the estimation of one key elasticity, the price elasticity of poached ivory supply. 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. Our finding highlights the challenges associated with interventions that act primarily to suppress demand, such as a ban on trade in elephant ivory. 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.

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 to date, and the first to enable the formal estimation of a key elasticity in the market for ivory.

[1] `https://obamawhitehouse.archives.gov/the-press-office/2015/09/25/fact-sheet-president-xi-jinpings-state-visit-united-states`.

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, 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. Under competitive speculation ivory prices follow the Hotelling no-arbitrage condition (Kremer and Morcom, 2000). Intuitively, agents must be indifferent in expectation between selling ivory today and earning the expected interest rate between today and tomorrow, and holding on to the ivory until tomorrow and selling it then. Thus, the expected increase in the price of ivory (net of storage costs) must be the same as the expected interest rate over the same period. Gold is another store of value that follows the same no-arbitrage condition. Thus, the gold price is a valid instrument for ivory prices under the assumption that shocks to the supply of poached ivory are too small to affect gold prices.

Second, 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 both 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 small sample size of only 13 observations.

Third, 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.

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. We find that the OLS estimates are potentially biased downward. The 2SLS estimates using gold prices as instruments are larger than their OLS counterparts. The downward bias in the OLS coefficients can be due to measurement error or the unobserved increased intensity of law enforcement. Our preferred 2SLS estimates put the poaching elasticity at roughly 0.4 with respect to either local or Chinese prices.

We believe our finding 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 (Bulte et al., 2003, 2007; Mason et al., 2012; Wasser et al., 2010).

Taylor (2011) presents evidence consistent with a price-elastic supply 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 the international prices for bison hides remained largely unchanged despite a sharp increase in demand. In lieu of a dramatic increase in prices, an elastic supply led to the animal being slaughtered en masse. The experience of the African elephant contrasts sharply with that of the North American bison. The difference in price elasticities of supply might be one explanation. An inelastic supply might have "protected" the African elephant from irreversible decimation as ivory prices kept growing. By the same token, a low supply elasticity will also limit the efficacy of the policy instruments intended to suppress demand.

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

The rest of the paper is organized as follows. Section 2 provides a description of the data used in the analysis. Section 3 lays out the model and the empirical methodology. Results are discussed in Section 4, and Section 5 concludes.

2 Data

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

2.1 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 is discussed below. We highlight three 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. Second, the China price series suggests that the price of ivory has been experiencing constant growth 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. And third, 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.[2]

