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Analysis

Civil unrest and the poaching of rhinos in the Kaziranga National Park, India

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ABSTRACT

Civil unrest and political instability have been associated with endangered species poaching. This paper accounts for a period of civil unrest in Assam, India, which saw a marked increase in rhino poaching. Census data on the greater one-horned rhinoceros (*Rhinoceros unicornis*) in the Kaziranga National Park in Assam are used to estimate a population growth function. In calibrating the growth function's parameters the census data are used in conjunction with rhino poaching data. The rhino population and poaching data are used to econometrically estimate a harvest function. The relationship between civil unrest and rhino poaching is identified as positive and significant. The analysis factors in the probable relationships between poaching and several additional variables — including black market rhino horn prices, potential size of black markets, and anti-poaching efforts. These variables are seen to have the predicted associations with poaching, and help isolate the latter's relationship with civil unrest in the regression models. The goodness of fit between the data on rhino population and poaching and the estimates from regression models are studied.

1. Introduction

The Kaziranga National Park (KNP), spread over an area of three hundred and seventy eight square kilometers, is located in the northeastern state of Assam in India. The state of Assam shares international borders with Bangladesh and Bhutan, and is geographically close to Myanmar. A flagship species of the KNP is the greater one-horned rhinoceros (*Rhinoceros unicornis*) — also known as the Indian rhinoceros. Concerns over rhino poaching led to the declaration of Kaziranga as a national park in January of 1974 in accordance with the Assam National Park Act, 1968 (Saikia, 2011). Rhino poaching increased significantly in the 1980s through the mid 1990s in the state of Assam (refer to Table 1). This time period coincided with extensive civil unrest in Assam. The war of independence of Bangladesh (East Pakistan until March 1971) from West Pakistan in 1971 led to an exodus of ten million refugees to neighboring parts of India, including the state of Assam (UNHCR, 2012). The large influx of refugees changed the demographics of Assam and made the task of identifying illegal residents difficult (ICM, 2012). In 1979 mass movements led by native Assamese separatists campaigned for the detection of illegal migrants, for their removal from state voter lists, and for their deportation to Bangladesh (Thakur and Pandey, 2009). Secessionist tendencies began to form amongst the native Assamese in the late 1970s and a militant organization called the United Liberation Front of Assam was established with the goal of separation from the Indian state (ICM, 2012). This network of militant separatists was speculated to have carried out rhino poaching in Assam during the period of civil unrest in order to fund arms purchases through the illicit sale of rhino horn (Agarwal et al., 1999; Menon, 1996).

During the late 1970s the Assam state government, led by the Congress (I) party, was more favorable to illegal immigrants because the immigrants formed a significant electoral voting block (Thakur and Pandey, 2009). Disagreement between the native Assamese separatists and the state government led to a breakdown of state administration, and Assam was brought under President's rule in December of 1979 (ICM, 2012). In 1980 the Indian Army was deployed in the state to maintain law and order. Talks between the separatists and the central government made no progress between 1980 and 1983. Elections were imposed by the Indian central government in 1983 despite opposition by the Assamese separatists. The Congress (I) party came back to power, but the election result was deemed unacceptable by the separatists. Attempts to force the separatists to accept the election result led to a breakdown of the state administration, and violence led to the deaths of over three thousand people (Thakur and Pandey, 2009).

A peace accord was signed between the separatists and the central government in 1985, which led to the dissolution of the Congress (I) state government, and the agreement to deport illegal immigrants. A new regional political party, the Asom Gana Parishad (AGP), came to power after the signing of the peace accord. Secessionist sentiments remained strong despite the peace accord and new political leadership, which led to the continuation of civil unrest and armed conflict. A lack of clearly defined rules to identify illegal immigrants meant that the provisions of the peace accord were not implemented meaningfully, and this

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Table 1
Empirical data.

Year	Rhino population [a]	Rhino poaching [a]	Civil unrest [b]	Civil unrest (non-binary)[c]	Agricultural wage rate [d]	Assam GDP per capita[e]	Poaching penalty [f]	Anti-poaching camps [g]	Poachers arrested/ killed[g]	GDP (China + Vietnam) [h]	Rhino horn price for poachers [i]	Political party [j]	Muslim population [k]
1972	658	5	0	1	4.79	2533	20319	75	0	74631	–	INC_Sinha	3710117
1973	–	3	0	1	5.27	2712	20553	75	0	86135	–	INC_Sinha	3828326
1974	–	3	0	1	5.74	3494	20793	75	0	85198	–	INC_Sinha	3946535
1975	–	5	0	1	6.61	3853	23753	75	0	91601	–	INC_Sinha	4064745
1976	–	1	0	1	6.61	3588	20897	75	0	82273	–	INC_Sinha	4182954
1977	–	3	0	1	6.85	3447	19696	75	0	88973	–	INC_Sinha	4301163
1978	939	5	0	2	7.56	3640	19099	75	0	105517	308	JP_Borbora	4419372
1979	–	2	0	2	7.76	3874	19625	75	0	122980	355	JP_Borbora	4537582
1980	–	11	1	8	8.44	4953	20726	75	0	133278	477	Pres_rule	4655791
1981	–	24	1	8	7.52	5651	20258	75	0	122001	530	Pres_rule	4774000
1982	–	25	1	9	8.78	7468	21376	75	0	120191	–	INC_Kesab	4933167
1983	–	37	1	10	10.03	7026	18171	75	0	126167	–	Pres_rule	5092333
1984	946	28	1	10	11.29	8144	18131	75	0	124809	–	INC_Saikia	5251500
1985	–	44	1	7	15.36	8660	16759	75	4	114418	1159	INC_Saikia	5410667
1986	–	45	1	8	17.87	8987	16022	75	4	103845	–	AGP_Mhnta	5569834
1987	–	23	1	9	18.81	8980	15023	75	4	104884	–	AGP_Mhnta	5729000
1988	–	24	1	9	19.44	9124	13750	75	4	117522	–	AGP_Mhnta	5888167
1989	–	44	1	9	19.44	8530	12087	75	4	106249	–	AGP_Mhnta	6047334
1990	–	35	1	10	20.59	8815	10664	75	4	86874	–	Pres_rule	6206501
1991	1129	23	1	10	26.65	8952	9447	75	4	88419	–	Pres_rule	6365667
1992	–	49	1	7	29.16	8667	8354	75	4	99156	–	INC_Saikia	6553162
1993	1164	40	1	6	29.78	8704	7760	75	4	115255	800	INC_Saikia	6740656
1994	–	14	0	2	32.92	8867	6936	75	4	88236	–	INC_Saikia	6928151
1995	1200	27	0	2	36.58	9127	6271	75	4	94350	–	INC_Saikia	7115645
1996	–	26	0	2	38.10	8973	5672	75	4	100301	–	AGP_Mhnta	7303139
1997	1250	12	0	1	37.49	10041	5964	75	4	104314	1200	AGP_Mhnta	7490634
1998	–	8	0	1	32.28	9665	5381	121	5	109815	–	AGP_Mhnta	7678128
1999	1552	4	0	1	31.77	9899	5000	121	20	117166	1400	AGP_Mhnta	7865622
2000	–	4	0	1	31.25	12763	4808	121	15	127801	–	AGP_Mhnta	8053117
2001	–	8	0	1	30.09	12782	4630	121	4	140447	–	AGP_Mhnta	8240611
2002	–	4	0	1	43.00	12149	4300	121	4	155508	400	INC_Gogoi	8379680
2003	–	3	0	1	41.16	14401	9147	121	4	176249	–	INC_Gogoi	8518750
2004	–	4	0	1	52.88	14881	8814	121	4	201834	–	INC_Gogoi	8657819
2005	–	7	0	1	46.50	15859	8455	121	4	230910	–	INC_Gogoi	8796889
2006	1855	7	0	1	59.74	16357	7965	150	9	277064	–	INC_Gogoi	8935958
2007	–	16	0	1	33.70	16495	7488	150	24	336632	–	INC_Gogoi	9075027
2008	–	6	0	1	44.92	16474	6911	150	4	408553	–	INC_Gogoi	9214097
2009	2048	6	0	1	52.99	16696	6234	150	7	450563	–	INC_Gogoi	9353166
2010	–	5	0	1	51.49	16803	55660	150	11	516367	–	INC_Gogoi	9492236
2011	–	3	0	1	48.80	16287	48805	152	8	603790	–	INC_Gogoi	9631305
2012	2290	11	0	1	45.66	16664	45656	152	19	661713	4581	INC_Gogoi	9770374

