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Can Domestication of Wildlife Lead to Conservation? The Economics of Tiger Farming in China

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ABSTRACT

Tigers are a threatened species that might soon disappear in the wild. Not only are tigers threatened by deteriorating and declining habitat, but poachers continue to kill tigers for traditional medicine, decoration pieces and so on. Although international trade in tiger products has been banned since 1987 and domestic trade within China since 1993, tigers continue to be poached and Chinese entrepreneurs have established tiger farms in anticipation of their demise. While China desires to permit sale of tiger products from captive-bred tigers, this is opposed on the grounds that it likely encourages illegal killing. Instead, wildlife conservationists lobby for more spending on anti-poaching and trade-ban enforcement. In this study, a mathematical bioeconomic model is used to investigate the issue. Simulation results indicate that, unless range states are characterized by institutions (rule of law, low corruption) similar to those found in the richest countries, reliance on enforcement alone is insufficient to guarantee survival of wild tigers. Likewise, even though conservation payments could protect wild tigers, the inability to enforce contracts militates against this. Our model indicates that wild tigers can be protected by permitting sale of products from tiger farms, although this likely requires the granting of an exclusive license to sellers. Finally, it is possible to tradeoff enforcement effort and sale of products from captive-bred animals, but such tradeoffs are worsened by deteriorating tiger habitat.

Keywords: endangered species and extinction; wildlife farming; economics of natural; mathematical bioeconomics

JEL Categories: Q27, C61, Q57

1. INTRODUCTION

Wild tiger populations have declined from some 100,000 in 1900 to perhaps as few as 3500 today. The Bali tiger became extinct during the 1930s, the Caspian tiger during the 1970s, and the Javan tiger disappeared a decade later. Six species of tiger (Bengal, Indo-Chinese, Siberian, South China, Malaysian and Sumatran) remain, scattered throughout eastern Russia, North Korea, China, Vietnam, Cambodia, Laos, Thailand, Malaysia, Indonesia, Myanmar (Burma), Bhutan, India and Nepal.[1] Poaching, depletion of prey and habitat destruction (including illegal logging) are major contributing factors to the demise of the tiger.

In an effort to stave off extinction, international trade in tigers has been prohibited since 1975 when the species was listed on Appendix I of the UN Convention on International Trade in Endangered Species (CITES), with the exception of the Siberian sub-species which was listed in 1987. As a result of international pressure, China imposed a domestic ban on trade in tiger bones and medicine made with tiger bone in 1993, with purveyors of traditional Chinese medicine adapting by providing a range of alternative products. Evidence indicates that illegal trade in wild tigers continues, however, with tiger bone still used in some traditional medicines.[2] Within China, the domestic ban led to the establishment of tiger farms that now house some 5000 animals (CATT, 2007; Gratwicke et al., 2008).[3] Wildlife groups are concerned that the sale of products from tiger farms (an inevitable outcome should that many tigers remain in captivity in China) will increase demand for tigers and facilitate the marketing of poached tigers.

[1] Information available from http://www.tigersincrisis.com/ as viewed 30 June 2008.

[2] Bhalla (2006) points out that some 300,000 of India's poorest people currently live in 28 tiger reserves, surviving on a variety of forest products including payments from criminal gangs to trap and kill tigers “to meet increasing demand from neighboring China, where skins have become status symbols in Tibet and body parts are used in traditional medicines.”

[3] Nowell and Ling (2007) estimate that there are more than 4000 captive tigers in China, while CITES (1999) estimates that about 200 kittens are born in captivity every year.

The government of China has considered partially lifting its domestic ban on trade in tiger products to allow products from captive breeding farms to be sold legally. The carcasses of tigers that have died in captivity are currently frozen and stored as owners speculate that the domestic trade ban will be relaxed, although there is concern that tiger farms are already a source of illegally traded products that contain tiger bone (Novell and Ling, 2007; EIA, 2007). Opponents to the sale of captive tigers argue that any weakening of the trade ban will legitimize consumption of tiger products and increase the demand for tiger parts; this, in turn, will increase poaching because detection of products from poached tigers would be more difficult.[4] Researchers have surveyed tiger populations and the extent of their habitat, the availability of tiger products in Chinese and international markets, the state of captive tiger breeding in China, and confiscations of poached tigers, and concluded that wild tigers will likely become extinct if the status quo is maintained (Gratwicke et al., 2008; Nowell and Ling, 2007; Dinerstein et al., 2006; Shepherd and Magnus, 2004; Bolze et al., 1998).