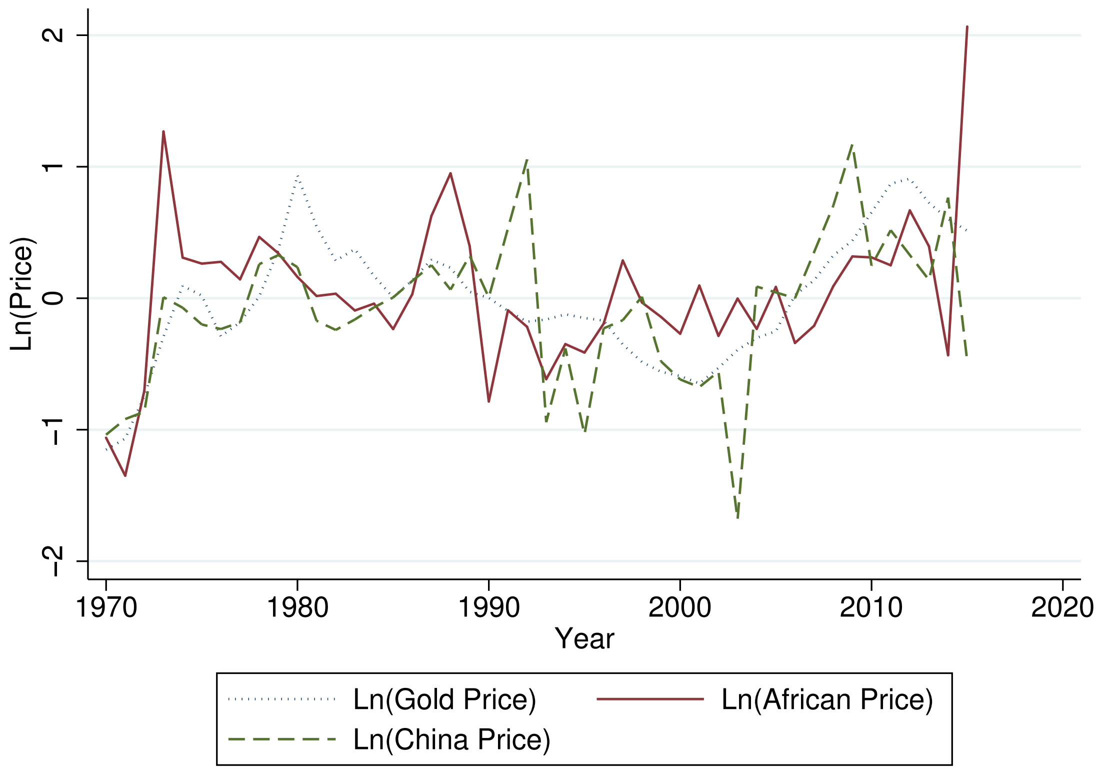

Figure 1: Gold and Ivory Prices

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 filtered price.

2.2 Poaching statistics

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). From the data, a variable labeled PIKE, proportion of illegally killed elephants, is constructed by calculating the ratio of the number of carcasses classified as illegally killed to total number of

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

carcasses encountered at each site.[3] The continental series indicates that PIKE has crossed the 0.5 mark in 2010 (CITES et al., 2013) and have remained above ever since (CITES, 2016). CITES considers poaching levels above that 0.5 cutoff "are cause of concern" (CITES, 2016).[4]

2.3 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 be using commodity prices, namely gold, as instruments for ivory prices. To that end, we use the London fix 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.[5] 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 *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.

3 Empirical methodology

We assume a competitive market for the illegal harvesting of elephants, where poachers live for one period and have quasi-linear utility. 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 utility

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

[3] Burn et al. (2011) discuss the validity of PIKE as an unbiased measure of poaching. Burn et al. (2011), CITES (2012), and CITES et al. (2013) provide a detailed description of the data and analyze the local, national, and global covariates of PIKE.

[4] 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.

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

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 Θ_{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 Θ_{sct} into a constant α, site fixed effects η_{sc}, and observable and unobservable time-varying site characteristics Z_{sct} and ε_{sct}, respectively, we obtain supply equation

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

Our parameter of interest is β, the poaching elasticity with respect to price. The simple 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 β we need to find a demand shifter that does not simultaneously affect supply.

In the case of ivory, the problem is further complicated by the fact that ivory is a storable commodity. Thus, demand from end-consumers and supply from poachers need not equalize in every period. 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.[6]

Denote by P_t and r_t the global price of raw ivory and the interest rate in year t, respectively. Assuming that traders are risk-neutral profit-maximizers and that there is free entry into the storage market, the Hotelling condition holds as long as storage levels are strictly positive:

$$E_t[(1 - \pi_{t+1})P_{t+1}] = E_t[(1 + r_{t+1})]P_t, \tag{5}$$

where π_{t+1} is the probability of seizure faced by the trader between t and $t+1$. 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 $E_t[(1 - \pi_{t+1})P_{t+1}]$ in expectation

[6] 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.

in the next period. If they instead sell today at price P_t, they earn an expected gross return $E_t(1 + r_{t+1})$.

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) provide a detailed theoretical analysis of ivory markets. Assuming that $Cov(\pi_t, P_t) = 0$, p_t (the logarithm of P_t) can then be assumed to follow a random walk with drift of the form

$$p_{t+1} - p_t = r_{t+1} + \pi_{t+1} + u_{t+1} + v_{t+1}, \tag{6}$$

where u_{t+1} and v_{t+1} are shocks to both current and future demand and supply of ivory, respectively, and r_{t+1} and π_{t+1} are year $t + 1$ realizations of interest and seizure rates, respectively. We assume that $E_t(u_t) = E_t(v_t) = 0$, $E_t(r_{t+1}) = r_t$, $E_t(\pi_{t+1}) = \pi_t$, and $Cov(u, v) = Cov(u, r) = Cov(u, \pi) = 0$.[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.

