The Price Elasticity of African Elephant Poaching

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What is this paper about?

- Estimate the supply elasticity with respect to price of an illegally-traded commodity
- Look at the elasticity of both price in producing countries and price in consuming countries
- First attempt in the context of elephant ivory

Why is it important?

- African elephants listed in Appendix I of CITES (except for three Southern African countries) - endangered
- Between 2007 and 2016 : reported decrease in the elephant population of more than 100,000 elephants out of 400+ thousand (Thouless et al. 2016)
- Decline attributed to poaching (CITES 2016)
- Supply elasticity to price (i.e. regulation) important to inform policy choices, whether in producing or consuming countries.

What do we do?

- Compile a data set on ivory prices
- Combine with output data
- Use demand shocks to instrument for price to measure supply elasticity

What do we find?

- Poaching is price inelastic:
  - elasticity wrt Africa prices = .44
  - elasticity wrt China prices = .40
  - price pass-through rate = .9
- Large price drop to induce sizable reduction in poaching

Literature

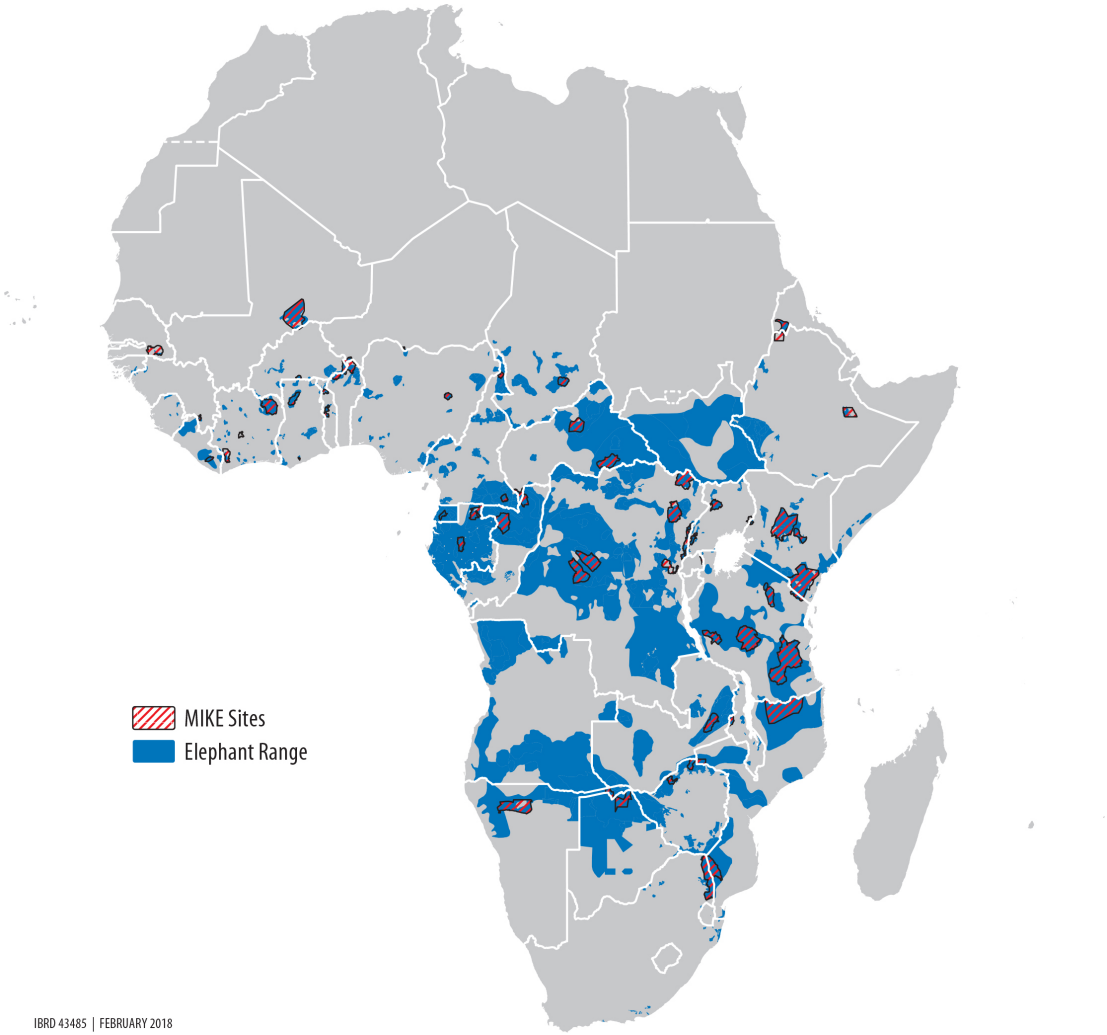
- Conservation: bison (Taylor 2011), whale (Allen and Keay 2004),
- Identifying supply elasticity (simultaneous equation problem) :
  - Oil, agricultural commodities
  - Fish: Angrist, Graddy, and Imbens (2000)
  - Drugs (Coca supply): Angrist and Kugler (2008);
  - Illegal trade, crime: Draca and Machin (2015)
- Market regulation
  - Fiscal policy
  - Becker, Murphy, and Grossman (2006)
  - Alcohol (Miron 2004)
  - Drugs (Keefer and Loayza 2010)