[a] Talukdar (2000, 2002, 2003, 2006), Vigne and Martin (1998), and various Forest Department Annual Reports.
[b] Agarwal et al. (1999); Thakur and Pandey (2009).
[c] Integer variable indicating extent of civil unrest based on Assam's history. Higher values indicate periods of President's rule, Indian Army deployments, and civilian deaths due to unrest. Lower values (1 – 2) indicate time periods of relative political stability in Assam.
[d] Real daily agricultural wage rate in 2005 Indian Rupees (INR); time-series data on wage rates are available from various census reports for Assam. Conversion to real rates using consumer price indices (CPI) for Assam (Directorate of Economics and Statistics, various years; Jose, 1988; Rao, 1980).
[e] GDP per capita (2005 INR; sources — various Assam state population and economic census reports). With no population census conducted in 1981 the population estimates are interpolated using growth rates between the 1971 and 1991 Census.
[f] Poaching penalties (2005 INR) as per Indian Wildlife Protection Act (1972) Section 51 and its Amendments in 2003 and 2010 (MoEF, 2013).
[g] Assam's Forest Department set up 152 anti-poaching camps in KNP by 2012 (Gray, 2013) and 121 camps during the late 1990s and early 2000s (Mathur et al., 2005). In the 2000s there were improvements made to the anti-poaching camps' infrastructure and equipment; additional staff/guards were also employed — this doubled from three armed guards per camp in earlier periods to six armed guards per camp in the 2000s (sources: AFD (2008); Gray (2013), and author's personal communication with Principal Chief Conservator of Forests (Wildlife) Assam office). Given this doubling of number of armed guards per camp the number of anti-poaching camps in earlier periods is taken to be half of that in the 2000s to reflect the improvement in KNP's anti-poaching efforts. In 2006 KNP was declared a tiger reserve, which facilitated additional staff employment (Dutta, 2013). Information on poachers arrested/killed based estimates from AFD (2008), Dutta (2013), Gray (2013), and Talukdar (2000).
[h] GDP ('0,000,000 s US$) of China and Vietnam in 2005 CPI prices: http://www.ers.usda.gov/datafiles/International_Macroeconomic_Data/Historical_Data_Files/HistoricalCPIsValues.xls (accessed September 2013).
[i] Reports of rhino horn prices (US$/kg) available to poachers: 1978–1981, 1985 (Sas-Rolfes, 1997); 1993 (Milliken et al., 1993); 1997 (Vigne and Martin, 2000); 2002 (Talukdar, 2002); and 2012 (Eustace, 2012; Sas-Rolfes, 2012). Missing data interpolated using linear trends. US$ converted to 2005 INR using exchange rates (http://fx.sauder.ubc.ca/etc/USDpages.pdf (accessed September 2013)).
[j] Political party ruling Assam; INC_Sinha: Congress (I) under S.Sinha; JP_Borbora: Janata Party under G.Borbora; INC_Kesab: Congress (I) under K.Gogoi; INC_Saikia: Congress (I) under H.Saikia; AGP_Mhnta: Asom Gana Parishad under P.Mahanta; Pres_rule: President's rule; and INC_Gogoi: Congress under T.Gogoi.
[k] Assam census reports and Sachar et al. (2006).

only strengthened the secessionist sentiment. In 1990, President's rule was once again enforced and the Indian Army was used to subdue the militant separatists (Thakur and Pandey, 2009). In 1993 another peace accord was signed between the state government (under the Congress (I) party) and the separatists, wherein army operations were suspended and amnesty was granted to surrendering militants. The remaining militant separatists moved across the international border to Myanmar and Bhutan (ICM, 2012).

This paper studies an important but inadequately understood relationship between civil unrest and endangered species protection. Animal species in tropical countries have been subject to poaching in regions that have witnessed political instability and civil unrest.

For instance, the Central African region has seen a prolonged period of civil strife along with escalated levels of poaching in the elephant range states (UNSC, 2013). Civil unrest in the Democratic Republic of Congo is associated with gorilla poaching (WWF, 2014). Given the political nature of extensive civil unrest in Assam during the 1980s and 1990s and the associated increase in rhino poaching, this paper attempts to identify this relationship. In the next section I describe the data on which the empirical analysis is based. Section 3 discusses a suitable biological model of population dynamics of the Indian rhinoceros. Section 4 presents an identification strategy for quantifying the relationship between rhino poaching and civil unrest, while accounting for several other variables that are probably associated with poaching — including black market rhino horn prices, the potential size of black markets, and anti-poaching efforts in the KNP. The predicted associations of these variables with rhino poaching are described in Section 4. Section 5 provides a discussion of the regression results, and Section 6 concludes.

2. The Data

Census enumerations of the rhino population have been carried out by Assam's State Forest Department every few years since the declaration of Kaziranga as a national park. These data are listed in Table 1. Civil unrest in Assam is indicated as a binary variable assuming a value of 1 in periods of extensive unrest and political instability, and a value of 0 in other time periods. In addition I define an alternative variable representing civil unrest in Assam, which assumes integer values between 1 and 10 — with higher values representing periods of greater political instability, unrest, and militancy. Rhino poaching incidents in the KNP are regularly recorded every year by Assam's Forest Department. The mean poaching level during the extensive civil unrest period (1980–1993, i.e. 14 periods) is 32 rhinos per year compared to an average of 8 rhinos per year in the other time periods (1972–1979; 1994–2012, i.e. 27 periods). The difference in means of rhino poaching per year in these two periods (samples) is 24. A *t*-test of this difference derives a t-statistic of 7.62, which is statistically significant at the 99% confidence level.