The most common recommendation for preventing extirpation of wild tigers is to increase enforcement of the international and Chinese trade bans, while opposing tiger farming on the grounds that farmed output removes the stigma of using tiger-based products and facilitates the laundering of illegal tiger parts. Proponents of tiger farming and trade in tiger parts, on the other hand, favor a supply-side approach to conservation, arguing that a captive breeding industry could meet all demand for tiger products, thereby eliminating illegal killing of

[4] For example, Gratwicke et al (2008) write: "Re-igniting demand for tiger parts and products among China's 1.4 billion consumers would increase poaching of wild tigers because the demand for wild tiger parts would not be satisfied by … farmed tigers for two reasons; 1) medicines made from wild tigers are believed to be more effective …, and 2) the demand for tiger products cannot be met from farms alone. Furthermore, a legal market of any kind would allow laundering of poached tiger products that would be virtually undetectable."

wild tigers and preventing their extinction.[5] Upon examining the issue in a theoretical framework, Damania and Bulte (2007) demonstrate that multiple equilibriums are possible in a game between poachers, organized purveyors of illegal wildlife products and wildlife farms. Thus, it is not possible to determine unambiguously whether products from captive-bred wildlife will increase or decrease harvests of wild animals. They also argue that, since the feed costs of raising tigers are considerable, farmers are unable to undercut suppliers of illegal wildlife products. However, they assume very low costs of bringing poached wildlife to a comparable stage in the processing chain and ignore the potential economies of scale in producing multiple products from tigers that are not available when activities must be hidden from the authorities.

Similar arguments have been raised concerning the African elephant and the ivory trade ban. There is fear that CITES-sanctioned 'one-off' sales of ivory will promote illegal killing of elephants. Given the extent and scope of poaching, van Kooten (2008) found that the elephant could go extinct in some African states despite a trade ban and high levels of enforcement. The so-called 'stigma effect' (Fischer, 2004), which has not been demonstrated empirically but postulates that the demand for illegal elephant products falls when trade is banned, had little effect in reducing the rate of decline in elephant populations in west and central Africa.[6] Van Kooten also demonstrated that the elephant is best protected by effectively linking their non-market value to actual on-the-ground payments to those best able to protect them.

[5] Proponents also argue that farmed tigers constitute a reserve that can be used to restock areas where tigers have disappeared, much as wolves from Canada were successfully used to restock Yellowstone National Park in the 1990s.

[6] The latest African Elephant Status Report (Blanc et al., 2007) found that elephant numbers in east and southern Africa are increasing by 4% annually. Although the 1999 sale of raw ivory stockpiled by southern states seems to have had no impact on elephant numbers (Bulte, Damania and van Kooten, 2007), it will take some time before the impact of the larger auction of ivory in Fall 2008 is known.

The present study contributes to the debate about tiger farming by using evidence from past studies to calibrate a mathematical bioeconomic model of wild tiger population dynamics and trade, using it to analyze the potential for heightened anti-poaching enforcement and/or liberalization of the captive tiger breeding industry for preventing the extinction of wild tigers. A major conclusion of our research is that anti-poaching and trade-ban enforcement must be increased to a rate that is seemingly unattainable if extirpation is to be prevented, but that a captive breeding industry and/or effective transfer payments from rich countries to poor ones for protecting wild tigers could potentially prevent the extirpation of wild tigers.

The fate of the wild tiger population is modeled by a tiger survivability function that is derived from economic principles. The survivability function is a differential equation that maps the tiger population, the rate of poacher detection, the output of tiger farms, the stigma effect, the amount of habitat available, and other relevant variables to the rate of change in the wild tiger population. Using the survivability function, we can determine for any combination of parameters whether the tiger population will reach a stable positive equilibrium or go extinct. We estimate the current levels of all of the parameters and then determine how much each must change, ceteris paribus, to prevent wild tigers from becoming extinct.

We begin in the next section by constructing a mathematical bioeconomic model of tiger poaching and trade that includes possibilities of sale of tiger products from captive-bred animals. In section 3, we use the model to focus on the role of anti-poaching, trade-ban enforcement and potential sale of farmed tigers, extending this to a consideration of habitat and conservation payments (non-market considerations) in section 4. We conclude in section 5 with a discussion of the policy issues raised by the modeling exercise.

