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

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ONLINE APPENDIX

A. Proofs of Propositions

Proof of Proposition 1

Proof. Time differentiating the PNS equilibrium conditions (9) and solving for $\dot{h}, \dot{q}, \dot{p}$ and $\dot{m}$ yields, where the signs assume that the direct price effects dominates cross-price effects when opposite:

$$\dot{h} = \underbrace{\frac{S_E^e\left[D_p^e(D_m^m - S_m^m) - D_m^e D_p^m\right]}{|J|}}_{(+)}\dot{E} + \underbrace{\frac{S_p^e\left[D_y^e(D_m^m - S_m^m) - D_m^e D_y^m\right]}{|J|}}_{(+)}\dot{y} + \underbrace{\frac{S_I^e\left[D_p^e(D_m^m - S_m^m) - D_m^e D_p^m\right]}{|J|}}_{(+)}\dot{I} + \underbrace{\frac{-S_p^e D_m^e S_R^m}{|J|}}_{(-)}\dot{R},$$

$$\dot{q} = \underbrace{\frac{-S_m^m D_p^m S_E^e}{|J|}}_{(-)}\dot{E} + \underbrace{\frac{-S_m^m\left[(D_p^e - S_p^e)D_y^m - D_p^m D_y^e\right]}{|J|}}_{(+)}\dot{y} + \underbrace{\frac{-S_m^m D_p^m S_I^e}{|J|}}_{(+)}\dot{I} + \underbrace{\frac{\left[D_m^m(D_p^e - S_p^e) - D_m^e D_p^m\right]S_R^m}{|J|}}_{(+)}\dot{R},$$

$$\dot{p} = \underbrace{\frac{(D_m^m - S_m^m)\,S_E^e}{|J|}}_{(-)}\dot{E} + \underbrace{\frac{\left[(D_m^m - S_m^m)D_y^e + D_m^e D_y^m\right]}{|J|}}_{(+)}\dot{y} + \underbrace{\frac{(D_m^m - S_m^m)\,S_I^e}{|J|}}_{(+)}\dot{I} + \underbrace{\frac{-D_m^e S_R^m}{|J|}}_{(-)}\dot{R},$$

$$\dot{m} = \underbrace{\frac{-D_p^m S_E^e}{|J|}}_{(-)}\dot{E} + \underbrace{\frac{\left[-D_y^m(D_p^e - S_p^e) + D_p^m D_y^e\right]}{|J|}}_{(+)}\dot{y} + \underbrace{\frac{-D_p^m S_I^e}{|J|}}_{(+)}\dot{I} + \underbrace{\frac{(D_p^e - S_p^e)S_R^m}{|J|}}_{(-)}\dot{R},$$

where $\qquad |J| = (D_m^m - S_m^m)(D_p^e - S_p^e) - D_m^e D_p^m > 0. \qquad (A.1)$

Under the assumption that $\dot{E} > 0$, $\dot{R} > 0$ and $\dot{y} = \dot{I} = 0$, we see from (A.1) that $\dot{p} < 0$ and $\dot{m} < 0$, so both ivory prices are falling. To get elephant ivory outputs falling, $\dot{h} > 0$, and mammoth ivory output rising, $\dot{q} > 0$, the effect of growth in $\dot{R}$ must be larger than the effect of the growth in $\dot{E}$, since these are of opposite signs. Observe that if $\dot{y} > 0$ or $\dot{I} > 0$ were to dominate the other two effects, then both outputs and both prices would be rising, contrary to what is observed. □

Proof of Proposition 2

Proof. When stores are being accumulated, $\dot{X} = s > 0$, $\dot{E} < 0$, $\dot{p} = rp > 0$, $s + h = S^e(p, E, I)$, $h = D^e(p, m, y)$, $q = S^m(m, R)$, and $q = D^e(m, p, y)$. Time differentiating the PWS equilibrium conditions (10) and solving for $\dot{h}$, $\dot{s}$, $\dot{q}$ and $\dot{m}$ as functions of $\dot{p} > 0$ and $\dot{E} < 0$ (whose signs are part of the equilibrium), and changes in the exogenous $\dot{I}$, $\dot{R}$, and $\dot{y}$, yields

$$\dot{h} = \underbrace{\left[\frac{D^e_p(D^m_m - S^m_m) - D^e_m D^m_p}{D^m_m - S^m_m}\right]}_{(+)}\dot{p} + \underbrace{\left[\frac{D^e_y(D^m_m - S^m_m) - D^e_m D^m_y}{D^m_m - S^m_m}\right]}_{(+)}\dot{y} + \underbrace{\frac{D^e_m S^m_R}{D^m_m - S^m_m}}_{(-)}\dot{R},$$