Outline

A few facts on African elephants

- largest land animal
- both male and female have tusks
- some population estimates: 3-5 million in early 20th century
- recent AfESG Report:
  - 415,428 +/- 20,111 in areas systematically surveyed
  - 117,127-135,384 elephants in areas not systematically surveyed
  - 62% of estimated known range covered

African elephant range



Demand for ivory products

- piano keys (pre 1989)
- bangles, chopsticks, figurines, trinkets, signature seal blanks
- price of carved piece can reach US$285,000 (Martin and Vigne 2017)

Poaching

- African Elephant Status Report : reduction of approx. 118,000 elephants between 2007 and 2016
- Combined with new discoveries: estimated decrease 104,000-114,000
- Since 2006: worst poaching crisis since pre-ban period (70s, 80s)

Policy environment

- 1989: African elephant down-listed to endangered (Appendix I of CITES)
  - International trade is banned
  - Exceptions for elephants in Botswana, Zimbabwe, and South Africa, but moratorium on trade
- Focus on three segments of supply chain
  - Stop the killing: increased law enforcement, community-led conservation
  - Stop the trafficking: customs enforcement
  - Stop the consumption: demand reduction initiatives, shutting down of consumer markets
- Recurrent debate on legalization

Outline

Supply curve

Technology

- In site s, country c, and year t, representative poacher
- Quasi linear utility:

$$U_{sct}(Y) = P_{ct}Y - C_{sct}(Y)$$

- Cost function:

$$C_{sct}(Y) = \frac{\beta}{\beta+1}\exp(-\frac{\Theta_{sct}}{\beta})Y^{\frac{\beta+1}{\beta}}$$

  - β: curvature of the cost function
  - Θ_{sct}: supply shifters

Supply curve

Market outcome

- Marginal cost = price

$$C'_{sct}(Y_{sct}) = P_{ct}$$

- in logs:

$$y_{sct} = \Theta_{sct} + \beta \cdot p_{ct}$$

Supply curve

Supply equation

- Decomposition of supply shifters:

$$\Theta_{sct} = \alpha + \eta_{sc} + Z_{sct} \cdot \gamma + \varepsilon_{sct}$$

- Estimating equation

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

  - OLS is biased: $Cov(\varepsilon, p|Z, \theta) \neq 0$

Demand curve

Hotelling condition

- Ivory is storable (Kremer and Morcom 2000)
- Hotelling condition (no arbitrage):

$$E_t[P_{t+1}] = E_t[(1 + r_{t+1})]P_t$$

  - Intuition: sell today vs. sell tomorrow
  - Competitive storage market

Demand curve

Random walk process

- Hotelling condition implies random walk process for prices:

$$p_t - p_{t-1} = r_t + u_t + v_t$$

  - r_t stochastic and shocks to ivory demand (u) and supply (v).
  - $E(u) = E(v) = 0$: on average, prices grow at rate r_t.
  - Identifying assumption: $Cov(u, v) = Cov(w, v) = 0$.

Instrumental variable

- Gold prices follow similar random walk process:

$$p_t^g - p_{t-1}^g = r_t - z_t$$

  - z_t: shocks to gold markets
- Substituting:

$$p_t - p_{t-1} = p_t^g - p_{t-1}^g + u_t + v_t + z_t$$

  - Exclusion restriction: $Cov(z, v) = 0$
    - Shocks to ivory markets do not affect gold markets
    - Shocks to gold prices do not supply shifters (e.g. poachers' outside option)

Price pass-through

- Price pass-through equation

$$p_{ct} = \theta p_t - \delta_{ct}$$

  - θ: pass-through rate
  - δ_{ct}: trade costs

Summary

- Supply elasticity w.r.t. local (Africa) prices:

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

  - p_t^g as instrument for p_{ct}.