2. BIOECONOMIC MODEL OF TIGER EXPLOITATION

An economic model of the interplay between killing of wild tigers and culling of farmed animals is provided in Figure 1. When there is no ban on farmed tigers, equilibrium occurs at point *z*, with the number of wild plus farmed tigers harvested equal to q^* and corresponding price of p^*; q_1 wild tigers are poached and $q^*–q_1$ ($=q^{legal}$) farm-produced tigers are killed. When there is a ban on products from Chinese tiger farms, the demand curve shifts inwards as indicated – it is assumed for simplicity that the slope of the demand function remains constant while the intercept shifts from *k* to *s* to account for the stigma effect. With a Chinese trade ban and demand function D_{Stigma}, the market equilibrium shifts from *z* to *w*, with price p^{**} and illegal quantity equal to q^{**}. This assumes that the illegal supply function is upward sloping; however, Nowell and Ling (2007) indicate that there has been little change in tiger bone prices from the early 1990s to 2006. If price has indeed remained constant since the Chinese trade ban came into effect in 1993, then either D_{Stigma} has shifted further to the left than indicated in Figure 1 (so it intersects the horizontal price line p^* at *v* rather than *y*) or the illegal supply curve is horizontal ($S'_{illegal}$), indicating constant marginal costs of poaching and marketing tigers. The only time that the trade ban will stop all illegal harvests is if, in Figure 1, the illegal supply function is upward sloping and its intercept lies above p^* (perhaps due to very successful enforcement). If not, then tigers will always be poached. The question is whether illegal harvests will still cause extirpation of wild tigers.

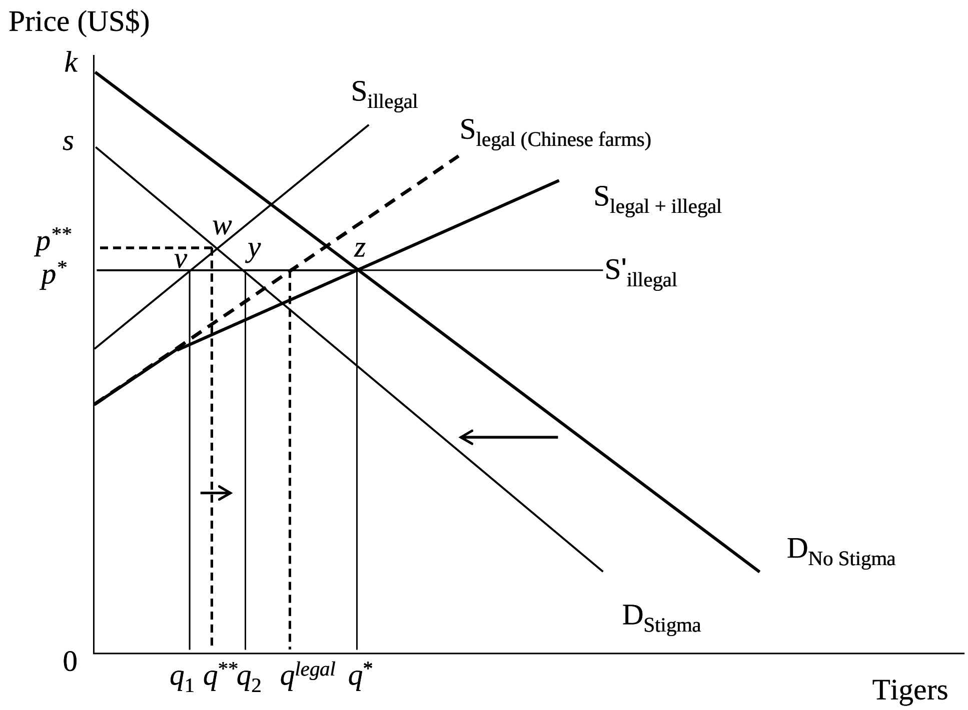


Figure 1: Tiger Market

Bioeconomic Model

The forgoing model neglects the dynamics of tiger reproduction, habitat loss and so on. A bioeconomic analysis begins by supposing that the population of wild tigers x is characterized by the following single-species growth function with Allee effect:

(1) $$g(x(t)) = \gamma x(t)\left(\frac{x(t)-m}{x(t)+m}\right)\left(1-\frac{x(t)}{K}\right),$$

where m is the minimum viable population, K is the population carrying capacity and γ is a growth constant (see Boukal and Berec, 2002). The rate at which tigers are harvested is given by a constant returns-to-scale, Cobb-Douglas production function:

(2) $$h(x, \tau) = \theta\, x^{½}\, \tau^{½}\,,$$

where θ is a catchability or scale parameter and τ is the fraction of time spent poaching.