As a measure of the opportunity cost of poaching in Assam I consider two variables: agricultural labor wage rates and gross state domestic product per capita. Data on wage rates, gross state domestic product, and Assam's human population are made available from various economic and population census reports. A penalty or fine is imposed by Assam's Forest Department for poaching. The penalty as per the Indian Wildlife (Protection) Act (1972) and its subsequent amendments are listed in Table 1. Assam's Forest Department employs anti-poaching staff or armed forest guards who regularly patrol the KNP to intercept and apprehend poachers (AFD, 2008). The Forest Department has a de facto shoot-to-kill policy, and more than one hundred poachers have been killed or arrested by forest guards since 1985 (Dutta, 2013). At present there are one hundred and fifty two anti-poaching camps in the KNP with approximately six armed forest guards in each camp (Gray, 2013). In earlier time periods there were fewer anti-poaching camps and forest guards in the KNP. Moreover, the anti-poaching camps' infrastructure – including communication, anti-poaching equipment, and staff survival kits – has improved significantly in the 2000s (AFD, 2008; Mathur et al., 2005). Table 1 lists the political party and chief minister in power in Assam. Different categorical values are assigned to the political parties under the different chief ministers in order to account for variation in state policy over time. I also note when President's rule was enforced in the state. The Muslim population is listed as per census reports and Sachar et al. (2006).

There is evidence of organized crime in the supply side of the rhino horn black market. Crime syndicates coordinate rhino horn supply through a network of poachers and middlemen who source horns from national parks in South Asia and South Africa, and ship them to China and Vietnam (Dutta, 2013; Sas-Rolfes, 2012; Somerville, 2012). Table 1 lists the gross domestic products of China and Vietnam as a measure of the external market demand. The few data of rhino horn price that poachers receive are listed in Table 1. Given that there are no regular time-series estimates of horn prices, I consider two such measures. As a *first measure* I assume a linear trend in the available information on horn prices to estimate the missing data points in Table 1. As a *second measure* I estimate a horn price index using a structural model of horn supply and demand through an organized crime network (see Appendix A). Demand is assumed to be a function of horn price and income in China and Vietnam. Supply is a function of horn price. Given that crime syndicates source horns from South Africa and South Asia, I use time-series data on rhino poaching in South Africa as an instrument for index estimation. Supply and demand functions are calibrated based on the assumption that the crime syndicate seeks to minimize the difference between supply and demand. This presumably ensures that horns move as quickly as possible from poacher to end consumer, and lowers the risk of getting caught by authorities (for instance, poachers are known to sell horns as quickly as possible to smugglers to avoid interception by authorities (Sas-Rolfes, 2012)). The index increases over time (see Table A.1) — reflecting the trend in the limited data on horn prices available to poachers.

3. A Population Model of Rhino in the KNP

Using the limited data on rhino census numbers I adopt the methodology of Cromsigt et al. (2002) to estimate rhino population for the intervening years during which no census was conducted. I estimate a rhino population model that best fits the observed data. The approach adopted by Cromsigt et al. is to assume the relationship between the modeled population, X_t, and the observed census population, P_t, as Eq. (1), where ϵ_t is the error term with an assumed expected value of zero, and a variance of σ^2. For a given initial population size, P_{1972}, the best possible estimates of the population model parameters can be computed by minimizing the sum of squared errors, $\sum \epsilon_t^2$ (for the years when census data is available, i.e. $t = 1972$, 1978, 1984, 1991, 1993, 1995, 1997, 1999, 2006, 2009, and 2012). A non-linear solver was used to find the parameters of the population model that minimized the sum of squared errors.

$$P_t = X_t + \epsilon_t \tag{1}$$

For a population growth function Cromsigt et al. find that the modified logistic growth function gives the best fit to population data on South African black rhinos (*Diceros bicornis*). Their modified logistic growth function fit observed black rhino population data better than other growth functions such as the exponential growth function, which has a constant specific growth rate r, and the ordinary logistic growth function. The modified logistic growth function assumes the form: $F(X_t) = rX_t(1 - (X_t/K)^z)$, where K is the carrying capacity and z (>1) is a skew parameter that allows for non-linearity in the relationship between X_t and the strength of density-dependence $(1 - X_t/K)$. When modeling mega-fauna there is empirical support for $z > 1$ because density-dependence becomes more important when the population is closer to carrying capacity (Cromsigt et al.). I use the time series data on poaching levels, H_t, to account for harvest subtracted from yearly growth, $F(X_t)$. The iterative map (2) describes rhino population dynamics in the KNP:[1]

$$X_{t+1} = X_t + rX_t\left(1-(X_t/K)^z\right)-H_t. \tag{2}$$

[1] Alternatively one can consider another growth function:

$$X_{t+1} = Xt + r(X_t-H_t)\left(1-((X_t-H_t)/K)^z\right)$$

Harvest, H_t, is not just a deductible term, as in Eq. (2), but influences both r and z. This is plausible when poaching takes place before species reproduction, or when poachers target only mature rhinos with larger horns for instance. Calibrated values for this growth function are: $r = 0.03132$, $z = 109.795$. The two estimated populations have a correlation coefficient = 0.9921.

I use the given initial population level, P_{1972}, as the starting value for the iterative map, i.e. $X_{1972} = 658$. I then assign initial guesses for the demographic model's parameters r, z, and K as per Table 2. The optimized values for the parameters are reported in Table 2. The best-fit value I obtain for $r = 0.0484$. Other studies – (Mason et al., 2012; Milner-Gulland and Leader-Williams, 1992) – have used an intrinsic growth rate of $r = 0.06$ to model population dynamics of African black rhinos. The best-fit skew parameter value I obtain for $z = 7.5676$. Mason et al. and Milner-Gulland & Leader-Williams use a skew parameter value of $z = 7$; Cromsigt et al. estimate a z value between 10 and 28. Rhino population estimates derived using the method of least squared errors are plotted in Fig. 1. These data are used to estimate a poaching model in the next section.

4. Estimating a Harvest Function and Identifying the Relationship between Civil Unrest and Rhino Poaching

I assume an exponential harvest function (Spence, 1973) to model poaching, *Yt*:

$$Y_t \equiv Y_t(X_t, E_t) = X_t(1 - \exp(-qE_t)) \tag{3}$$

X_t	rhino population in year t
E_t	harvesting effort ($E_t = 0 \Rightarrow Y_t = 0$; as $E_t \to \infty$, $Y_t \to X_t$)
q	catchability parameter ($q > 0$).