$$\dot{q} = \underbrace{\frac{-D^m_p S^m_m}{D^m_m - S^m_m}}_{(-)}\dot{p} + \underbrace{\frac{-D^m_y S^m_m}{D^m_m - S^m_m}}_{(+)}\dot{y} + \underbrace{\frac{D^m_m S^m_R}{D^m_m - S^m_m}}_{(+)}\dot{R},$$

$$\dot{s} = \underbrace{\left[\frac{D^e_m D^m_p - (D^e_p - S^e_p)(D^m_m - S^m_m)}{D^m_m - S^m_m}\right]}_{(+)}\dot{p} + \underbrace{\left[\frac{-D^e_y(D^m_m - S^m_m) + D^e_m D^m_y}{D^m_m - S^m_m}\right]}_{(-)}\dot{y}$$
$$+ \underbrace{S^e_E}_{(+)}\dot{E} + \underbrace{S^e_I}_{(-)}\dot{I} + \underbrace{\frac{D^e_m S^m_R}{S^m_m - D^m_m}}_{(+)}\dot{R},$$

$$\dot{m} = \underbrace{\frac{-D^m_p}{D^m_m - S^m_m}}_{(+)}\dot{p} + \underbrace{\frac{-D^m_y}{D^m_m - S^m_m}}_{(+)}\dot{y} + \underbrace{\frac{S^m_R}{D^m_m - S^m_m}}_{(-)}\dot{R}, \qquad \text{and}$$

$$\dot{h} + \dot{s} = \underbrace{S^e_p}_{(+)}\dot{p} + \underbrace{S^e_E}_{(+)}\dot{E} + \underbrace{S^e_I}_{(-)}\dot{I}. \tag{A.2}$$

All else constant, the rising illegal ivory price, $\dot{p} > 0$, increases harvesting of elephants both for production, h, and for storage, s, and raises both mammoth ivory prices, m, and

mammoth ivory production, q. The falling elephant population $\dot{E} < 0$, in contrast, lowers the harvest of elephants for addition to stores, s, has no effect upon harvest for production, h, and thus lowers total poaching, $h + s$. Increases in income, $\dot{y} > 0$, increase the elephant harvest for production, h, and the mammoth ivory production, q, but has no effect upon total poaching, $h + s$. Since rising R would cause m to fall and rising I would cause s and $h + s$ to fall, neither of these supply side effects can dominate and be consistent with the observables. □

B. Data and Sources

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

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

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

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

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

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

Expenditures on Public Order Source: International Monetary Fund (IMF) Government Finance Statistics Database. Expenditure on Public Order is calculated as the sum of

expenditures on public safety at the local level, state level, and central government level as a share of GDP. Units: Percentage of GDP spend on public order and safety in local, state, and central level.

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

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

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

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

Russian Mineral Rents: Russian Mineral Rents are constructed by multiplying Russian Mineral Rents share of GDP with Russian GDP. Units: billions of constant 2005 U.S. Dollars.

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

Russian GDP: Source: World Bank Development Indicators, series code: NY.GDP.MKTP.KD. Data description: GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. Units: billions of constant 2005 U.S. dollars.

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

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

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

PIKE: Source: Source: CITES - MIKE Data Portal. `https://www.google.com/fusiontables/DataSource?docid=1juiqNCOUwqperYcoq_uCWaZ5lEs8t09hfRry_I37#rows:id=4`. Proportion of Illegally Killed Elephants. Units: Proportion of kills which were illegal (0 to 1 in value).

Illegal Kills: Source: CITES - MIKE Data Portal. `https://www.google.com/fusiontables/DataSource?docid=1juiqNCOUwqperYcoq_uCWaZ5lEs8t09hfRry_I37`. Number of elephant carcasses determined to be killed by poachers. Units: Number of carcasses of elephants illegally killed by poachers.

Number of Interdictions: Source: 1989- 2011 data is from MIKE report to CITES (2011, Table 7, pp. 38-45). Number of Elephant Ivory Seizures. Units: Number of elephant ivory seizures reported by authorities to CITES in each country.

C. Supplementary Tables

C.1 Summary Statistics

C.2 Panel Estimation First-Stage Results

Table C.2 reports the first-stage regression results for the number of seizures panel.

C.3 Instrumental Variable Regressions by Region of Africa

This subsection presents the second stage instrumental variable results for the savannah region of Africa (Southern and Eastern Africa) and for the forest region of Africa (Western and Central Regions of Africa) using the ETIS interdictions data. The reported specifications correspond to the specifications in models (1), and (2) and (6) in Table 4.