Gold prices as instruments for ivory prices Ivory is used as a store of value. Other assets such as gold are similarly used as stores and (log) gold prices p_t^g follow the same Hotelling condition, which we write

$$p_{t+1}^g - p_t^g = r_t - z_t, \tag{7}$$

where z_t are (demand and supply) shocks to the gold market, which we assume satisfy $E(z_t) = 0$. Plugging into (6) yields

$$p_t - p_{t-1} = p_t^g - p_{t-1}^g + \pi_t + z_t + u_t + v_t. \tag{8}$$

Our exclusion restriction therefore postulates that gold prices are not correlated with poached ivory supply shocks, or $Cov(z, v) = 0$. In other words, the gold market is assumed to be

[7] Equation (6) describes the world market for ivory, and thus the supply shock v_{t+1} should be thought of as a world shock. It is an aggregate of the site-level supply shocks ε_{sct+1} defined in (4) as well as any other supply-side disturbances in the world ivory market.

sufficiently large relative to the ivory market for shocks to the latter not to affect the former.[8]

From global to local prices Finally, to use gold prices as instruments for local prices, we need to specify the relationship between global prices p_t and local prices p_{ct}. We assume that:

$$p_{ct} = \theta p_t - \delta_{ct}. \tag{9}$$

The local price is thus a function of the global price with pass-through θ, while δ_{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

$$y_{sct} = \alpha + \tilde{\beta} p_t + Z_{sct} \cdot \gamma + \eta_{sc} + \tilde{\varepsilon}_{sct}, \tag{10}$$

with $\tilde{\beta} = \beta \cdot \theta$ and $\tilde{\varepsilon}_{sct} = \varepsilon_{sct} - \beta\tilde{\delta}_{ct}$, where $\tilde{\delta}_{ct}$ is the component of δ_{ct} not absorbed by site fixed effects and parametric regressors. Equations (4) and (10) can be estimated to assess the poaching elasticity with respect to ivory prices in Africa and China, respectively, instrumenting prices with gold prices. We will also consider commodities such as silver to test the robustness of our results to alternative choices of instruments.

4 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, and the discontinuity is rooted in both the poaching data and the price data. Appendix Tables A1 and A2 summarize the patterns of availability for both data sources. At the site level, only 9 out of 77 sites have complete coverage between 2002 and 2015, and the median site has only 9 out of 14 years of data available. At the country level, no country has a complete coverage of data. The longest continuous coverage for any country is only 19 years out of 46

[8] The exclusion restriction would also be violated if, for example, a surge in the price of gold and other minerals would increase labor demand in mining, creating a shortage of would-be poachers. To look into this issue, we use data on mining extraction from Berman et al. (2017) and find that the geographical overlap between the elephant range and mines is negligible. There is furthermore only one MIKE site with active mining, located in South Africa (see Figure A1 in the online Appendix). Our estimates are robust to dropping that single MIKE site; estimates and additional details available upon request.

years of data, and the median country only has 12 non-continuous years of data.

4.1 Stationarity and co-integration of price and quantity variables

A prediction of the storage model is that prices are not stationary. The data have too many gap years that do not coincide to allow for estimation in first differences. However, non-stationarity of the instrument and the variables being instrumented is not a challenge to the estimation strategy. Indeed, Phillips and Hansen (1990) show that the IV estimate is consistent even when both of those variables are non-stationary.

To explore the features of the data, 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.[9] 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.

In addition, we test for co-integration of the variables of interest. The lower panel of Appendix Table A3 report 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 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

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

reject the null of *no co-integration*.

4.2 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). As discussed earlier, our main outcome variable, y_{sct}, is measured by $\ln(PIKE_{sct})$, the (logarithm of) the Proportion of Illegally-Killed Elephants 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 furthermore adopt the parametric Moulton (1986) correction factor. We also implement alternative clustering approaches – without Moulton correction and two-way (year and country) clustering – 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 0.237. Controlling for the total number of carcasses found at a given site in a given year and site fixed effects, the estimated elasticity is statistically significant at the 1 percent level with a point estimate of 0.178 (column 2). 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 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.

Admittedly, OLS might be biased downward: 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. 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. Graphically, Figure 1 hints at a high degree of co-movement between ivory prices, both in Africa and China, and gold prices, suggesting strong first stages. The first stage results are displayed in the lower panel of Table 1 columns 5-8 and consistently indicate that the