Poudyal et al. (2009) use time-series data on rhino poaching in Nepal to estimate a reduced-form harvest function under the assumption of zero-profits with de facto open access. The variables they consider in the profit function are the price received by local poachers for rhino horn (p), quantity of horns harvested ($h(\cdot)$), and anti-poaching effort (B). Harvest, $h(\cdot)$, is a function of the anti-poaching effort, poaching effort (E), and the rhino population (X). They net out both the expected poaching fine ($\theta(B,E)[F + ph]$), where $\theta(\cdot)$ is the probability of getting caught, and the cost of poaching ($c(A)E$), where $c(\cdot)$ is a function of the opportunity cost of poaching such as local wage rates (A). Under the assumption of zero profits, they solve for the reduced-form equilibrium poaching effort, E^*, which is a function of B,X,A,F p. There are other characteristics that might be pertinent to estimating poaching effort, for which one must rely on proxy information. Poudyal et al. proxy the fines imposed on convicted poachers by poaching fines set as per Nepalese law. They proxy the international demand for rhino horn by East Asian gross domestic product, given that an inverse demand relationship determines black market horn price.

I assume aggregate harvesting effort to be represented by a composite term $E_t = (1 + \beta_1 R_t + \beta_2 A_t + \beta_3 P_t + \beta_4 G_t + \beta_5 W_t + \beta_6 C_t + \beta_7 B_t + \beta_8 I_t + \varepsilon_t)$, which is estimated econometrically using the data in Table 1 and the estimated rhino population from the previous section. I define the individual terms of E_t:

R_t	civil unrest in Assam (binary and discrete [1, 10])
A_t	number of anti-poaching camps in KNP (or number of armed forest guards)

Table 2
Population model's parameter calibration.

Census populations (P_t)	Initial value guesses	Calibrated values
$P_{1972} = 658$, $P_{1978} = 939$	$r = 0.10$	$r = 0.0484$
$P_{1984} = 946$, $P_{1991} = 1129$, $P_{1993} = 1164$,	$z = 1$	$z = 7.5676$
$P_{1995} = 1200$, $P_{1997} = 1250$, $P_{1999} = 1552$,	$K = 2400$	$K = 2420$
$P_{2006} = 1855$, $P_{2009} = 2048$, $P_{2012} = 2290$	$\sum \epsilon_t^2 = 24,300$	$\sum \epsilon_t^2 = 3,752$

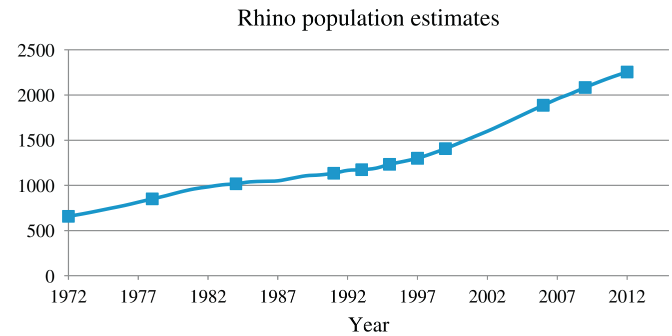

Fig. 1. Estimated rhino population for r, z, and K that minimizes $\sum_t \epsilon_t^2$.

P_t	poaching penalty in Assam
G_t	gross domestic product (GDP) per capita in Assam
W_t	agricultural labor wage rate in Assam
C_t	GDP of China/Vietnam
B_t	black market horn price for poachers
I_t	estimated price index (see Appendix A)
ε_t	error term.

Rearranging the terms of Eq. (3) yields an estimable Eq. (4):

$$ln[1 - Y_t/X_t] = -q(1 + \beta_1 R_t + \beta_2 A_t + \beta_3 P_t + \beta_4 G_t + \beta_5 W_t + \beta_6 C_t + \beta_7 B_t + \beta_8 I_t + \varepsilon_t). \tag{4}$$

The natural log term on the left-hand side of Eq. (4) is taken to be the dependent variable in the regression models. The exponential harvest function, Eq. (3), requires that the constant term, q, be greater than zero. Given the observed increase in rhino poaching during the period of extensive civil unrest in Assam, I predict that the coefficient of R_t will be positive ($\beta_1 > 0$). The presence of more anti-poaching camps and armed forest guards would increase the likelihood that poachers get caught and thereby reduce poaching ($\beta_2 < 0$). Poaching is predicted to decrease with the poaching penalty ($\beta_3 < 0$). I expect that Assam GDP per capita (G_t) would have a negative effect on poaching ($\beta_4 < 0$). Similar to (Poudyal et al., 2009) I predict that since income of China and Vietnam would have a positive effect on poaching ($\beta_6 > 0$). Higher black market horn prices would create an additional incentive to poach ($\beta_7 > 0$). Alternatively the horn price index, I_t, is predicted to be positively related to E_t, i.e. $\beta_8 > 0$. I_t should be used as a covariate in regression models without C_t and B_t to avoid the problem of multicollinearity because C_t is used to estimate I_t. Since $-q$ is multiplied through the parenthesis in Eq. (4) the regression coefficient estimates should be the opposite of the signs predicted: $-q\beta_1 < 0$, $-q\beta_2 > 0$, $-q\beta_3 > 0$, $-q\beta_4 > 0$, $-q\beta_5 > 0$ $-q\beta_6 < 0$, $-q\beta_7 < 0$, and $-q\beta_8 < 0$.

Since poaching was higher during civil unrest one might encounter omitted variable bias in the regression coefficient estimates. Such bias might occur when there is some variable that is correlated with both the dependent and the independent variables, and for which there are usually no data available (Angrist and Pischke, 2009). To provide an unbiased estimate of the effect of the independent variable of interest (civil unrest) on the dependent variable (rhino poaching) an econometric model should include any determinants of the dependent variable that are also correlated with the independent variable of interest (Angrist and Pischke, 2009). I consider two instrumental variables to identify the relationship between civil unrest and rhino poaching: “ruling political party in Assam” and “Muslim population in Assam”. Given Assam's historical context these instruments are probably associated with civil unrest, but not correlated with other independent variables that affect rhino poaching.

5. Results and Discussion

Eq. (4) is econometrically estimated and the results are listed in Table 3. In the first model, (OLS_0), ordinary least squares (OLS) is used to examine the relationship between civil unrest and poaching. The catchability coefficient, q, estimated at 0.0056, has the expected positive sign and is statistically significant. The civil unrest coefficient, β_1, has the predicted positive sign and is statistically significant. The regression coefficients, β_i, are calculated by dividing $-q\beta_i$ by $-q$, $i = 1,\ldots,8$. I calculate $\beta_1 = -0.025 \,/\, -0.006 = 4.46$, which suggests that the unrest period in Assam was associated with at least four times more poaching effort per year as compared to the non-unrest time period. This interpretation of β_1 follows from the binary definition of civil unrest, R_t, in Eq. (4). One needs to consider additional covariates; this is done in model (OLS_1). A higher number of anti-poaching camps in the KNP appear to significantly reduce poaching. Poaching penalty has an expected negative effect but is not statistically significant. Other controls of GDP per capita and agricultural wages in Assam are not statistically significant. The external demand for rhino horn appears to rise with income in China as predicted, but the coefficient (β_6) is not statistically significant. Similarly horn price coefficient (β_7) is positively related to poaching. I find that the relationship between unrest and rhino poaching is positive ($\beta_1 > 0$) and significant. The Durbin–Watson statistic indicates that the error terms are not serially correlated.