The ETIS samples by regions of Africa are considerably smaller than the sample used in Table 4, since the ETIS included data from demand regions as well as from the supply

Table C.1: Summary Statistics for Variables Used in Analysis

Time Series Variable	Observations	Mean	Std. Dev.	Min	Max
Elephant Ivory Seizures (Tonnes, ETIS)	25	21.9	13.1	6.9	58.0
Russian Mammoth Ivory Exports (Tonnes)	25	41.0	31.3	0.7	99.8
Russian Mineral Rents (Millions 2005 USD)	23	3,859	4,064	0	11,572
China GDP per Capita (2005 USD)	25	4,279	2,605	1,288	9,798
Polity II Index	25	2.65	2.46	-5.01	5.68
Rule of Law Index	18	-0.62	0.24	-.92	-0.22
CITES Permitted Elephant Ivory Trade (Tonnes, CITES)	25	30.1	51.5	1.4	205.9
CITES Imputed Elephant Ivory Trade (Tonnes, Comtrade)	25	31.4	27.2	8.8	132.6
Raw Elephant Ivory Export Price (Nominal USD per Kilogram)	25	53.51	57.8	19.87	295.55
Raw Mammoth Ivory Export Price (Nominal USD per Kilogram)	25	77.82	62.88	15.33	253.14
Panel Regression Variables					
Proportion of Illegally Killed Elephants (PIKE/ site)	605	0.5	0.4	0	1
Number of Illegally Killed Elephants (Animals / site)	605	11.99	25.45	0	225
Number of Elephant Ivory Interdictions (Interdictions / Country)	2149	12.45	33.03	0	735

regions in Asia. Nevertheless, the results are qualitatively similar to those in Table 4.

C.4 Panel Data Estimation Using Mike Surveys

This subsection reports results using data from the MIKE surveys. This data is available only after 2002.

Table C.4 reports the first-stage regression results. These again show that Russian mineral rents have good explanatory power in predicting Russian mammoth ivory exports.

Table C.5 presents the panel fixed-effects instrumental variable regression results for the PIKE panel of surveys on 73 sites of elephant carcasses in Africa.[1] The variable of interest, Russian mammoth ivory exports, however, is statistically zero in all specifications. Thus, Russian mammoth ivory appears to have had little or no effect upon the proportion of elephant carcasses found to have been illegally killed. Chinese GDP per capita has a positive effect upon PIKE, and in specification (5), both the Rule of Law and Expenditures on Public Order variables have positive coefficients. CITES Elephant Ivory Sales have a positive but statistically insignificant effect upon PIKE.

Table C.6 presents the results for the panel of the number of illegally killed elephants panel of surveys on 73 sites of elephant carcasses in Africa. All specifications show that an increase in Russian mammoth ivory exports reduce number of illegally killed elephants, and all coefficients are statistically significant. As with the PIKE panel, Chinese GDP per capita

[1]There were also surveys on 24 Asian sites, but these are not included in Table C.5. The regression results, however, do not change substantially when the Asian sites are included.

Table C.2: First Stage Panel IV Regression Results Using Number of Elephant Ivory Seizures as Dependent Variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mineral Rents	***2.670	***4.366	***2.683	***2.138	***4.373	***2.675	***2.131
	(0.0260)	(0.0142)	(0.0268)	(0.0196)	(0.0152)	(0.0272)	(0.0199)
China GDP per Capita	***5.045	***-3.103	***4.922	***8.106	***-3.088	***5.003	***8.179
	(0.118)	(0.0779)	(0.127)	(0.0955)	(0.0970)	(0.143)	(0.108)
Polity II Index	***0.464	**0.520	***0.447	**0.268	*0.489	*0.339	0.199
	(0.143)	(0.210)	(0.146)	(0.105)	(0.260)	(0.194)	(0.138)
Rule of Law Index		-1.299			-0.424		
		(2.106)			(2.414)		
Conflict Index			*-0.567	**-0.446		-0.488	-0.346
			(0.288)	(0.207)		(0.439)	(0.313)
Permitted Elephant Ivory Sales				***-0.225			***-0.226
				(0.000863)			(0.000856)
Expenditures on Public Order					-0.498	0.0548	0.131
					(0.392)	(0.473)	(0.370)
Constant	***3.393	***32.56	***4.356	*0.622	***33.11	***3.796	0.0440
	(0.212)	(0.732)	(0.435)	(0.317)	(1.074)	(1.021)	(0.760)
Observations	3366	2420	3311	3311	1661	2272	2272
R^2	0.763	0.729	0.763	0.852	0.729	0.762	0.852
Number of Countries (Fixed Effects)	167	165	163	163	112	111	111
Number of Countries (Clusters)	167	165	163	163	112	111	111
F	66344.7	50031.4	44587.4	78610.9	32195.9	35726.6	103947.4

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

is positively and statistically significantly correlated with count of illegally killed elephants. Among the four measures of the institutional quality, Polity II index and Expenditures on Public Order have negative coefficients, though only the Polity II index is statistically different from zero (in columns (5) and (6)). In contrast to Hsiang and Sekar (2016), CITES Elephant Ivory Sales have a negative and significant effect upon the number of illegally killed elephants.