If the potential penalties poachers face if caught are independent of how much they poach, an expected utility maximizing poacher will choose τ so that

(3) $$½\,\theta\, x^{½}\, \tau^{-½}\,(1-\pi)\,p = w,$$

where the parameter π is the probability of apprehension, p is the market price of a tiger, and w is the wage rate in other employment. Solving (3) for τ and substituting the result into equation (2) gives:

(4) $$h(x) = \frac{\theta^2(1-\pi)xp}{2w}.$$

We can also solve for

(5) $$\theta = \sqrt{\frac{2hw}{(1-\pi)xp}}\,.$$

Tiger Survivability Function

The tiger survivability function is the solution to the differential equation:

(6) $$\frac{dx}{dt} = \dot{x} = g(x) - h(x) = \frac{\gamma\, x(x-m)}{x+m}\left(1-\frac{x}{K}\right) - (1-\pi)\frac{\theta^2 xp}{2w}\,.$$

If demand is perfectly elastic so that p is fixed, the survival function can easily be parameterized. If demand is not perfectly elastic then price is a function of output and we replace x with $p(x)$. As discussed below, the case where output from tiger farms affects the price of tigers is the one of most interest. If this is not the case, then tiger farming has no effect on wild tigers and policymakers need to think of strategies to save wild tigers that are independent of decisions regarding the legitimacy of tiger farms.

The illegal supply of tigers is given by $(1 - \pi)\, h$, or

$$(7) \qquad S(p) = \frac{\theta^2 (1-\pi)^2 xp}{2w}.$$

We assume a linear derived demand function for wild tigers, D(p)= α + β p, with $\alpha \geq 0$ and $\beta < 0$. Setting S(p)=D(p) and solving for price gives:

$$(8) \qquad p = \frac{2w\alpha}{\theta^2 (1-\pi)^2 x - 2w\beta}.$$

Tiger Survival Parameterization

As indicated in Figure 1, projections regarding the survivability of wild tigers depend on the parameters chosen for the model. Without adequate data for regression analyses, the bioeconomic model is parameterized using the little data that are available from various sources. Nowell and Ling (2007) report that, in 1992, some 200 wild tigers were harvested with a total industry value of $US 12.4 million, or $62,000 per tiger. There is evidence that poachers working in the forest only receive about $800 per tiger, but that those with organized crime gangs receive considerably more (CITES, 2009).[7] We choose a price of $20,000 per wild tiger, but consider scenarios with lower and higher prices.

Each tiger produces approximately 10 kg of bone; thus, 200 wild tigers would yield 2000 kg of bone. Over the period 1999-2005, an average of 60 kg of tiger bone was seized annually, or 3% of the 1992 illegal harvest, which represents a detection rate of $\pi = 0.03$. If more wild tigers

[7] An article in *The Times of India* (June 9, 2008), entitled “Vietnam police arrest tiger smuggler”, reports that a man was arrested for smuggling a 190-kg tiger carcass from Laos into Vietnam. He had paid $20,000 for the tiger with the intention of using it to make traditional medicines.

had been harvested, the detection rate would be lower. Given that there were perhaps 5000 wild tigers in 1992, of which 200 were harvested, the rate of poaching is about 4.5%. However, tigers are also lost due to declining habitat and depletion of prey by encroaching peasants.

Based on an historic tiger population of 100,000 and loss of 93% of historical habitat, the carrying capacity of the wild tiger population is estimated to be 7000. Empirical evidence suggests that the current wild tiger population of 3500 is lower than the estimated 5000 to 7000 that existed in the early 1980s (CITES, 1999, 2001; BBC, 2008). The current range of the wild tiger is estimated to be 40% less than it was in the mid 1990s (Dinerstein et al., 2006), an annual loss of some 3.4%. We assume that, as a result of habitat loss and prey depredation, that carrying capacity declined from some 19,000 to 10,000 tigers in the 15 years prior to the Chinese trade ban, and then declined further from 10,000 to 7000 in the period following 1993. This corresponds to an assumed decline in wild tiger stocks from 10,000 to 5000 animals in the pre-ban period and a further decline to 3500 animals in the period after 1993. Lacking evidence concerning the minimum viable population of wild tigers, we conjecture that because habitat is fragmented it is at least 1000.

To determine the growth constant γ, we need an estimate of the growth rate of a wild tiger population that is not subject to poaching. Karanath et al. (2006) measure a growth rate of 3% for a population in a protected area in India. The natural population growth rate $g(x)$ is set equal to 3% of the current tiger population:

(9) $$\frac{\gamma\, x(x-m)}{x+m}\left(1-\frac{x}{K}\right)=0.03x\,.$$

Given x=3500, m=1000 and K=7000, the growth constant is γ = 0.108.

The annual wage rate, w, is assumed to be \$US 450, based on an exchange rate of 0.18

\$US/CNY reported in IMF financial statistics, and a per capita GDP of 2711 CNY reported by the National Bureau of Statistics of the People's Republic of China.