In model (OLS_2) I consider different covariates and again find the relationship between unrest and poaching to be positive and significant: $\beta_1 = -0.022/-0.0117 = 1.89$, i.e. the unrest period is associated with nearly twice as much poaching effort per year. A higher number of armed forest guards in KNP's anti-poaching camps appear to significantly reduce poaching. I also consider the GDP of both China and Vietnam, C_t, and find that income in these two countries is positively associated with poaching. Similar to OLS_1 horn price, B_t, is positively related to poaching effort. The poaching penalty coefficient (β_2) has the predicted negative sign but is not statistically significant. In model (OLS_3) I consider the effect of the horn price index, I_t, which is estimated using the income of China and Vietnam. The effect of the price index has the predicted positive effect and is significant. Poaching penalty and anti-poaching camps reduce poaching significantly. The catchability coefficient, q, is however not statistically significant. In models (OLS_4) and (OLS_5) I note that B_t and C_t significantly increase poaching. I check for endogeneity in the regression results by calculating the correlation between the error terms from the biological parameter calibration, ϵ_t (Eq. (1)), and the regression residuals, ε_t. The R^2 value (last row of Table 3) indicates very low correlation between these error terms.

I now check for endogeneity caused by omitted variable bias. Model (IV_1) uses the instrumental variable indicating the category of the political party ruling Assam. The argument for using this instrument is that civil unrest was political in nature and there is no correlation between political parties and the other independent variables affecting rhino poaching. The signs and statistical significance of the coefficients are similar to model (OLS_1). Civil unrest and the catchability coefficients are positive and significant. The test of the null hypothesis of over-identifying restrictions is satisfied, given that there are more instruments (eight categories of political parties) than the endogenous

Table 3
Regression estimates with dependent variable = $\ln[1 - Y_t/X_t]$.

Independent variable	Coefficient	(OLS_0)	(OLS_1)	(OLS_2)	(OLS_3)	(OLS_4)	(OLS_5)	(IV_1)	(IV_2)
Constant	$-q$	−0.00569 (0.0010)***	−0.02596 (0.0063)***	−0.01171 (0.0031)***	0.01461 (0.0191)	−0.02333 (0.0070)***	−0.02493 (0.0071)***	−0.02902 (0.009)***	−0.01072 (0.0052)**
Civil unrest, R_t (binary)	$-q\beta_1$	−0.02507 (0.0028)***	−0.01922 (0.0043)***	−0.02223 (0.0043)***	−0.01799 (0.0042)***	−0.02054 (0.0035)***	−0.02165 (0.0032)***	−0.01697 (0.0069)**	−0.02117 (0.0076)***
Anti-poaching camps, A_t	$-q\beta_2$	–	0.00030 (0.0001)***	-	0.00029 (0.0001)***	0.00017 (0.00006)**	0.00020 (0.00007)***	0.00035 (0.0001)**	-
Anti-poaching guards, A_t	$-q\beta_2$	–	–	0.00002 (0.00001)*	–	–		–	0.00002 (0.00002)
Poaching penalty, P_t	$-q\beta_3$	–	1.03e − 07 (8.62e − 08)	1.09e − 07 (8.95e − 08)	1.06e − 07 (5.52e − 08)*	1.79e − 07 (8.20e − 08)**	2.61e − 07 (1.15e − 07)**	1.02e − 07 (7.72e − 08)	1.14e − 07 (9.06e− 08)
Assam GDP (per capita), G_t	$-q\beta_4$	–	−7.45e − 07 (7.74e − 07)	2.22e − 07 (6.97e − 07)	−9.00e − 07 (8.55e − 07)	–	–	−1.07e − 06 (1.16e − 06)	−2.38e − 07 (8.29e − 07)
Wage rate, W_t	$-q\beta_5$	–	−0.00006 (0.00013)	−0.00018 (0.00016)	0.00012 (0.00017)	–	–	−0.00001 (0.00017)	−0.00009 (0.0002)
GDP (China), C_t	$-q\beta_6$	–	−7.17e − 09 (2.68e − 08)	–	–	–	–	−6.44e − 09 (2.48e − 08)	−2.35e − 08 (2.35e − 08)
GDP (China + Vietnam), C_t	$-q\beta_6$	–	-	−7.00e − 09 (2.56e − 08)	–	–	−3.70e − 08 (1.59e − 08)**	–	–
Horn price (for poacher), B_t	$-q\beta_7$	–	−0.00004 (0.00007)	−0.00007 (0.00009)	–	−0.00009 (0.00005)*	–	−0.00004 (0.00007)	–
Horn price (index), I_t	$-q\beta_8$	–	–	–	−0.09173 (0.0493)*	–	–	–	–
Instrumental variable		–	–	–	–	–	–	Political party	Muslim population
R^2		0.7426	0.8085	0.7832	0.8155	0.7824	0.7853	0.8063	0.7770
F-statistic		78.50	17.37	16.78	23.60	26.54	25.57	702.84[f]	2.97[f]
D–W statistic[a]		1.4322	2.0328	1.7625	2.0102	1.6816	1.7847	–	–
C–H test[b]		–	–	–	–	–	–	0.7854	0.3209
Hansen J test (p-value)[c]		–	–	–	–	–	–	0.2229	–
Endogeneity test (p-value)[d]		–	–	–	–	–	–	0.6673	0.7942
Under-identification test[e]		–	–	–	–	–	–	0.1112	0.1675
Correlation of residuals[g]		0.0031	0.0007	0.0002	8.78e − 06	0.0059	0.0131	0.0001	0.0235

Observations = 41; robust standard errors in parentheses; statistical significance at 1% (***), 5% (**), 10% (*) error levels.
[a] Durbin–Watson test statistic for auto-correlation.
[b] Cumby–Huizinga chi-square test statistic's p-value; null hypothesis: error terms not serially correlated at order one.
[c] Hansen's J-statistic for test of over-identifying restrictions when there are more instruments than endogenous variables.
[d] Durbin–Wu–Hausmann test of endogeneity (p-value reported); null hypothesis: variables are exogenous.
[e] Kleibergen–Paap LM test statistic for under-identification under null hypothesis (p-value reported).
[f] First stage F-statistic of instrumental variable regression.
[g] Correlation between residuals (ϵ_t) from Eq. (1) and regression residuals.

variable. The first stage F-statistic exceeds the benchmark of 10, which indicates a strong instrument (Stock et al., 2002). Including additional covariates appears not to change the magnitude of the civil unrest coefficient much, which implies that the instruments aren't correlated with the covariates — a condition that satisfies the exclusion restriction in instrumental variable regression (Angrist and Pischke, 2009). The endogeneity test reports a probability value of 0.6673 — indicating that civil unrest is not endogenous. Model (IV_2) uses the instrument indicating population of Muslims in Assam. The argument for using this instrument is that since unrest was the response of Assamese separatists to the illegal immigration of Muslims from neighboring Bangladesh, this population presumably affected poaching effort only indirectly through the unrest variable, and is not correlated with the other independent variables. The results suggest that civil unrest was associated with twice as much poaching on average (i.e. $\beta_1 = -0.021\ /\ -0.011 \approx 2$). The first stage F-statistic is less than 10, which suggests that the instrument of Muslim population is not strong. The Cumby–Huizinga test statistic produces a probability value of 0.321 suggesting that the error terms aren't serially correlated.