Table C.3: Number of Interdictions IV Regressions, by African Region

	Eastern and Southern Africa			Western and Central Africa		
	(1)	(2)	(3)	(4)	(5)	(6)
Russian Mammoth Ivory Exports	-0.00675	-0.00241	0.00247	-0.00286	-0.00171	-0.0101**
	(0.0157)	(0.0086)	(0.0178)	(0.0038)	(0.0027)	(0.0044)
China GDP per Capita	0.0368	-0.0882	-0.0646	0.0821**	0.0592**	0.131**
	(0.214)	(0.110)	(0.270)	(0.039)	(0.029)	(0.063)
Polity II Index	-0.0268	0.283***	0.112***	-0.00000237	0.00658	0.000555
	(0.058)	(0.073)	(0.042)	(0.009)	(0.012)	(0.009)
Rule of Law Index		1.003***			0.0508	
		(0.382)			(0.170)	
Conflict Index			0.276**			-0.0199*
			(0.124)			(0.012)
Expenditures on Public Order			0.217			-0.683**
			(0.350)			(0.269)
Observations	168	120	126	294	210	105
R^2	0.029	0.138	0.063	0.033	0.026	-0.2
Countries (Fixed Effects)	8	8	6	14	14	5
F	0.154	9.953	6.466	2.399	3.006	81.72

Table C.4: First Stage Panel IV Regression Results Using PIKE and Illegally Killed Elephants as Dependent Variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mineral Rents	***2.826	***2.820	***2.886	***2.168	***2.928	***2.902	***2.251
	(0.236)	(0.236)	(0.261)	(0.233)	(0.265)	(0.255)	(0.270)
China GDP per Capita	-0.545	-0.534	-0.773	***2.214	-0.462	-0.513	**2.016
	(0.753)	(0.738)	(0.808)	(0.760)	(0.842)	(0.746)	(0.842)
Polity II Index	0.195	0.188	0.257	-0.0971	-0.328	-0.288	-0.200
	(0.591)	(0.582)	(0.590)	(0.425)	(0.688)	(0.623)	(0.493)
Rule of Law Index		2.315			-13.33		
		(12.74)			(13.00)		
Conflict Index			*0.669	**0.832		0.359	***0.607
			(0.380)	(0.308)		(0.315)	(0.184)
Permitted Elephant Ivory Sales				***-0.218			***-0.206
				(0.00543)			(0.00918)
Expenditures on Public Order					*-15.51	-14.03	-7.721
					(8.446)	(8.227)	(4.644)
Constant	***41.08	***42.59	***41.12	***38.97	***62.26	***65.18	***52.60
	(2.269)	(8.442)	(2.283)	(1.870)	(14.23)	(12.73)	(7.845)
Observations	463	463	463	463	300	300	300
R^2	0.319	0.319	0.322	0.680	0.368	0.365	0.683
Sites (Fixed Effects)	76	76	76	76	46	46	46
Countries (Number of Clusters)	37	37	37	37	19	19	19
F	281.6	208.3	213.1	771.8	94.15	107.7	508.2

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

Table C.5: Proportion of Illegally Killed Elephants by Site, by Year, Panel Fixed-Effects Instrumental Variable Regression Results, 2003-2012, All Sites

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory [a]	-0.000771	-0.000980	-0.000806	-0.000640	0.000699	0.00110	0.00165
	(0.00191)	(0.00192)	(0.00191)	(0.00268)	(0.00192)	(0.00188)	(0.00256)
China GDP per Capita [b]	***0.0578	***0.0587	***0.0581	***0.0562	***0.0486	***0.0471	**0.0412
	(0.0139)	(0.0137)	(0.0135)	(0.0193)	(0.0141)	(0.0136)	(0.0188)
Polity II Index [c]	-0.000529	-0.00115	-0.000623	-0.000429	-0.00487	-0.00471	-0.00477
	(0.00732)	(0.00758)	(0.00728)	(0.00734)	(0.00382)	(0.00310)	(0.00345)
Rule of Law Index [c]		0.228			*0.282		
		(0.166)			(0.152)		
Conflict Index [c]			-0.00109	-0.00131		-0.00129	-0.00209
			(0.00927)	(0.00935)		(0.0102)	(0.0103)
CITES Elephant Ivory Sales [a]				0.000146			0.000502
				(0.000739)			(0.000676)
Expenditures on Public Order [c,d]					*0.0893	0.0694	0.0617
					(0.0541)	(0.0540)	(0.0532)
Observations	460	460	460	460	300	300	300
R^2	0.097	0.103	0.097	0.097	0.105	0.091	0.092
Sites (Fixed Effects)	73	73	73	73	46	46	46
Countries (Clusters)	36	36	36	36	19	19	19
Anderson LR Test $\chi^2(1)$	103.2	102.2	105.1	118.9	78.51	76.98	87.61