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

LHS = Ln(Poaching)	OLS				2SLS, IV = Gold Price			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ln(Median Price)	0.237	0.178	0.180	0.165	0.431	0.436	0.637	-0.301
	(0.137)	(0.053)	(0.054)	(0.109)	(0.082)	(0.082)	(0.148)	(0.193)
Ln(Total Carcass Found)		1.053	1.046	1.080	0.984	0.973	1.124	0.980
		(0.052)	(0.053)	(0.064)	(0.053)	(0.053)	(0.060)	(0.053)
Number of Conflicts			-0.123	-0.187		-0.196	-0.350	-0.055
			(0.166)	(0.179)		(0.157)	(0.168)	(0.159)
GDP Growth Rate			-0.019	-0.002		-0.016	0.009	-0.035
			(0.022)	(0.022)		(0.018)	(0.019)	(0.019)
Total Seizure				0.014			-0.114	
				(0.054)			(0.058)	
Year								0.132
								(0.043)
Constant	2.228	-0.885	-0.910	-1.089	-0.360	-0.457	0.488	-265.697
	(0.146)	(0.733)	(0.798)	(0.868)	(0.575)	(0.591)	(0.412)	(86.649)
					First Stage			
Ln(Gold Price)					1.226	1.222	0.818	-1.167
					(0.272)	(0.269)	(0.132)	(0.325)
N	151	151	151	114	151	151	114	151
First Stage F statistic					55.455	54.542	54.132	17.338
Site FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean, Ln(Poaching)	2.251	2.251	2.251	2.067	2.251	2.251	2.067	2.251
SD, Ln(Poaching)	1.494	1.494	1.494	1.478	1.494	1.494	1.478	1.494

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

instrument is particularly strong with a partial F-statistic always above 50. The upper panel reports the second stage estimates, with column 5-7 mirroring the specifications adopted in the OLS regressions in columns 2-4. In our preferred specifications (columns 5-6), the 2SLS estimates suggest a poaching elasticity with respect to price of around 0.44. The estimates are statistically significant at the 1 percent level. The 2SLS coefficient is markedly higher than the OLS one, which might be due to measurement error but also OLS being potentially biased downward as discussed above. In addition, column 8 indicates that once a time trend is accounted for, prices no longer have any predicting power on poaching rates. However, the omission of the time trend by itself does not bias the 2SLS estimation of the elasticity.

A 0.44 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 4.4 percent decrease in poaching. A more concrete way to interpret this elasticity would be to consider an increase in law enforcement intensity. Although we do not have any information on the probability of apprehension faced by poachers, the elasticity of illegal elephant killing with respect to price tells us how, say, a doubling of such probability would affect poaching. Assuming that (i) poachers are risk-neutral, (ii) when a poacher is caught, he only loses the value of the ivory, and (iii) the demand for illegal ivory is perfectly price-elastic, then doubling apprehension probabilities is akin to dividing the price of ivory by two. A 0.44 poaching elasticity with respect to price implies that poaching will drop by 26 percent. Starting from a 0.63 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.

Appendix Table A5 assesses robustness of the results. We first repeat the estimation while restricting the sample to "large" sites, i.e. the sites that report at least 8 or 12 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 (column 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. While each method produces different standard errors, the elasticities remain precisely measured.

Lastly we 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. The results are essentially the same.

4.3 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 θ by estimating equation (9). 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 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.[10] 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.

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

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

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 9 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.

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. Note that, as opposed to Table 1, column 8 indicates that after controlling for a linear time trend, the elasticity is still measured with precision (though the point estimate drops to 0.22). 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 (Table 2, column 6) we get $0.436 \times 0.900 = 0.392$, roughly equal to the 0.398 measured elasticity with respect to global prices. Appendix Table A6 checks robustness of the results in a similar fashion as we did for the estimation of the elasticity with respect to African 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.

Table 3: Poaching Elasticity with Respect to Prices in China

LHS = Ln(Poaching)	OLS				2SLS, IV = Gold Price			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ln(Median Price), China	0.202	0.129	0.129	0.159	0.395	0.398	0.327	0.224
	(0.166)	(0.050)	(0.050)	(0.053)	(0.066)	(0.066)	(0.067)	(0.084)
Ln(Total Carcass Found)		1.027	1.030	1.063	1.010	1.012	1.052	0.994
		(0.029)	(0.029)	(0.042)	(0.028)	(0.029)	(0.041)	(0.030)
Number of Conflicts			0.031	-0.032		0.000	-0.088	-0.025
			(0.069)	(0.106)		(0.067)	(0.105)	(0.069)
GDP Growth Rate			-0.003	0.008		-0.005	0.006	-0.004
			(0.005)	(0.008)		(0.005)	(0.008)	(0.005)
Total Seizure				0.019			-0.011	
				(0.047)			(0.046)	
Year								0.022
								(0.009)
Constant	1.870	1.086	1.235	-0.245	0.678	0.703	-0.191	-43.746
	(0.117)	(2.093)	(2.124)	(0.498)	(1.437)	(1.470)	(0.397)	(18.884)
					First Stage			
Ln(Gold Price)					0.911	0.922	1.179	1.344
					(0.345)	(0.349)	(0.435)	(0.636)
N	422	422	422	248	422	422	248	422
First Stage F statistic					155.102	152.438	142.073	98.212
Site FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean, Ln(Poaching)	1.910	1.910	1.910	1.795	1.910	1.910	1.795	1.910
SD, Ln(Poaching)	1.385	1.385	1.385	1.383	1.385	1.385	1.383	1.385

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 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.