It remains to determine the demand function and the stigma effect. Assume the following linear demand function for wild tigers at the place they are poached:

(10) $$q = \alpha + \beta p,$$

where α and β are the intercept and slope parameters, respectively, and q refers to the number of tigers that are 'consumed'. The effect of the trade ban, or stigma effect, enters the model through a reduction in the demand intercept α from k to s in Figure 1 – a downward shift in demand. Prior to 1993, there was no stigma effect. To determine the values of the pre-ban and post-ban demand intercept terms, $\alpha_{\text{no stigma}}$ and α_{stigma} respectively, we employ a constrained optimization model that is solved separately for each of the pre- and post-trade ban periods. In doing this, we assume values of q, p, w, initial x, and π =0.03. The results are provided in Table 1, where the value of θ calculated from equation (5) is also provided.

The tiger survivability function can be viewed graphically by plotting dx/dt on the vertical axis against $x(t)$ on the horizontal axis. For any $x(t)$ for which $dx/dt > 0$, the tiger population is growing, while it shrinks whenever $dx/dt < 0$. If $dx/dt < 0$ for all $x \leq x(t)$ then the tiger will become extinct. This is the case in Figure 2 for parameters associated with four of the scenarios in Table 1. Our model supports the conclusions of tiger researchers as it predicts extinction of the wild tiger, even under a Chinese trade ban, and this result is robust to a large number of scenarios. The remainder of this analysis is largely concerned with how policies might prevent extinction.

Table 1: Parameterization of the Demand Functions, w=$450, π =0.03

	Carrying Capacity		Wild Tiger Stocks			
Item	Beginning	Ending	Beginning	Ending		
Pre-1993	19,090	11,560	10,000	5,000		
Post-1993	11,560	7000	5000	3500		
	Price =$2000		Price =$20,000		Price =$31,000	
	Free Trade	Trade Ban	Free Trade	Trade Ban	Free Trade	Trade Ban
q (harvest)[a]	450	200	450	200	450	200
$\theta^2(x_0 \in \{5000, 10,000\})$[a]	0.0208763	0.0185567	0.0020876	0.0018557	0.0013469	0.0011972
α(β=–0.005)[b]	826	396	1041	589	1173	708
α(β=–0.01)[b]	850	417	1281	806	1548	1045
α(β=–0.02)[b]			1767	1241		
θ^2 (x_0=3500)[c]	0.02650957		0.002650957		0.0017103	

Notes:

[a] Assumed harvests in the pre-1993 (free trade) and post-1993 (trade ban) periods that are used to calculate θ via equation (5), with respective beginning wild tiger populations employed for x.

[b] The free trade and trade ban values of α are the 'no stigma' and 'stigma' values of the demand intercepts, k and s respectively in Figure 1.

[c] This value of θ is used in the sensitivity analyses along with the given parameters of the 'no stigma' (free trade) and 'stigma' (trade ban) demand functions.

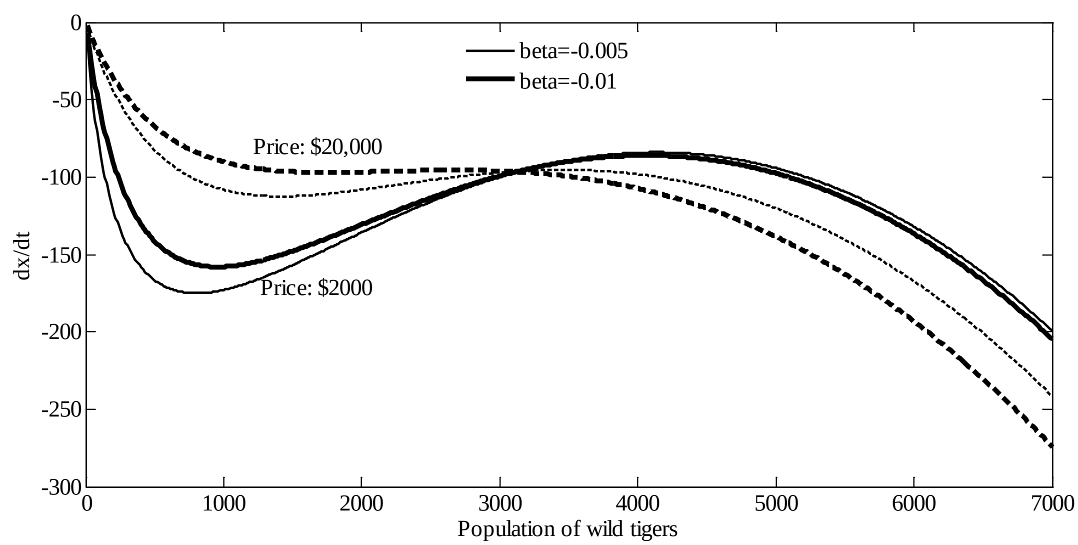


Figure 2: Tiger Survivability for Various Population Levels, with Trade Ban, Wild Tiger θ *Determined from Assumed Prices of $2000 and $20,000,* x_0*=3500*