Notes: Dependent variable: Proportion of Illegally Killed Elephants by Site, by Year. Instrumental variable panel fixed-Effects regression estimates. Standard errors (clustered by Country) in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Units: [a] Tonnes. [b] Thousands of 2005 U.S. Dollars. [c] Country-Specific. [d] Percent of GDP.

Table C.6: Log of the Number of Illegally Killed Elephants by Site, by Year, Panel Fixed-Effects Instrumental Variable Regression Results, 2003-2012, All Sites

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Russian Mammoth Ivory Exports [a]	**-0.0111**	**-0.0116**	*-0.0110*	*-0.0154*	**-0.0102**	*-0.00961*	**-0.0133**
	(0.00565)	(0.00557)	(0.00564)	(0.00798)	(0.00487)	(0.00503)	(0.00676)
China GDP per Capita [b]	***0.261***	***0.263***	***0.259***	***0.308***	***0.302***	***0.305***	***0.344***
	(0.0618)	(0.0602)	(0.0636)	(0.0858)	(0.0798)	(0.0828)	(0.105)
Polity II Index [c]	-0.000320	-0.00161	0.0000621	-0.00503	*-0.0330*	*-0.0349*	-0.0345
	(0.0273)	(0.0267)	(0.0270)	(0.0270)	(0.0194)	(0.0211)	(0.0217)
Rule of Law Index [c]		0.473			0.766		
		(0.666)			(0.968)		
Conflict Index [c]			0.00440	0.0102		-0.0196	-0.0142
			(0.0268)	(0.0256)		(0.0388)	(0.0364)
CITES Elephant Ivory Sales [a]				*-0.00382*			*-0.00339*
				(0.00223)			(0.00193)
Expenditures on Public Order [c,d]					-0.115	-0.191	-0.139
					(0.312)	(0.344)	(0.308)
Observations	460	460	460	460	300	300	300
R^2	0.109	0.108	0.111	0.117	0.180	0.179	0.186
Sites (Fixed Effects)	73	73	73	73	46	46	46
Countries (Clusters)	36	36	36	36	19	19	19
Anderson LR Test $\chi^2(1)$	103.2	102.2	105.1	118.9	78.51	76.98	87.61

Notes: Dependent variable: Log of the Number of Illegally Killed Elephants plus one, by Site, by Year. Instrumental variable panel fixed-Effects regression estimates. Standard errors (clustered by Country) in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Units: [a] Tonnes. [b] Thousands of 2005 U.S. Dollars. [c] Country-Specific. [d] Percent of GDP.

C.5 IV Regressions by Region of Africa Using Mike Surveys

This subsection presents the second stage instrumental variable results for the savannah region of Africa (Southern and Eastern Africa) and for the forest region of Africa (Western and Central Regions of Africa). The reported specifications correspond to the specifications in models (1), (2), and (6) in Tables C.5 and C.6, respectively.

Table C.7: PIKE (Proportion of Illegally Killed Elephants) IV Regressions, by African Region

	Eastern and Southern Africa			Western and Central Africa		
	(1)	(2)	(3)	(4)	(5)	(6)
Russian Mammoth Ivory Exports	0.00374*	0.00381*	0.00252	-0.00641	-0.00648*	-0.00176
	(0.0022)	(0.0023)	(0.0020)	(0.0039)	(0.0039)	(0.0034)
China GDP per Capita	0.0353**	0.0346**	0.0463***	0.0953***	0.0934***	0.0988***
	(0.016)	(0.016)	(0.012)	(0.028)	(0.028)	(0.024)
Polity II Index	0.0091	0.0107	0.0159	0.00825	0.00837	
	(0.007)	(0.007)	(0.015)	(0.031)	(0.032)	
Rule of Law Index		-0.0808			0.12	
		-0.106			-0.35	
Conflict Index			-0.0660***			0.00777***
			-0.0146			-0.00217
Expenditures on Public Order			0.0832*			0.430***
			-0.05			-0.119
Observations	159	159	130	167	167	53
R^2	0.093	0.092	0.195	0.092	0.091	0.251
Sites (Fixed Effects)	21	21	17	26	26	9
Countries (Clusters)	10	10	7	15	15	5

Table C.8: Number of Illegally Killed Elephants IV Regressions, by African Region