I conduct robustness checks using the alternative (non-binary) definition of civil unrest (see Table 1), and the alternative rhino population estimates (using growth equation in footnote 1). In Table 4 under model (OLS_ 6) I use the same covariates as model (OLS_1) except that the unrest variable is non-binary. Unrest is still positively and significantly associated with poaching except that the magnitude of β_1 is lower because of the non-binary definition. I note that the coefficients of catchability, anti-poaching, income in China, and horn prices have the same signs and magnitudes as those in OLS_1. Model (OLS_7), which uses the alternative rhino population estimates and the same covariates as model (OLS_2), yields similar signs and magnitudes of the regression coefficients as the other models. In model (IV_3) I use the political party instrument to check for omitted variable bias. The results are similar to those in model (IV_1). In model (OLS_8) I find no significant effect of the number of poachers arrested/killed by forest guards on reducing poaching. Model (OLS_9), using the same covariates as model (OLS_5), shows that the difference between external GDP and domestic GDP (i.e. China + Vietnam–Assam) has a positive and significant effect on rhino poaching. In model (OLS_10) I consider interactive terms of unrest with anti-poaching camps, GDP of China, and horn price for poachers. The interactive terms show the effect of these variables on poaching during civil unrest. GDP of China is a significant determinant of poaching. The poaching penalty coefficient is negative and significant. The coefficient ($\beta_1\beta_7$) of the interactive term, unrest × horn price, is positive and significant, thus suggesting that price had a stronger effect on poaching during unrest.

The main result of this paper is that civil unrest is positively and significantly associated with rhino poaching in Assam — the unrest period is associated with up to four times more poaching effort per year compared to other time periods. The results in this paper are similar to those of Poudyal et al. who find that civil unrest (defined as Maoist insurgency in Nepal) led to significantly higher rhino poaching; that anti-poaching by the Nepalese Forest Department significantly reduces poaching; that GDP in East Asia has a positive but insignificant effect on poaching; and that poaching penalty insignificantly reduces poaching. In this paper I find that anti-poaching efforts of the Assam Forest Department significantly reduce poaching; poaching penalty reduces poaching (significantly in OLS models 3,4,5,9,&10); Chinese and Vietnamese GDP are positively associated with poaching (significantly in OLS models 5,9, &10); and that both measures of horn price are positively associated with poaching (significantly in OLS models 3,4,&10).

Having estimated Eq. (4) I now fit the data on rhino poaching and population to the estimated trend to examine the goodness of fit of

Table 4
Robustness checks for regression estimates.

Independent variable	Coefficient	(OLS_6)	(OLS_7)[a]	(IV_3)	(OLS_8)	(OLS_9)	(OLS_10)
Constant	$-q$	−0.02593 (0.0080)***	−0.00933 (0.0040)**	−0.03071 (0.0098)***	−0.00515 (0.0026)*	−0.02020 (0.0061)***	−0.02269 (0.0057)***
Civil unrest (non-binary)	$-q\beta_1$	−0.00223 (0.0006)***	−0.00274 (0.0006)***	−0.00183 (0.0007)**	−0.00334 (0.0005)***	−0.00290 (0.0004)***	–
Anti-poaching camps	$-q\beta_2$	0.00034 (0.0001)***	–	0.00041 (0.0001)***	–	0.00018 (.00006)***	0.00023 (0.00008)***
Anti-poaching guards	$-q\beta_2$	–	0.00003 (0.00001)*	–	–	–	–
Poachers arrested/killed	$-q\beta_2$	–	–	–	−0.00033 (0.00027)	–	–
Poaching penalty	$-q\beta_3$	1.04e − 07 (9.63e − 08)	9.80e − 08 (9.55e − 08)	1.03e − 07 (8.59e − 08)	2.07e − 10 (1.04e − 07)	2.24e − 07 (9.96e − 08)**	1.87e − 07 (1.87e − 07)**
Assam GDP (per capita)	$-q\beta_4$	−1.05e − 06 (8.72e − 07)	−1.04e − 07 (7.65e − 07)	−1.50e − 06 (1.02e − 06)	1.03e − 06 (7.62e − 07)	-	1.59e − 08 (7.28e − 07)
Wage rate	$-q\beta_5$	−0.000017 (0.00015)	−0.00009 (0.00016)	0.00005 (0.0001)	−0.00028 (0.00019)	–	−0.00016 (0.00016)
GDP (China)	$-q\beta_6$	−7.16e − 09 (3.25e − 08)	-	−6.02e − 09 (2.92e − 08)	2.97e − 08 (4.28e − 08)	–	−4.38e − 08 (1.81e − 08)**
GDP (China + Vietnam)	$-q\beta_6$	–	−1.99e − 09 (3.06e − 08)	–	–	–	–
GDP (China + Vietnam–Assam)	$-q\beta_6$	–	–	–	–	−3.37e − 08 (1.36e − 08)**	–
Horn price (for poacher)	$-q\beta_7$	−0.00004 (0.00009)	−0.0001 (0.0001)	−0.00005 (0.00008)	−0.00007 (0.00012)	–	0.000069 (0.00005)
Unrest × anti-poaching camps	$-q\beta_1\beta_2$	–	–	–	–	–	-0.00041 (0.0003)
Unrest × GDP of China	$-q\beta_1\beta_6$	–	–	–	–	–	1.64e − 07 (2.02e − 07)
Unrest × Horn price for poacher	$-q\beta_1\beta_7$	–	–	–	–	–	−0.00033 (0.00018)*
Instrumental variable		–	–	Political party	–	–	–
R^2		0.7612	0.7471	0.7576	0.7220	0.7446	0.8313
F-statistic		13.31	12.87	267 (First stage)	9.99	20.93	13.17

Observations = 41; robust standard errors in parentheses; statistical significance at 1% (***), 5% (**), 10% (*) error levels.
[a] Rhino population estimated using alternative growth function (see footnote 1).