5 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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Online Appendix
(Not for publication)

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."[11] 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 A7 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 is "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 A8 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.

[11] `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. Table A9 summarizes this variation by regressing the logarithm of the price on the various characteristics described above. All the specifications control for country fixed effects. 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.[12] In other words, 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 do not partial out country fixed effects and time trend. 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” and those from Chinese sample as “China prices” or “international prices.” Columns 9-10 in Table A9 report the regressions on which the partialling-out is based.

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

B Additional Figures and Tables

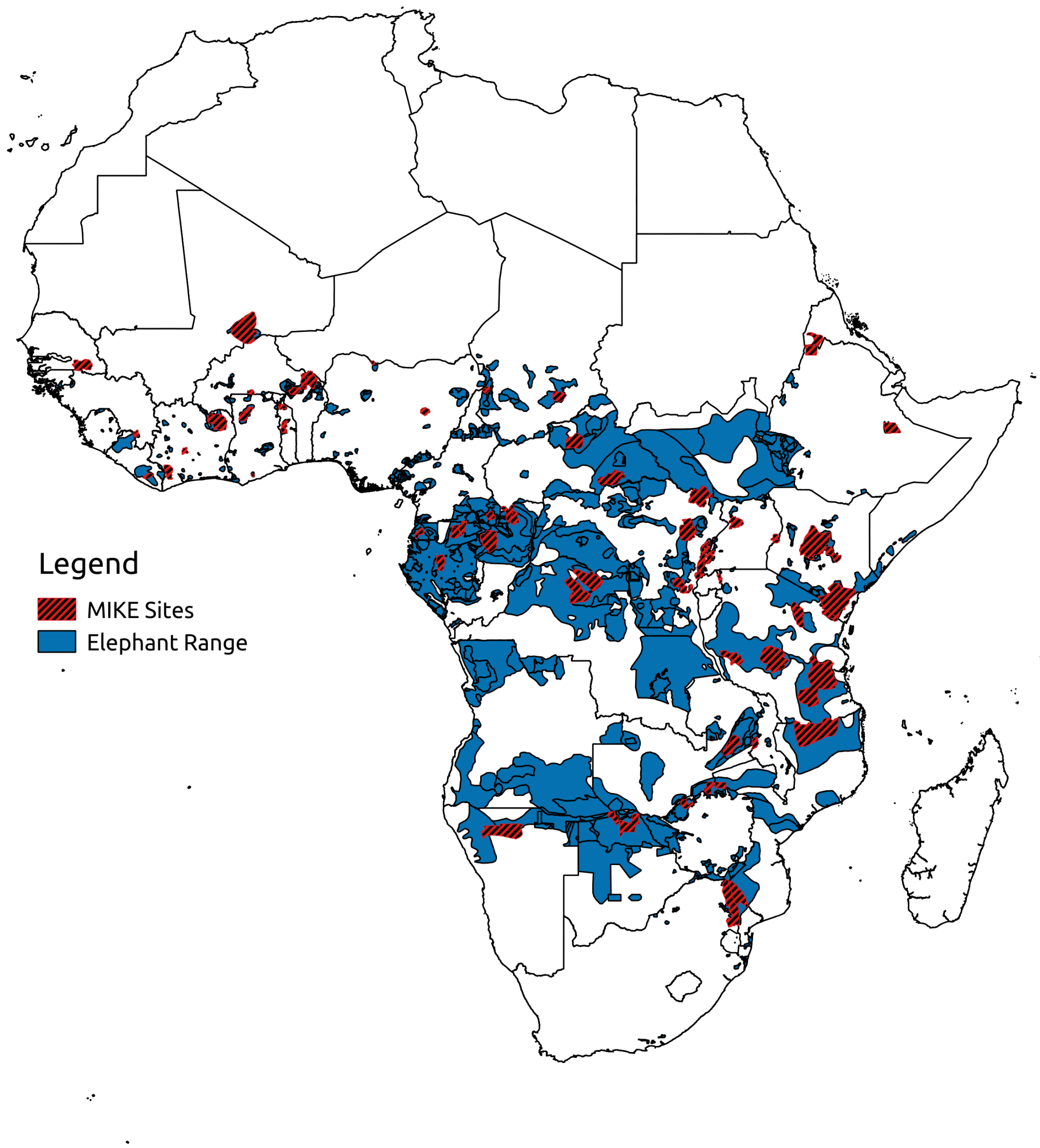

Figure A1: Elephant range (known, probable, and doubtful) and MIKE sites in Africa