3. PREVENTING EXTIRPATION BY FOCUSING ON POACHING

To prevent tigers from becoming extinct, policies need to be enacted to reduce the prevalence of poaching. Tigers are fairly susceptible to modest increases in mortality, and less likely to recover quickly after population declines (Chapron et al., 2008). Since the current tiger population is above the hypothesized minimum viable population, policy can affect the parameters of the tiger survivability function in such a way that it becomes positive at $x(t)$ = 3500. An example of a parameter that can be changed is the rate of poacher detection, π. If the rate at which poachers are caught increases sufficiently, it will become far less profitable for poachers to harvest tigers, and poaching pressure will be reduced to a level at which the survivability function is positive.

A second policy option is to introduce farmed tiger products to the market. The presence of captivity-bred tigers would increase the total supply of tiger products, reducing the price of those products and making poaching a less profitable occupation. If the price is reduced enough, the tiger survivability function will become positive and extinction will be prevented. However, by introducing farmed tigers to the market, the stigma effect associated with the prohibition of tiger trade will disappear, which will tend to increase poaching.

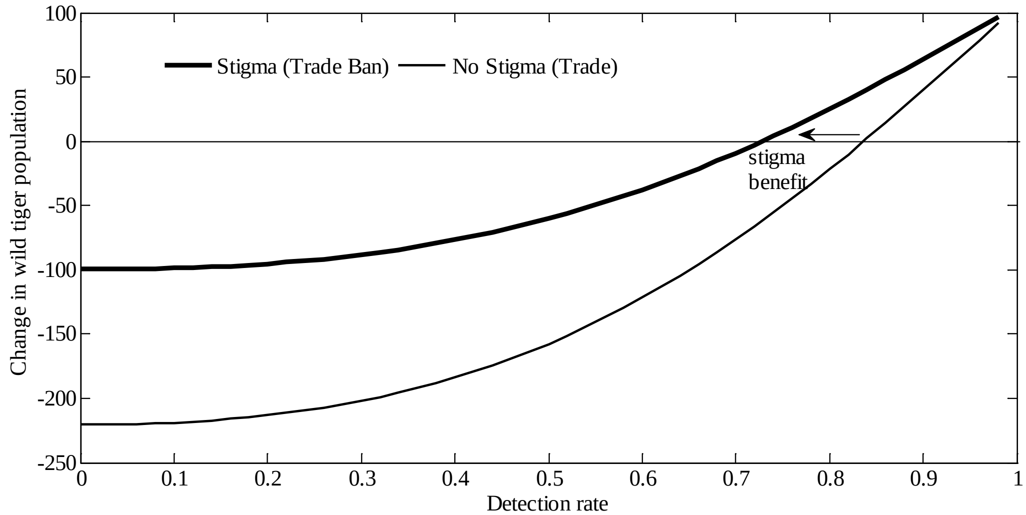
Finally, we are interested in combinations of policy options that can prevent extinction. For example, we may want to know whether a particular combination of enhanced enforcement and farmed products can prevent extinction. There are many possible minimum combinations of the two policies that can prevent extinction, and these combinations can be used to determine what we will describe as a policy frontier.

How Much Enforcement?

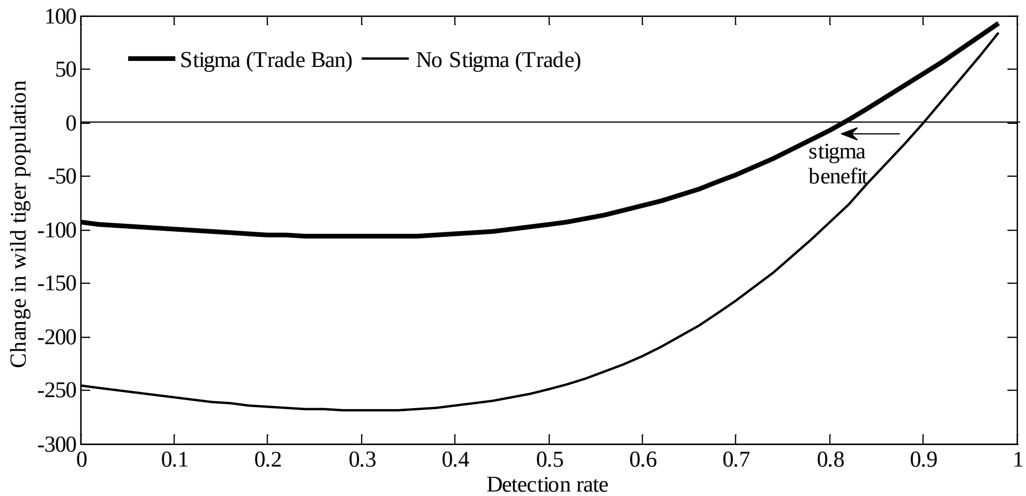
Increased expenditures on enforcement will result in higher rates of poacher detection.