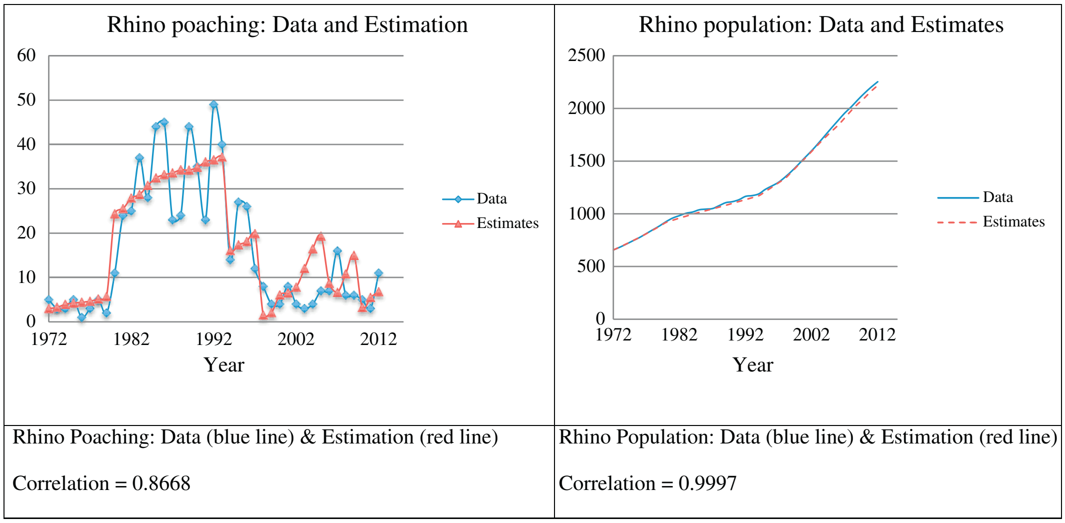

Fig. 2. Rhino poaching and rhino population fit between data and estimates (*model OLS_1*).

the regression results. The coefficients of the regression models (q & β_i, $i = 1,\ldots,8$) can be used to estimate rhino poaching levels, Y_t, as given by Eq. (3): $Y_t = X_t(1-e^{-qE_t})$, where $E_t = (1 + \beta_1 R_t + \beta_2 A_t + \beta_3 P_t + \beta_4 G_t + \beta_5 W_t + \beta_6 C_t + \beta_7 B_t + \beta_8 I_t + \varepsilon_t)$. Given that the actual rhino poaching data (H_t) is econometrically estimated as Y_t, the rhino population estimates can now be calculated using Eq. (2): $X_{t+1} = X_t + rX_t(1 - (X_t/K)^z) - Y_t$. This provides estimates of rhino population and poaching levels from 1972 through 2012. I examine the goodness of fit between the data and estimates from models (OLS_1), (OLS_2), (IV_1), and (IV_3). I plot the data and the estimates of poaching and population as per these regression models in Figs. 2–5 respectively, and list the correlation coefficients between the data and the estimates. I find that the ordinary least squares regression model, (OLS_1), suggests a correlation coefficient of 0.8668 between the poaching data and their estimates, which is higher than that in the instrumental variable regression models (IV_1) and (IV_3). Model (OLS_2) does not appear to provide as good a fit in the poaching data and their estimates as the other models. The correlation coefficient between the poaching data and their estimates from model (IV_2) that uses the Muslim population instrument is 0.7800; this is lower than 0.8636 — the corresponding correlation coefficient in model (IV_1) that uses the political party instrument. This suggests that the model using the political party instrument yields better explanatory power than that using the Muslim population instrument.

6. Conclusion

In this paper I have examined the historical context of extensive civil unrest in Assam and the concurrent increase in rhino poaching. Using data on rhino poaching in the Kaziranga National Park I have undertaken two exercises. The first exercise is a calibration of the biological parameters of a rhino population growth function. Given that animal census enumerations are expensive and not undertaken regularly in Assam, I have adopted the methodology of previous studies to estimate rhino population levels for time periods in which data aren't available. The empirically calibrated parameters are similar to those derived in other studies of rhino populations.

In the second exercise this paper identifies the relationship between extensive civil unrest and rhino poaching in Assam. Given the illicit nature of rhino poaching one would encounter the problem of missing relevant data — such as regular time-series data on black market rhino horn prices and international market demand for rhino horn. Data

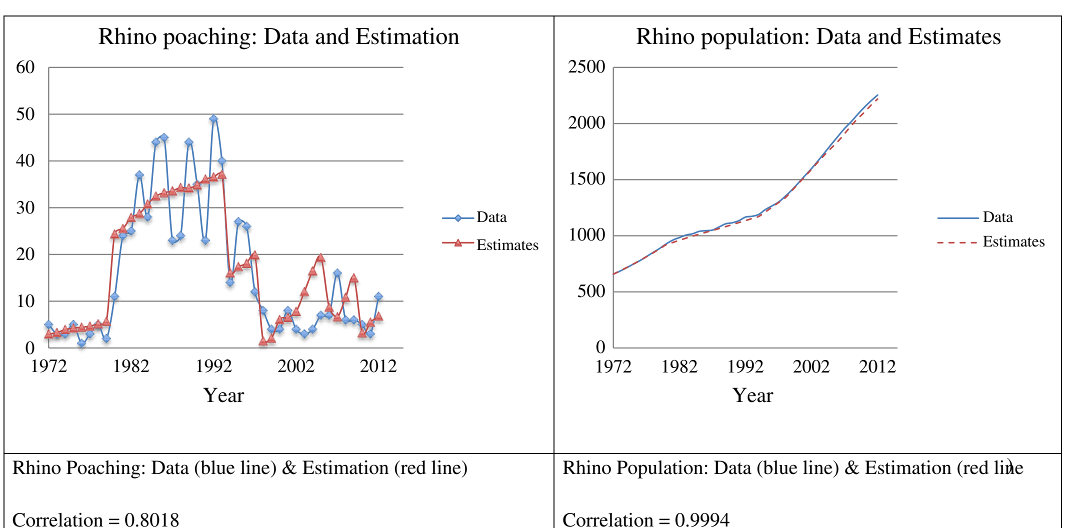

Fig. 3. Rhino poaching and rhino population fit between data and estimates (*model OLS_2*).

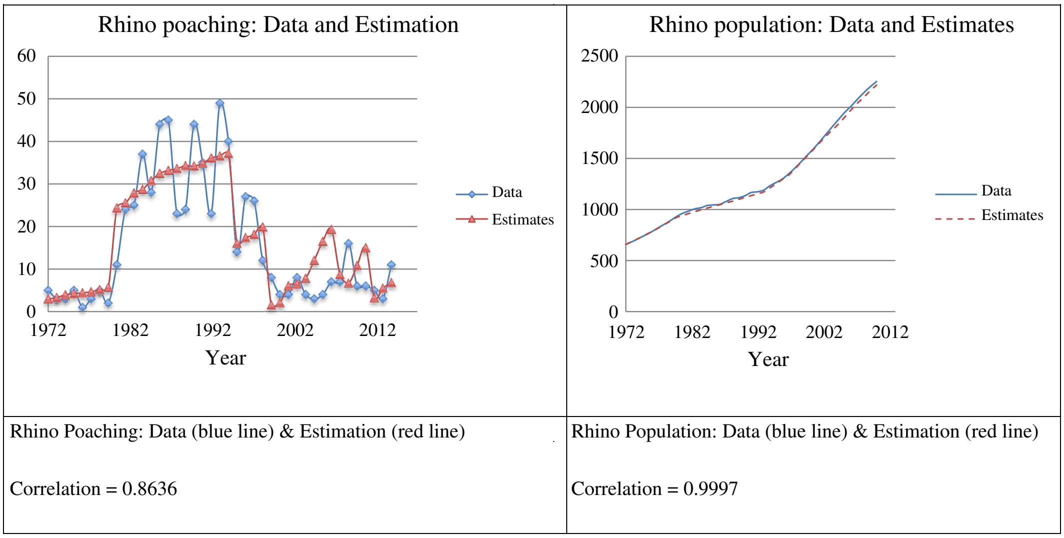

Fig. 4. Rhino poaching and rhino population fit between data and estimates (*model IV_1*); instrument = political party.