- Supply elasticity w.r.t. global (China) prices:

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

  - p_t^g as instrument for p_t.

Outline

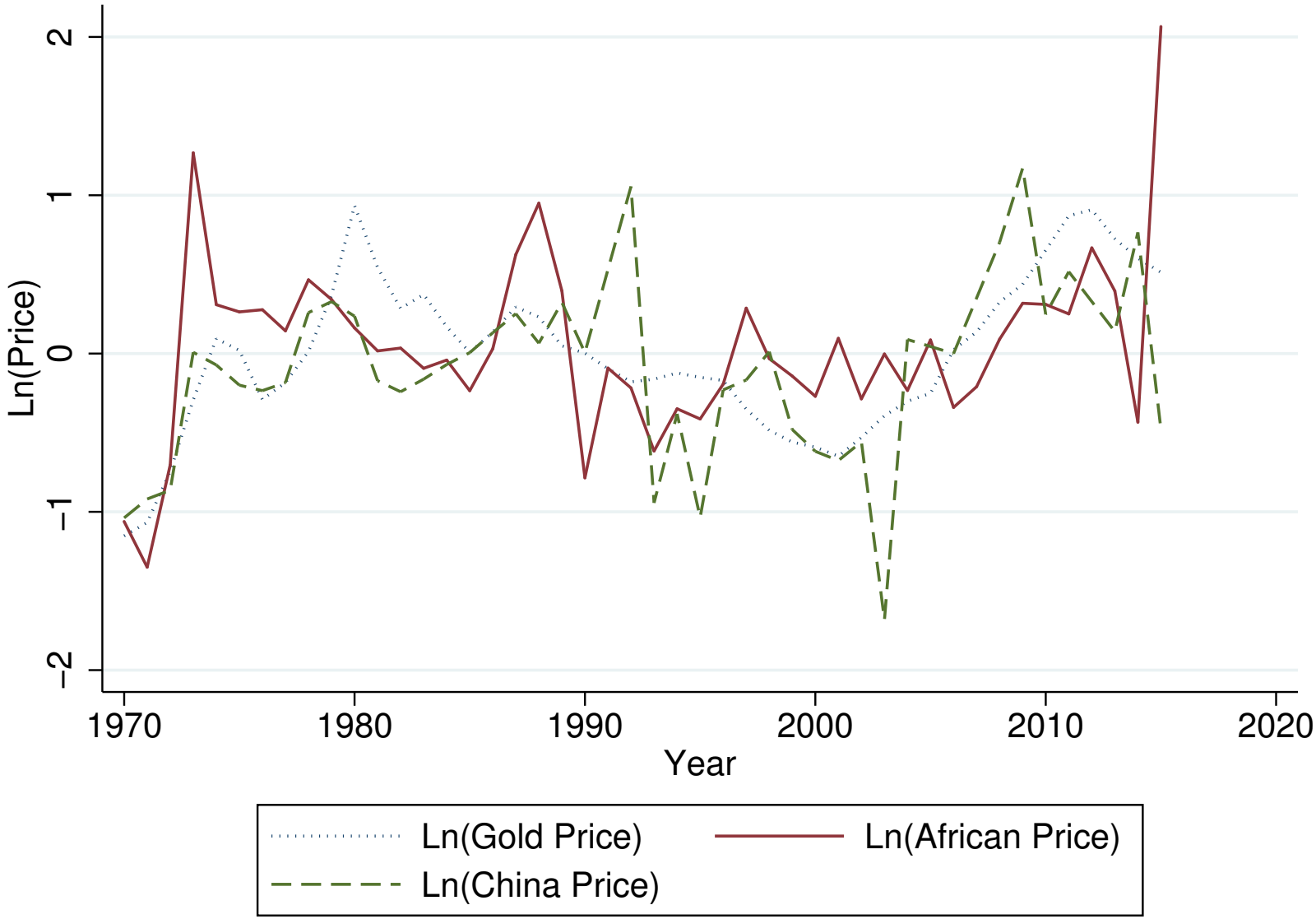
Data collection: sources

- Data on prices collected from
  - published reports
  - data from seizures (ETIS)
  - proprietary industry data and customs data
  - websites
  - government-held databases
  - market monitoring data from TRAFFIC
- 21,395 data points
  - raw and carved: 4,873 raw ivory prices
  - 91% African elephant
  - every segment of supply chain, but mostly importers (33%) and middlemen in country of production (27%)
  - 40% of the data are pre-1989