Here we determine by how much detection probabilities might have to increase given that the likely status quo in our model is extinction (Figure 2). Results are provided in Figure 3 for different rates of detection under the base case scenario where θ is determined using a price of \$20,000 per wild tiger. To prevent extirpation of wild tigers, anti-poaching and trade-ban enforcement must be substantially enhanced, with the increase required highly dependent on whether or not there is a stigma effect.[8] If a ban on tigers does not lead to a stigma effect, the rate of detection must exceed 75%. Even if there is a stigma effect, the rate of detection must rise to above 65% from the current rate of 3%. The stigma effect causes the required rate of detection to forgo extirpation to fall from 76% to 65% in the base case if $\beta = -0.02$, to fall from 84% to 73% if $\beta = -0.01$, and from 91% to 82% if $\beta = -0.005$. If the value of θ is based on a price for wild tigers of \$2000, then required detection rates must always exceed 90% and a trade ban has only a small effect on lowering the level of detection that is needed to arrest extinction. If price is \$31,000, the required detection rate is 79% (86%) for $\beta = -0.01$ ($\beta = -0.005$), falling to 68% (76%) with a stigma effect. For range states to attain these levels of detection appears particularly daunting. We return to the enforcement issue in the policy recommendations below.

[8] Recall that there is no statistical support for the existence of a stigma effect, although research such as that reported by Gratwicke et al. (2008) certainly hints at it.



(a) β = –0.010, $\alpha_{no\ stigma}$=1281, α_{stigma}=806



(b) β = –0.005, $\alpha_{no\ stigma}$=1041, α_{stigma}=589

Figure 3: Impact of Detection Rate on Survival of Wild Tigers, Base Case Price Scenario

We are also interested in how quickly the tiger population will grow and what the population projections might be if an increased enforcement policy that prevents extinction is acted upon. Historical records of the dynamics of the Amur tiger (*P. t. altaica*) population in Russia show that recovery of this population from an estimated low of 20-30 individuals (Kaplanov, 1948) to an estimated 415-476 adults in 1996 (Miquelle et al., 2007) depended largely on the outlawing of hunting and strict controls on poaching, and required about 40 years.

Our results are provided in Table 2. They suggest that, assuming habitat and other factors permit, the population of wild tigers could increase from 3500 to over 4000 if adequate enforcement of trade and poaching bans results in detection probabilities of 75% or more, and there is a real stigma effect associated with the ban on products from Chinese tiger farms. If there were no stigma effect, then a much higher level of enforcement success would be required. Finally, if rich country institutions were available in all of the tiger states so that detection rates are nearer 95%, it might be possible to increase populations to some 6000 animals in the long run for all scenarios.

Table 2: Projected Tiger Populations after 20 and 100 Years with Varying Levels of Enforcement for β=–0.01, x_0 = 3500, and Mid and High Price Scenarios[a]

Detection rate (π)	Population without stigma effect				Population with stigma effect			
	Mid: θ^2 = 0.00265		High: θ^2 = 0.00171		Mid: θ^2 = 0.00265		High: θ^2 = 0.00171	
	20 yrs	100 yrs	20 yrs	100 yrs	20 yrs	100 yrs	20 yrs	100 yrs
0.40	863	0	1340	0	2182	0	2429	0
0.45	1009	0	1517	0	2317	0	2582	2
0.50	1185	0	1719	0	2473	0	2751	15
0.55	1396	0	1948	0	2651	4	2938	234
0.60	1645	0	2207	0	2855	61	3144	1551
0.65	1938	0	2499	2	3084	1063	3370	2952
0.70	2281	0	2824	77	3342	2808	3617	3890
0.75	2677	11	3185	1956	3631	3934	3884	4571
0.80	3131	1595	3582	3774	3950	4713	4172	5132
0.85	3643	3951	4015	4829	4300	5350	4481	5634
0.90	4214	5195	4484	5634	4679	5926	4808	6106
0.95	4839	6147	4984	6341	5084	6472	5153	6559

Note:
[a] Price scenarios are determined by the values of θ; the 'mid' (base case) scenario is associated with a price of $20,000 per tiger, the 'high' scenario with a price of $31,000 (see Table 1).

How Much Farmed Product?