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

Table A1: Data availability: poaching

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CAP	■	■	■	■	■	■	■	■	■	■	■	■	■	■
CHE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
CHO	■	■	■	■	■	■	■	■	■	■	■	■	■	■
ETO	■	■	■	■	■	■	■	■	■	■	■	■	■	■
KRU	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NYA	■	■	■	■	■	■	■	■	■	■	■	■	■	■
QEZ	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SBR	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SLW	■	■	■	■	■	■	■	■	■	■	■	■	■	■
GAR	□	■	■	■	■	■	■	■	■	■	■	■	■	■
KTV	□	■	■	■	■	■	■	■	■	■	■	■	■	■
MCH	■	■	■	□	■	■	■	■	■	■	■	■	■	■
OKP	□	■	■	■	■	■	■	■	■	■	■	■	■	■
RHR	□	■	■	■	■	■	■	■	■	■	■	■	■	■
SAL	□	■	■	■	■	■	■	■	■	■	■	■	■	■
TSV	□	■	■	■	■	■	■	■	■	■	■	■	■	■
BBK	□	■	■	■	■	■	■	■	■	■	■	■	■	□
EGK	□	■	■	■	■	■	■	■	□	■	■	■	■	■
GOU	■	■	■	■	■	■	■	■	■	□	□	■	■	■
LOP	□	■	■	■	■	■	■	■	■	■	■	■	■	□
MKB	□	■	■	■	■	■	■	■	■	■	■	■	■	□
NAZ	■	□	■	■	■	□	■	■	■	■	■	■	■	■
NDK	□	■	■	■	■	■	■	■	■	■	■	■	■	□
ODZ	□	■	■	■	■	■	■	■	□	■	■	■	■	■
TGR	□	■	■	□	■	■	■	■	■	■	■	■	■	■
YKR	■	■	■	■	□	□	■	■	■	■	■	■	■	■
ZAK	□	■	■	■	■	■	■	■	■	■	■	■	□	■
DZA	□	□	□	■	■	■	■	■	■	■	■	■	■	■
GSH	■	■	■	□	■	■	■	■	■	□	■	■	■	□
PDJ	■	■	■	□	□	□	■	■	■	■	■	■	■	■
SEL	□	■	■	□	□	■	■	■	■	■	■	■	■	■
WAZ	□	■	■	■	■	■	■	■	■	■	■	□	■	□
MRU	□	□	□	□	■	■	■	■	■	■	■	■	■	■
VIR	□	□	□	■	■	■	■	■	■	■	■	■	■	□
WNE	■	■	■	□	□	□	□	■	■	■	■	■	■	■
XBN	■	■	■	■	■	■	■	■	■	■	□	□	□	□
EDO	□	■	■	■	■	■	■	■	■	■	□	□	□	□
GRO	□	■	■	■	■	■	■	■	■	■	□	□	□	□
MAG	■	■	■	□	□	□	□	□	■	■	■	■	■	■
NIA	□	□	■	□	■	□	■	□	■	■	■	■	■	■
SGB	□	■	■	□	□	□	■	■	■	■	■	■	□	■
SKP	■	■	■	■	■	□	■	■	■	□	□	■	□	□
WAY	□	■	■	□	■	□	■	■	■	■	■	■	□	□
ZIA	□	■	■	□	□	■	■	■	□	□	■	■	■	■
AKG	□	□	■	■	■	□	□	□	■	■	■	■	■	□
BGS	□	■	■	□	□	□	□	□	■	■	■	■	■	■
CHR	□	■	■	□	■	■	■	■	■	■	□	□	□	□
DHG	□	□	■	■	■	■	■	■	■	■	□	□	□	□
GMS	□	□	□	■	■	■	■	■	■	■	■	□	□	□
KAK	■	■	■	□	□	■	■	■	■	□	□	■	□	□
KLU	□	□	□	■	■	■	■	■	■	■	■	□	□	□
MBJ	□	□	■	■	■	■	■	■	■	■	□	□	□	□
MOL	■	■	■	■	□	■	■	□	■	□	□	■	□	□
SVK	□	□	□	■	■	■	■	■	■	■	■	□	□	□
WBF	■	□	■	□	□	□	■	■	□	■	■	■	■	□
WBJ	■	■	■	□	□	□	□	■	□	□	■	■	■	■
CHU	□	□	□	■	■	■	■	■	□	□	■	■	□	□
DEO	□	□	□	■	■	■	■	■	■	■	□	□	□	□
MYS	□	□	□	■	■	■	■	■	■	■	□	□	□	□
NIL	□	□	□	□	■	■	■	■	■	■	□	□	□	□
SCH	□	□	□	■	■	■	■	■	□	■	□	□	□	□
BBS	□	□	□	□	■	□	□	□	■	■	■	■	□	□
KUI	□	□	□	■	■	□	□	□	■	■	■	□	□	□
SAP	□	□	□	□	□	■	■	■	□	■	■	□	□	□
BBL	□	□	□	□	□	□	□	□	□	□	■	■	■	■
CTN	□	□	□	□	■	□	□	■	■	■	□	□	□	□
KSH	□	□	□	□	□	□	□	□	□	□	■	■	■	■
MAR	□	□	□	□	□	■	■	■	□	□	□	■	□	□
MKZ	□	□	□	□	□	□	□	□	□	■	■	■	□	■
TAI	□	□	■	□	□	□	□	□	□	□	□	■	■	■
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
AGO	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
BDI	□	□	□	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	□	□	□	□	□
BWA	□	□	□	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	□	□	□	□	□
CAF	□	□	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	■	□	□	□	□	□
CIV	□	□	□	□	□	□	□	□	□	□	■	■	■	■	■	■	□	□	□	■	□	■	□
CMR	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	■	□	□	□	■	■	■	■
COD	□	□	□	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	■	■	□	■	□
COG	□	□	□	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	□	■	□	■	□
ETH	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
GAB	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	■	■	□	□	□
KEN	□	□	□	■	■	□	□	□	■	■	■	■	■	■	■	■	■	■	□	■	■	■	□
LBR	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	■	□	□
MOZ	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
MWI	□	■	□	□	□	□	□	□	■	■	■	■	■	■	■	■	□	□	□	■	□	■	■
NAM	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
NGA	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	■	□	□	□
REU	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
SDN	□	□	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	■	□	□	□	□	□
SEN	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
SWZ	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
TCD	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	■	□	□	□	□	□	□	□
TGO	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
TZA	□	□	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	■	□	■	□	■	□
UGA	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
ZAF	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	□	□	□
ZMB	□	□	□	□	■	□	□	□	■	■	□	□	■	■	■	■	■	□	□	■	■	■	□
ZWE	■	□	■	■	□	□	□	■	■	□	■	■	■	■	■	■	■	■	■	■	■	■	□