Price partialling out

- Restrict to raw ivory prices
- Systematic variation:
  - prices from customs declaration: lower
  - prices from "expert opinion" : higher
  - prices from middlemen (local) or poacher: lower
- Price partialling out:
  - regress price on dummies (source, location on supply chain, ...) except year and country
  - take residuals - take median
  - variation at the year x country level

Price series: AFR vs CHN



CHN prices: 1970-2015

Random walk?

CHN prices: 1970-2015

Testing for unit root

- Prices increase at constant rate (5%) both before and after 1992 (5.03% vs. 5.52%)
- 1992 attributable to 1989 CITES ban
- drop equivalent to 17 years of price growth
- unit-root test
  - Dickey-Fuller test and Phillips-Perron test (regress $p_t - p_{t-1}$ on p_{t-1} and tests if the coefficient is zero)
  - run separately pre/post 1992
  - fail to reject random walk (with drift) hypothesis

Outline

Poaching data

- In 1997, CITES institutes monitoring of illegal killing of elephants: MIKE programme
- Survey of selected sites (60 in 30 range states) for elephant carcasses: classification of carcasses as legally vs. illegally killed.
- Construction of PIKE: Proportion of illegally-killed elephants
- Data coverage: 2003 onwards

PIKE over time (2003-2016)

Other data

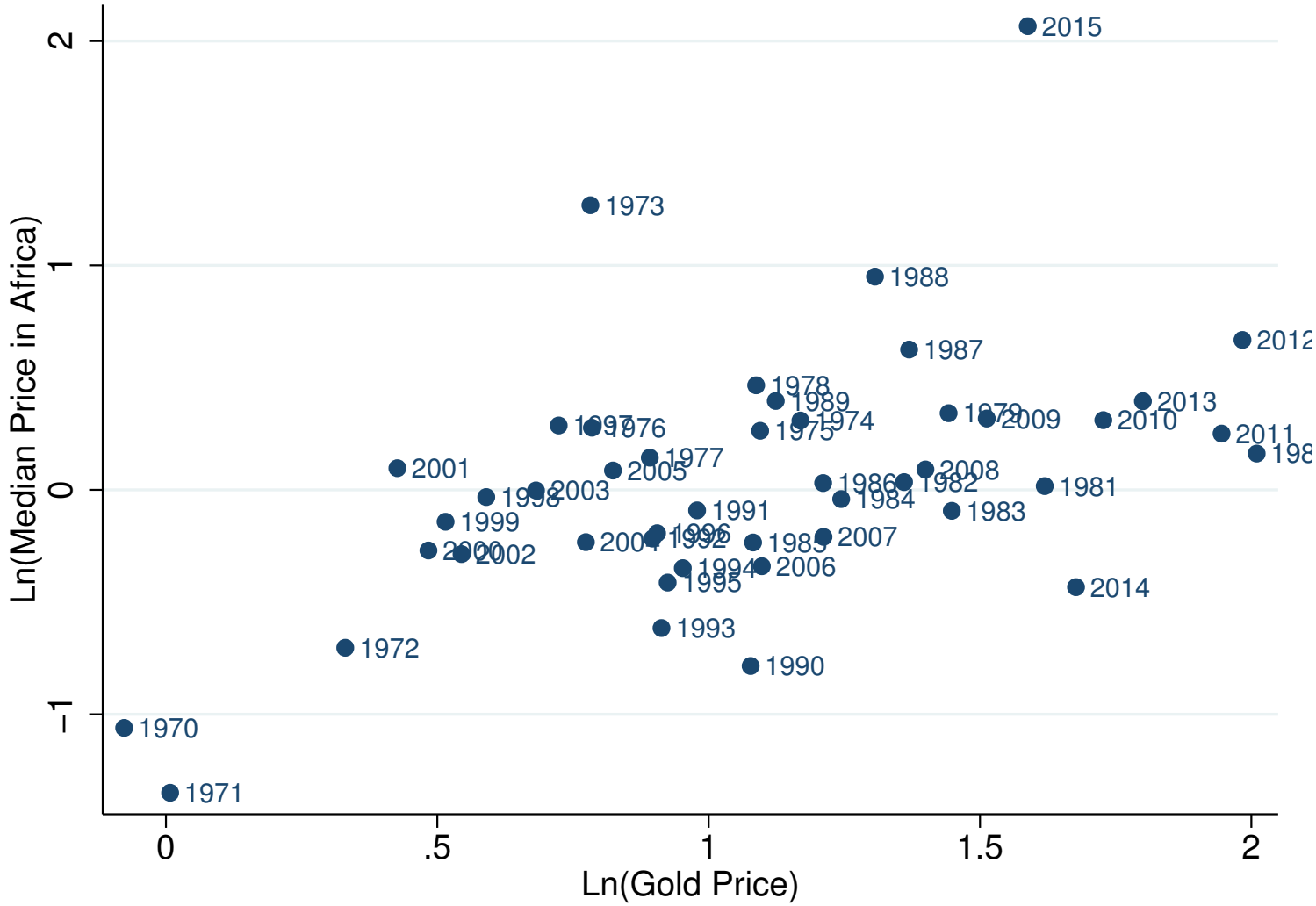
- Total amount of ivory seized (ETIS)
- Land area of a site
- GDP growth, Civil conflict variable