unavailability could lead to omitted variable bias in econometric estimations. In this paper I have estimated proxies of such data. Incomes of China and Vietnam, which proxy the market demand for rhino horn, are positively associated with poaching. Both measures of horn prices (one being a linear trend in the limited data on horn prices, and the other being a novel index estimated using a structural model of supply and demand through an organized crime network) are also positively related to poaching. In addition to including several covariates in the regression analyses – poaching penalties, Assam's GDP, and agricultural wages – I have considered the anti-poaching policy of Assam's Forest Department, which is seen to significantly reduce poaching. Given that civil unrest is associated with political instability in Assam, and an unchecked influx of Muslim refugees from Bangladesh, I have accounted for probable endogeneity in the regression results by using two instruments — political party and Muslim population. I find no evidence to suggest that the OLS models are endogenous. This paper finds that civil unrest in Assam is positively and significantly associated with rhino poaching in the KNP. The results are robust to different specifications of the civil unrest variable, alternative rhino population estimates, and to the inclusion of several additional covariates. This paper studies an important and inadequately understood relationship between civil unrest, political instability, and the conservation of endangered species.

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Appendix A

A.1. Estimating a Rhino Horn Price Index

Given the presence of organized crime networks in the supply of rhino horn from South Africa and Asia, and that demand comes primarily from China and Vietnam, I define the following terms:

$D_t(C_t, I_t)=$
Demand for Indian rhino horn; C_t: income in China and Vietnam; $I_t > 0$ is the estimable horn price index.

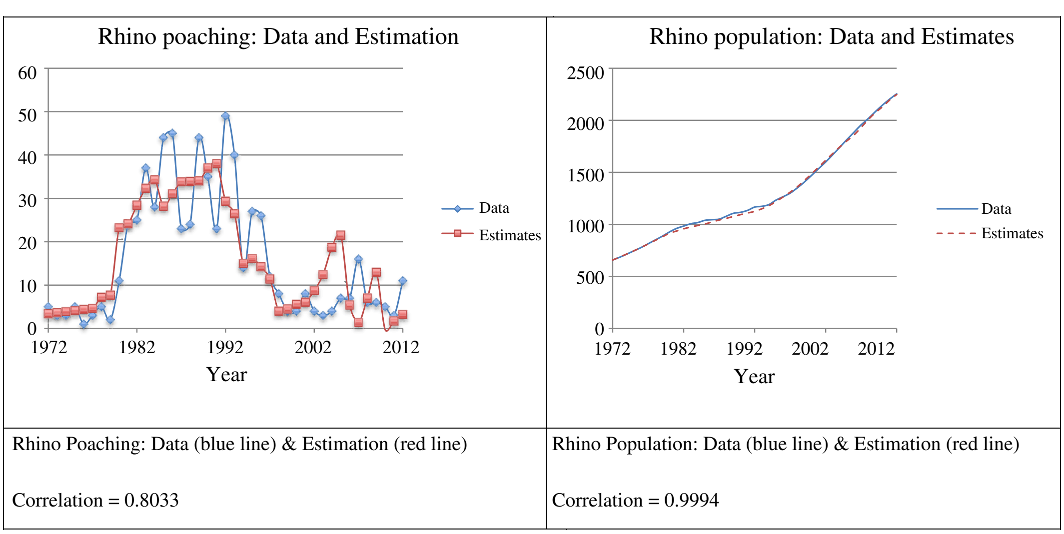

Fig. 5. Rhino poaching and rhino population fit between data and estimates as per (*model IV_3*); instrument = political party.

$S_t(R_t, I_t)$= Number of Indian rhinos killed by poachers in year t; R_t represents civil unrest in Assam.
J_t= Total number of rhinos killed by poachers in South Africa.
$I_t = I_t(J_t)$ Horn price index. I treat J_t as an instrument for I_t because I assume that black market price is a function of poaching in South Africa.
V_t= Unobservable inventory of Indian rhino horn held by the crime syndicate.
$V_{t+1} - V_t$= $S_t(R_t, I_t) - D_t(C_t, I_t)$: change in Indian rhino horn inventory held by the syndicate over time.

I assume the following functional forms for supply, S_t, and demand, D_t:

$$S_t(R_t, I_t) \equiv S_t(I_t(J_t), R_t) = \alpha J_t^{-\beta} R_t, \quad \alpha>0, \beta>0 \tag{A.1}$$

$$D_t(C_t, I_t) \equiv D_t(I_t(J_t), C_t) = \gamma J_t^{\eta} C_t \quad \gamma>0, \eta>0. \tag{A.2}$$

As noted in the Data section the crime syndicate presumably has an incentive to maintain as low a difference between horn supply and demand levels. This could ensure that horns move as quickly as possible from poacher to end consumer — presumably lowering the risk of getting caught by authorities. Function parameters are calibrated by minimizing the sum of squared differences between $S_t(\cdot)$ and $D_t(\cdot)$:

$$\underset{\alpha,\beta,\gamma,\eta}{\text{minimize}} \sum_{t=0}^{T} \left(\alpha J_t^{-\beta} R_t - \gamma J_t^{\eta} C_t\right)^2. \tag{A.3}$$

Time-series data on rhino poaching in South Africa's national parks, J_t, are listed in Table A.1 (Knight and Emslie, 2012; Milliken and Shaw, 2012). Data on GDP of China and Vietnam, C_t, and civil unrest in Assam, R_t, are listed in Table 1. These data are used in a non-linear solver to yield the calibrated values as per (A.3): $\alpha = 1.04418$, $\beta = 2.03751$, $\gamma = 4.58e-08$, $\eta = 0.05082$. These values are used to derive the market price index for rhino horn as: $I_t \equiv I_t(J_t) = \gamma J_t^{\eta}$ by using Eq. (A.2).

Table A.1
Data on rhino poaching in South Africa, J_t, as an instrument for horn price index, I_t.

Year	Rhino poaching in South Africa, J_t	Estimated price index, $I_t = \gamma J_t^{\eta}$
1990	14	0.5240481540
1991	5	0.4973286495
1992	18	0.5307850539
1993	14	0.5240481540
1994	27	0.5418372794
1995	14	0.5240481540
1996	6	0.5019587467
1997	6	0.5019587467
1998	12	0.5199582682
1999	13	0.5220779407
2000	12	0.5199582682
2001	9	0.5124107389
2002	25	0.5397219137
2003	22	0.5362264970
2004	12	0.5199582682
2005	17	0.5292452588
2006	36	0.5498182454
2007	13	0.5220779407
2008	83	0.5736644738
2009	122	0.5850060943
2010	333	0.6156377863
2011	448	0.6249906309
2012	455	0.6254833376

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