	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
AGO	□	□	□	□	□	□	□	□	□	□	□	□	■	□	□	□	□	□	□	□	□	■	□
BDI	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
BWA	□	□	■	■	□	■	■	■	■	■	■	■	■	■	■	■	■	■	■	□	■	□	□
CAF	□	□	□	□	□	□	■	□	□	■	□	□	□	□	■	□	■	□	□	□	□	□	□
CIV	□	□	□	□	■	■	■	□	□	■	■	□	□	□	□	□	□	□	□	□	□	□	□
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 and co-integration 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
	Cointegration tests					
	Z-stat			Critical Values		
				1%	5%	10%
P(Africa), P(Gold)	45	-5.1924		-4.1509	-3.4753	-3.1400
P(China), P(Gold)	37	-7.1020		-4.1770	-3.4892	-3.1495
P(Africa), P(China), P(Gold)	37	-7.1100		-4.6649	-3.9556	-3.6060
Global Poaching, P(Africa)	13	-3.2907		-4.8722	-3.8465	-3.3868
Global Poaching, P(China)	7	-3.2903		-5.2169	-4.0154	-3.4958
Global Poaching, P(Gold)	13	-3.7587		-4.8722	-3.8465	-3.3868

Note: The upper panel 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. The lower panel reports Engel-Granger co-integration tests with the the MacKinnon critical values. P(Africa) is the median price in Africa, and P(China) is the median price in China and Hong Kong, SAR.