Outline

OLS results

LHS = Ln(Poaching)	OLS		2SLS, IV = Gold Price			
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Median Price)	0.178***	0.180***	0.431***	0.436***	0.637***	-0.301
	(0.053)	(0.054)	(0.082)	(0.082)	(0.148)	(0.193)
Ln(Total Carcass Found)	1.053***	1.046***	0.984***	0.973***	1.124***	0.980***
	(0.052)	(0.053)	(0.053)	(0.053)	(0.060)	(0.053)
Number of Conflicts		-0.123		-0.196	-0.350**	-0.055
		(0.166)		(0.157)	(0.168)	(0.159)
GDP Growth Rate		-0.019		-0.016	0.009	-0.035*
		(0.022)		(0.018)	(0.019)	(0.019)
Total Seizure					-0.114*	
					(0.058)	
Year						0.132***
						(0.043)
			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	151	114	151
First Stage F statistic			55.455	54.542	54.132	17.338
Site FE	Yes	Yes	Yes	Yes	Yes	Yes

Instrumental variables: first stage



2SLS results

LHS = Ln(Poaching)	OLS		2SLS, IV = Gold Price			
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Median Price)	0.178***	0.180***	0.431***	0.436***	0.637***	-0.301
	(0.053)	(0.054)	(0.082)	(0.082)	(0.148)	(0.193)
Ln(Total Carcass Found)	1.053***	1.046***	0.984***	0.973***	1.124***	0.980***
	(0.052)	(0.053)	(0.053)	(0.053)	(0.060)	(0.053)
Number of Conflicts		-0.123		-0.196	-0.350**	-0.055
		(0.166)		(0.157)	(0.168)	(0.159)
GDP Growth Rate		-0.019		-0.016	0.009	-0.035*
		(0.022)		(0.018)	(0.019)	(0.019)
Total Seizure					-0.114*	
					(0.058)	
Year						0.132***
						(0.043)
			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	151	114	151
First Stage F statistic			55.455	54.542	54.132	17.338
Site FE	Yes	Yes	Yes	Yes	Yes	Yes

When variables are not stationary

- Price and poaching series are not stationary (trend)
- Correlations might be spurious unless variables are co-trending
- Regression in first differences?
- IV is in any case consistent (Phillips and Hansen 1990)

Co-integration test

- Test of co-integration (Engel-Granger)
- Two-step process:
  - Compute linear relationship between variables of interest
  - Test stationarity of residuals

Variables	N	z-statistics	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

Robustness

- Restrict to larger sites (problem of sites with zero carcasses found) - heterogeneity
- Clustering methods: no Moulton correction - two-way clustering (country x year)
- Alternative instrument: silver prices