	Eastern and Southern Africa			Western and Central Africa		
	(1)	(2)	(3)	(4)	(5)	(6)
Russian Mammoth Ivory Exports	-0.0116	-0.0115	-0.0114**	-0.0187*	-0.0186*	-0.00495
	(0.0090)	(0.0095)	(0.0053)	(0.0109)	(0.0108)	(0.0070)
China GDP per Capita	0.434***	0.433***	0.504***	0.212***	0.214***	0.185***
	(0.087)	(0.090)	(0.061)	(0.063)	(0.064)	(0.055)
Polity II Index	0.0334	0.0343	-0.213**	0.0328	0.0327	
	(0.053)	(0.059)	(0.088)	(0.054)	(0.054)	
Rule of Law Index		-0.0462			-0.102	
		(0.974)			(0.912)	
Conflict Index			-0.309***			0.0374***
			(0.048)			(0.004)
Expenditures on Public Order			-0.414			1.273***
			(0.434)			(0.162)
Observations	159	159	130	167	167	53
R^2	0.367	0.368	0.44	-0.065	-0.064	0.179
Sites (Fixed Effects)	21	21	17	26	26	9
Countries (Clusters)	10	10	7	15	15	5

D Other Possible Equilibria

This appendix examines the SNP and PNS, extinction equilibria.

D.1 The Extinction PNS Subpath

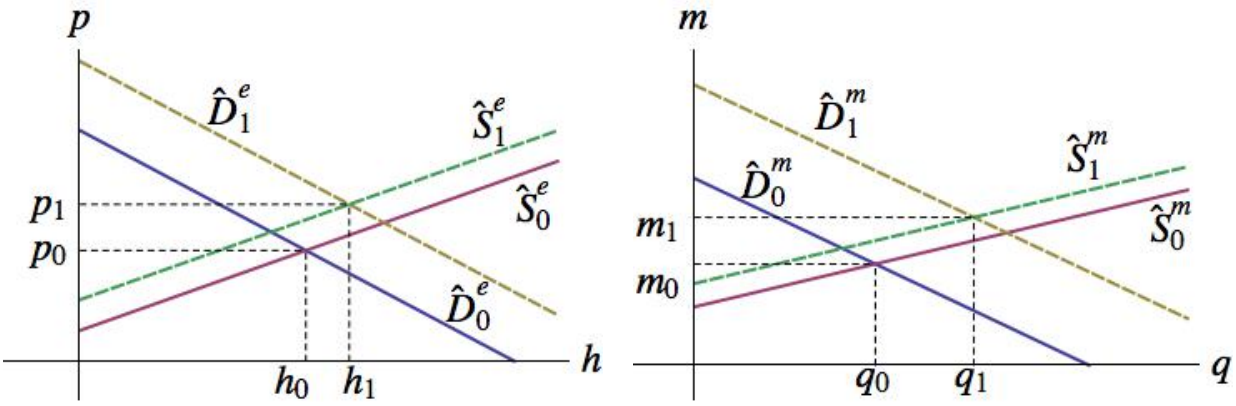
In the post-2007 era, ivory poaching and mammoth ivory production both increased, both ivory prices increased, and the elephant population fell.

The extinction PNS path is consistent with the falling elephant population. Suppose for the moment that the falling elephant population is the only causal effect. This shifts the inverse poaching supply curve upwards, raises poaching costs, which increases the elephant ivory price p. That, in turn, causes mammoth ivory demand to increase by substitution effects, raising both the mammoth ivory output q and the mammoth ivory price m, all else constant. As long as the feedback effect from increasing mammoth ivory prices is smaller than the direct effect of increasing the poaching costs by lowering the elephant population, elephant poaching falls. Thus, falling elephant population alone cannot explain the observed increasing poaching and interdiction rates.

To explain the increasing poaching and interdiction rates, we also need the elephant ivory demand to increase. An obvious candidate is the rising income in China. Figure D.1 shows an example where demand for both types of ivory increase, which when combined with the substitution effects from rising prices of the substitute, cause demand to increase in both markets. Thus, as long as the combined demand shift due to increasing income and to increasing substitute price is sufficiently large, elephant and mammoth ivory output and prices will both rise. This is summarized as follows:

Proposition D.1. *In the PNS extinction equilibrium, where the elephant population falls, to get rising elephant poaching, rising mammoth ivory production, rising mammoth and elephant ivory prices, it is necessary that that demand shifts be larger than the combined supply shifts in both markets.*

An alternative explanation, suggested by Hsiang and Sekar (2016), is that the 2008 permitted ivory sale is the cause of the rise in interdictions, mammoth ivory exports, and ivory prices. They postulate two possible causes. A supply effect may occur because the increased ivory from the sale makes it easier to launder illegal ivory. This effect, however, would reduce the elephant ivory price, and through substitution effects would cause both



a: Elephants. b. Mammoths.