Table A4: Summary statistics of variables in IV regressions

	Mean	SD	Min	Max
Poaching	25.424	38.306	1.000	225.000
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(Poaching)	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	0.526	0.576	0.606	0.431	0.436	0.431	0.436	0.581	0.602	0.334	0.323
	(0.100)	(0.100)	(0.122)	(0.125)	(0.111)	(0.114)	(0.133)	(0.136)	(0.134)	(0.134)	(0.073)	(0.077)
Ln(Total Carcass Found)	0.973	0.959	0.990	0.964	0.984	0.973	0.984	0.973	0.943	0.926	1.011	1.005
	(0.060)	(0.060)	(0.069)	(0.071)	(0.065)	(0.061)	(0.092)	(0.088)	(0.061)	(0.062)	(0.052)	(0.053)
Number of Conflicts		-0.293		-0.481		-0.196		-0.196		-0.244		-0.164
		(0.172)		(0.275)		(0.087)		(0.097)		(0.164)		(0.162)
GDP Growth Rate		-0.017		-0.019		-0.016		-0.016		-0.014		-0.017
		(0.020)		(0.022)		(0.023)		(0.019)		(0.019)		(0.020)
Constant	-0.524	-0.473	-0.506	-0.465	19.655	20.931	19.655	20.931	-0.049	-0.162	-0.562	-0.657
	(0.493)	(0.495)	(0.581)	(0.596)	(3.797)	(5.201)	(3.883)	(4.631)	(0.632)	(0.657)	(0.627)	(0.697)
	First Stage											
Ln(Gold Price)	1.168	1.167	1.181	1.176	1.226	1.222	1.226	1.222			2.803	2.868
	(0.289)	(0.288)	(0.261)	(0.264)	(0.220)	(0.217)	(0.256)	(0.256)			(0.533)	(0.537)
Ln(Silver Price)									0.669	0.681	-1.517	-1.587
									(0.287)	(0.283)	(0.469)	(0.476)
N	117	117	80	80	151	151	151	151	151	151	151	151
First Stage F statistic	36.586	35.898	28.702	27.189	55.455	54.542	55.455	54.542	17.195	17.390	46.473	46.408
Site FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The dependent variable is the log of poaching 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. The next two columns cluster the standard errors at the year level without using the Moulton correction. The next two columns two-way cluster the standard errors at the site and year level without using Moulton correction. 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: Poaching Elasticity with Respect to Prices in China

LHS = Ln(Poaching)	Large Sites (8)		Large Sites (16)		One-way Clustering		Two-way Clustering		Silver as IV		Gold and Silver	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ln(Median Price), China	0.484	0.512	0.644	0.660	0.395	0.398	0.395	0.398	0.339	0.346	0.380	0.386
	(0.090)	(0.092)	(0.127)	(0.129)	(0.136)	(0.138)	(0.144)	(0.144)	(0.081)	(0.081)	(0.065)	(0.066)
Ln(Total Carcass Found)	1.037	1.034	1.056	1.057	1.010	1.012	1.010	1.012	1.013	1.015	1.011	1.013
	(0.034)	(0.034)	(0.044)	(0.044)	(0.031)	(0.029)	(0.039)	(0.037)	(0.029)	(0.029)	(0.028)	(0.029)
Number of Conflicts		-0.068		-0.020		0.000		0.000		0.006		0.002
		(0.076)		(0.118)		(0.052)		(0.059)		(0.069)		(0.068)
GDP Growth Rate		-0.007		-0.005		-0.005		-0.005		-0.005		-0.005
		(0.006)		(0.009)		(0.005)		(0.004)		(0.005)		(0.005)
Constant	-1.394	-1.382	-1.539	-1.541	95.193	95.111	95.193	95.111	0.765	0.807	0.700	0.727
	(0.459)	(0.460)	(0.504)	(0.507)	(41.974)	(42.035)	(20.535)	(20.325)	(1.729)	(1.755)	(1.441)	(1.474)
	First Stage											
Ln(Gold Price)	0.833	0.844	0.805	0.818	0.911	0.922	0.911	0.922			0.688	0.719
	(0.342)	(0.352)	(0.331)	(0.338)	(0.471)	(0.471)	(0.465)	(0.465)			(0.712)	(0.734)
Ln(Silver Price)									0.774	0.773	0.230	0.206
									(0.325)	(0.328)	(0.651)	(0.666)
N	281	281	176	176	422	422	422	422	422	422	422	422
First Stage F statistic	90.327	86.188	54.732	52.823	155.102	152.438	155.102	152.438	131.036	127.193	79.349	77.531
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 for the first four columns. The dependent variable is the log of poaching at the site level. The first four columns restrict the sample to sites with average number of carcass above 8 or 16. The next two columns cluster the standard errors at the year level without using the Moulton correction. The last two columns two-way cluster the standard errors at the site and year level without Moulton correction. Columns 9 and 10 use silver price as IV and columns 11 and 12 use gold and silver prices as IV. Silver price comes from the London Bullion Market. Variable definitions and sources are described in detail in the text.

Table A7: 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 A8: 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 A9: 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.