Robustness - results

LHS = Ln(Poaching)	Large (8)	Large (16)	One-way	Two-way	Silver	Silver& Gold
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Median Price)	0.526***	0.606***	0.436***	0.436***	0.602***	0.323***
	(0.100)	(0.125)	(0.114)	(0.136)	(0.134)	(0.077)
Ln(Total Carcass Found)	0.959***	0.964***	0.973***	0.973***	0.926***	1.005***
	(0.060)	(0.071)	(0.061)	(0.088)	(0.062)	(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)
	First Stage					
Ln(Gold Price)	1.167***	1.176***	1.222***	1.222***		2.868***
	(0.288)	(0.264)	(0.217)	(0.256)		(0.537)
Ln(Silver Price)					0.681**	-1.587***
					(0.283)	(0.476)
N	117	80	151	151	151	151
First Stage F statistic	35.898	27.189	54.542	54.542	17.390	46.408
Site FE	Yes	Yes	Yes	Yes	Yes	Yes

Policy

- Supply is inelastic: .44
- Partial equilibrium interpretation:

$$\arg\max_Y P_{sct} Y - \frac{\beta}{\beta+1} Y^{\frac{\beta+1}{\beta}} e^{-\frac{\Theta_{sct}}{\beta}} = \arg\max_Y e^{\frac{\Theta_{sct}}{\beta}} P_{sct} Y - \frac{\beta}{\beta+1} Y^{\frac{\beta+1}{\beta}}$$

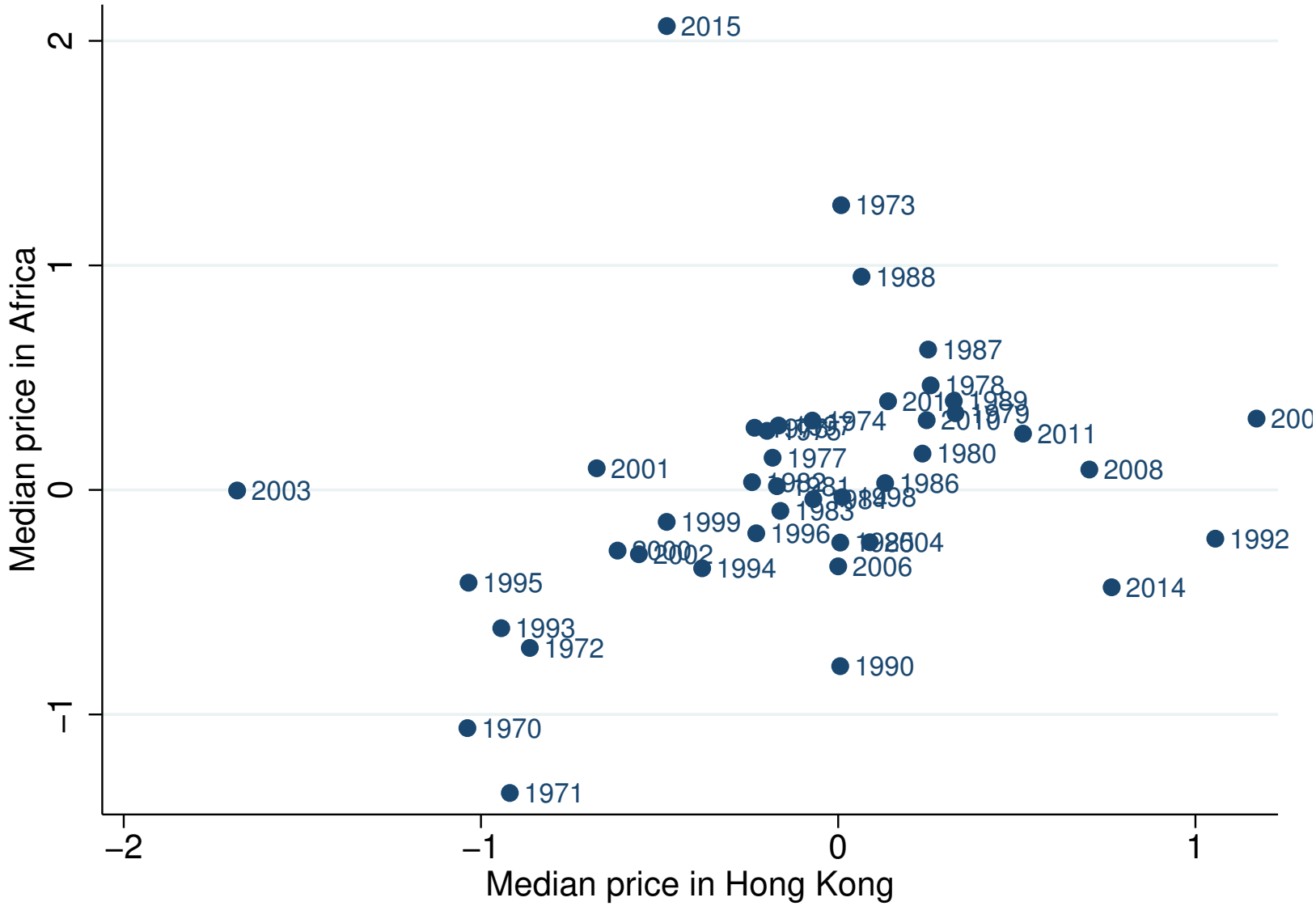
- If law enforcement increases probability of apprehension 10%, poaching drops by 4.4%
- Half of all tusks seized leads to PIKE dropping to .46 (from .63).