Figure D.1: The Extinction PNS Equilibrium.

mammoth ivory prices and output to fall. Since these were not observed post-2007, we ignore the supply-side explanation.

The other possibility is that demand for elephant ivory may have risen because there is a reduced stigma associated with buying elephant ivory given the availability of additional elephant ivory from the permitted sale. The increase in demand would increase both price and output of elephant ivory, and the substitution effect would cause mammoth ivory price and output to also rise. Thus, this explanation is consistent with the post-2007 stylized facts. Hsiang and Sekar, however, note that a secondary market has arisen for the photographs used by the Chinese government to track ivory sales (2016, p. 8). Since the government photograph is what constitutes proof that the ivory was legally purchased, thereby reducing the stigma from its purchase, this is inconsistent with the explanation that demand increased because of the reduced stigma.

D.2 The Storage, No Poaching Subpath, SNP

In the SNP subpath, there is no supply by poachers, so that $h = 0 \geq S^e(p, E, I)$, but all of demand is satisfied by drawing down stores: $-\dot{X} \equiv s = D^e(p, m, y) > 0$ for $X > 0$, and the storage condition is satisfied. Since there is no poaching of elephants, $\dot{E} = G(E) > 0$ for $0 < E < K$ as drawing down of stores s replaces poaching h in demand. Thus, both the elephant stock E and the price of elephant ivory p rise during this equilibrium, and the stock

of elephant ivory stores X falls. The equilibrium conditions in the SNP subpath satisfy

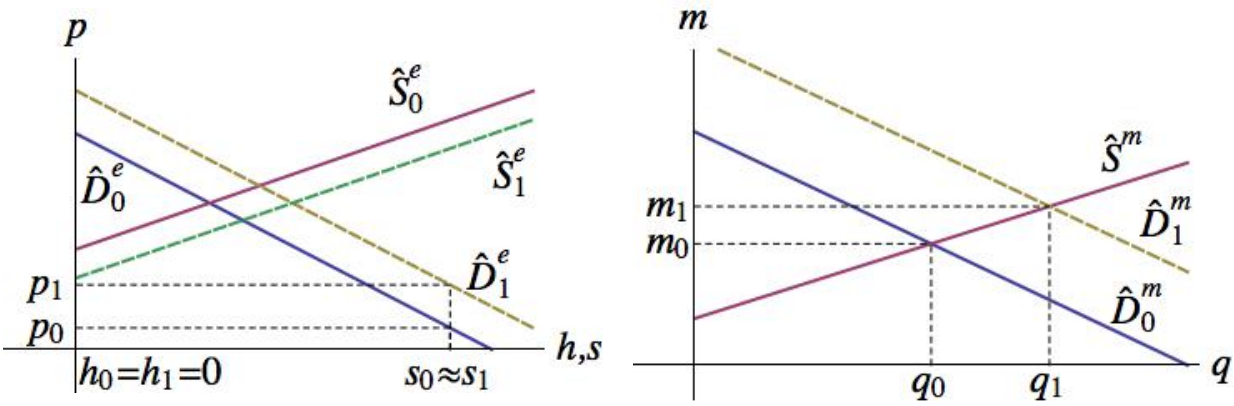
$$\dot{X} = -s < 0, \qquad s = D^e(p, m, y), \qquad q = S^m(m, R), \qquad q = D^m(m, p, y),$$
$$h = 0 \geq S^e(p, E, I), \qquad \dot{p} = rp > 0, \qquad \text{and} \qquad \dot{E} = G(E) > 0. \quad \text{(D.1)}$$

Boundary conditions for stores and the elephant population are given by their initial condition. The boundary condition for the poaching price p depends upon what subpath follows. For example, if the PNS subpath follows, then at the moment T when stores $X_T = 0$ are depleted, the elephant ivory price implicitly satisfies $D^e(p_T, m_T, y_T) = S^e(p_T, E_T, I_T)$.