Estimating the price pass-through rate

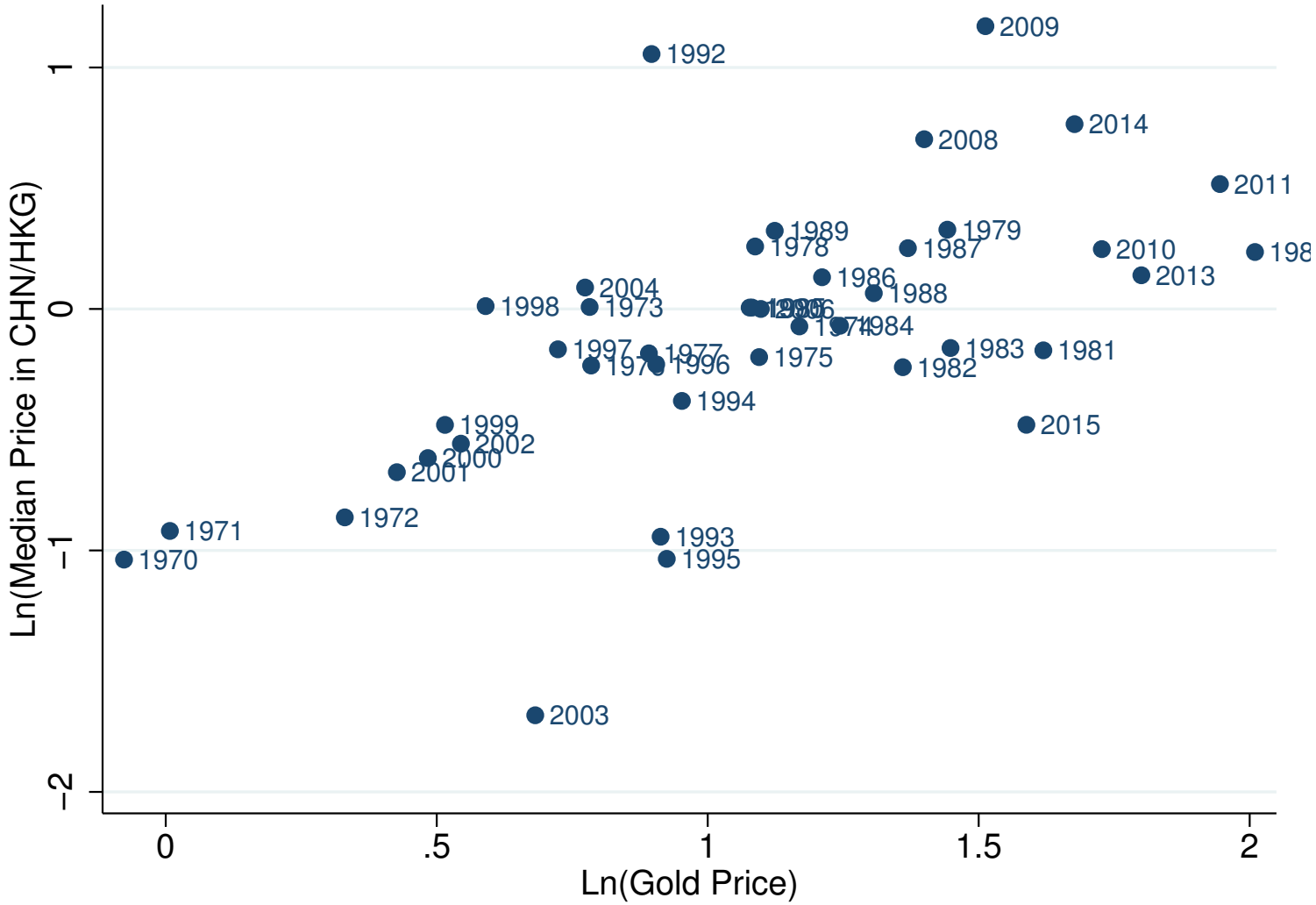
$$p_{ct} = \theta p_t + \delta_{ct}$$

- Prices over 1970-2014
- IV using gold prices

Correlation AFR - CHN prices



First stage


Ln(Median Price in CHN/HKG)
1
0
−1
−2
0
.5
1
1.5
2
Ln(Gold Price)
2009
1992
2014
2008
2011
1989
1979
1978
1987
2010
198
1986
2013
2004
1988
1998
1973
1984
1997
1977
1983
1981
1975
1996
1982
1994
1999
2015
2002
2000
2001
1971
1972
1993
1970
1995
2003

Results

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

Discussion

- Unitary price pass-through rate: no arbitrage opportunities in shipping
- OLS lower than 2SLS: consistent with law enforcement (seizures)

Elasticity of poaching with respect to China prices

- Same regression specification but with global (China) prices instead of local (African countries).
- IV global (China) prices with gold prices

OLS and 2SLS

LHS = Ln(Poaching)	OLS		2SLS, IV = Gold Price			
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Median Price), China	0.129**	0.129**	0.395***	0.398***	0.327***	0.224***
	(0.050)	(0.050)	(0.066)	(0.066)	(0.067)	(0.084)
Ln(Total Carcass Found)	1.027***	1.030***	1.010***	1.012***	1.052***	0.994***
	(0.029)	(0.029)	(0.028)	(0.029)	(0.041)	(0.030)
Number of Conflicts		0.031		0.000	-0.088	-0.025
		(0.069)		(0.067)	(0.105)	(0.069)
GDP Growth Rate		-0.003		-0.005	0.006	-0.004
		(0.005)		(0.005)	(0.008)	(0.005)
Total Seizure					-0.011	
					(0.046)	
Year						0.022**
						(0.009)
			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	422	248	422
First Stage F statistic			155.102	152.438	142.073	98.212
Site FE	Yes	Yes	Yes	Yes	Yes	Yes

Robustness

LHS = Ln(Poaching)	Large (8)	Large (16)	One-way	Two-way	Silver	Silver& Gold
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Median Price), China	0.512***	0.660***	0.398***	0.398***	0.346***	0.386***
	(0.092)	(0.129)	(0.138)	(0.144)	(0.081)	(0.066)
Ln(Total Carcass Found)	1.034***	1.057***	1.012***	1.012***	1.015***	1.013***
	(0.034)	(0.044)	(0.029)	(0.037)	(0.029)	(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)
			First Stage			
Ln(Gold Price)	0.844**	0.818**	0.922*	0.922**		0.719
	(0.352)	(0.338)	(0.471)	(0.465)		(0.734)
Ln(Silver Price)					0.773**	0.206
					(0.328)	(0.666)
N	281	176	422	422	422	422
First Stage F statistic	86.188	52.823	152.438	152.438	127.193	77.531
Site FE	Yes	Yes	Yes	Yes	Yes	Yes

Discussion

- $P_t \Rightarrow P_{ct} \Rightarrow Y_{sct}$
  - A = pass-through rate = .900
  - B = supply elasticity wrt local prices = .436
  - AxB = 0.392
  - C = supply elasticity wrt global prices = 0.398

Discussion

On the closing of the Chinese market

- Documented drop in prices of up to 2/3 between 2014 and 2017 (Martin and Vigne 2017)
- With a 2014 PIKE estimate at .63, 2017 estimate inferred to be down to .42
- What to expect?
  - Poaching has not dropped to zero
  - Storage condition not binding
  - Prices will move upward again

Outline

Summary

- Compute elasticity of poaching with respect to prices (in producing and consuming countries)
- Supply is found to be inelastic: large price changes necessary to affect poaching.
- Still a lot of uncertainty in terms of larger picture of elephant conservation.