Suppose that the equilibrium is characterized by the SNP subpath, and, for now, that the only two causal effects are that the elephant ivory price is rising according to the storage condition, and that the elephant population is rising since all demand is from stores. Then the equilibrium dynamics are as depicted in Figure D.2, drawn for inverse demand and supply functions, $p = \hat{D}^e(s_t, m_t, y_t)$ and $p = \hat{S}^e(h_t, E_t, I_t)$ for elephants and $m = \hat{D}^m(q_t, p_t, y_t)$ and $m = \hat{S}^m(q_t, R_t)$ for mammoths, respectively. At price p_0, and given supply S_0^e and demand D_0^e for elephant ivory, all demand is satisfied from stores, so poaching h_0 is zero. Because the elephant poaching price is rising, the first-order effect is a reduction in the quantity demanded from stores. But the increase in elephant ivory price causes demand for mammoth ivory to rise to D_1^m from D_0^m, increasing mammoth ivory output to q_1 from q_0 and the mammoth ivory price to m_1 from m_0. The second-order effect upon elephant ivory is that the increase in mammoth ivory prices causes elephant ivory demand to increase to D_1^e from D_0^e. If this shift in elephant ivory demand is sufficiently large, then the net effect is that demand for stores may remain roughly constant which is consistent with the interdictions data pre-2007. This is also consistent with rising mammoth ivory production, but it is not consistent with the observed falling prices of both mammoth and elephant ivory pre-2007.[2] Furthermore, at least from 2002 forward, there is unambiguous evidence from the PIKE data that poaching h was positive, not zero.

Proposition D.2. *The SNP subpath is inconsistent with falling ivory prices observed pre-2007 and with the positive poaching observed post-2007.*

[2]This result is unchanged by increases in income in China (which shifts the demands in the same direct as the substitution effects), or by increases in institutional quality, which shift the poaching supply in the opposite direction as the increase in the elephant population, but neither have any effect upon poaching, demand served from stores, nor elephant ivory prices, since $h = 0$. An increase in Russian mining activity could cause mammoth ivory prices in net to fall.



a: Elephants. b. Mammoths.

Figure D.2: The SNP Equilibrium.

Therefore, the SNP subpath has not been observed in the data.

D.3 Comparative Statics

This appendix subsection provides the comparative statics to the PWS equilibrium when $\dot{X} < 0$ and for the SNP equilibrium. We assume throughout that own price effects dominate cross-price effects when the two are in opposition.

PWS Equilibrium

In the case where stores are being depleted, i.e., $\dot{X} = -s < 0$, $s + h = D^e(p, m, y)$ and $h = S^e(p, E, I)$, the comparative statics on h and s are:

$$\dot{s} = \underbrace{\left(\frac{D_m^e D_p^m}{S_m^m - D_m^m} - D_p^e\right)}_{(+)} \dot{p} + \underbrace{\left(\frac{D_m^e D_y^m}{S_m^m - D_m^m} + D_y^e\right)}_{(+)} \dot{y} + \underbrace{\frac{-D_m^e S_R^m}{S_m^m - D_m^m}}_{-} \dot{R},$$

$$\dot{h} = \underbrace{S_p^e}_{(+)} \dot{p} + \underbrace{S_E^e}_{(+)} \dot{E} + \underbrace{S_I^e}_{(-)} \dot{I}$$

$$\dot{h} + \dot{s} = \underbrace{\left(D_p^e + S_p^e - \frac{D_m^e D_p^m}{S_m^m - D_m^m}\right)}_{(\pm)} \dot{p} + \underbrace{S_E^e}_{(+)} \dot{E} + \underbrace{\left(\frac{D_m^e D_y^m}{S_m^m - D_m^m} - D_y^e\right)}_{(-)} \dot{y} + \underbrace{S_I^e}_{(-)} \dot{I} + \underbrace{\frac{D_m^e S_R^m}{S_m^m - D_m^m}}_{+} \dot{R}, \tag{D.2}$$

and the comparative statics for m and q the same as in PWS in the text.

SNP Equilibrium

Time differentiating (D.1) and solving for the equilibrium $\dot{s}$, $\dot{m}$, and $\dot{q}$ yields

$$\dot{s} = \underbrace{\left[D_p^e + \frac{D_m^e D_p^m}{S_m^m - D_m^m}\right]}_{(-)}\dot{p} + \underbrace{\left[D_y^e + \frac{D_m^e D_y^m}{S_m^m - D_m^m}\right]}_{(+)}\dot{y} + \underbrace{\frac{D_m^e S_R^m}{S_m^m - D_m^m}}_{(+)}\dot{R}, \qquad \dot{q} = \underbrace{\frac{S_m^m D_p^m}{S_m^m - D_m^m}}_{(+)}\dot{p}$$
$$+ \underbrace{\frac{S_m^m D_y^m}{S_m^m - D_m^m}}_{(+)}\dot{y} + \underbrace{\frac{-D_m^m S_R^m}{S_m^m - D_m^m}}_{(+)}\dot{R} \quad \text{and} \quad \dot{m} = \underbrace{\frac{D_p^m}{S_m^m - D_m^m}}_{(+)}\dot{p} + \underbrace{\frac{D_y^m}{S_m^m - D_m^m}}_{(+)}\dot{y} + \underbrace{\frac{-S_R^m}{S_m^m - D_m^m}}_{(-)}\dot{R}. \tag{D.3}$$