If tigers are farmed, there will be some number Ω produced by the farms. The supply of tigers will differ from equation (7) because legal sales will need to be added to the illegal supply:

(11) $$S(p) = \frac{\theta(1-\pi)^2 xp}{2w} + \Omega.$$

Although poaching remains illegal, Chinese domestic trade using bred captive tigers is now taken to be legal so that the stigma effect no longer holds. As a result, the demand intercept (α) increases from what it is with a stigma effect back to what is was prior to the trade ban (see Table 1). The results are provided in Figure 4.

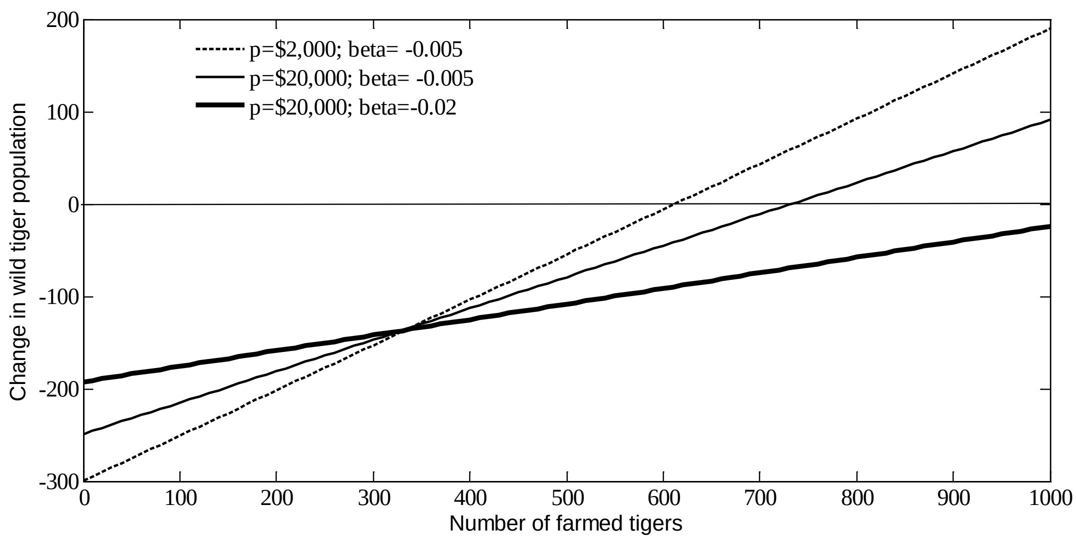


Figure 4: Legalizing Tiger Farming to Prevent Extinction, Loss of Stigma Effect, x_0*=3500*

Extinction of wild tigers is avoided when the number of farmed animals sold into the market reaches about 600 or more annually, which is where the change in population becomes positive. Ten years ago the annual number of tigers born in captivity was about 200 (CITES, 1999), but is probably significantly higher today. Given that annual production is likely nearing that which will prevent wild tigers from being extirpated, it seems reasonable to permit sales of farmed tigers for traditional medicines and other uses. This is discussed further in the policy recommendations below.

In Table 3, we present wild tiger population growth projections for various levels of tiger farm production (Ω). These indicate that wild tiger populations will come under less pressure and expand in numbers (at least within the parameters of our model) as the output from tiger farms increases from 650 to 850 or more bred animals per year. However, if less that about 650 farmed tigers are permitted into the market each year, the population of wild tigers will continue to decline, primarily because demand is shifted out because there is no stigma effect.

Table 3: Projected Tiger Populations after 20 and 100 Years with Various Marketing of Farmed Tigers, x_0 = 3500, and Selected Scenarios[a]

Farmed tigers	Low: θ^2 = 0.02651				β = –0.005			
	β = –0.01		β = –0.005		Mid: θ^2 = 0.00265		High: θ^2 = 0.00171	
(Ω)	20 yrs	100 yrs	20 yrs	100 yrs	20 yrs	100 yrs	20 yrs	100 yrs
600	3236	0	3370	730	2569	0	2335	0
650	3750	4906	3905	5321	2921	0	2611	0
700	4233	5801	4403	6020	3274	739	2892	0
750	4686	6293	4866	6468	3623	4220	3177	270
800	5111	6673	5297	6830	3967	5225	3463	3238
850	5510	6997	5699	7144	4304	5766	3748	4602
900	5884	7287	6074	7426	4633	6162	4031	5269
950	6235	7551	6425	7684	4953	6492	4312	5718

Note:
[a] Scenarios are determined by the values of β and θ; the 'low' scenario is associated with a price of \$2000 per tiger, the 'mid' (base case) scenario with a price of \$20,000, and the 'high' scenario with a price of \$31,000 (see Table 1).

Combining Policy Instruments

We now compute minimum policy combinations that are required to prevent extinction. We do this heuristically by fixing an enforcement level and then calculating what the production of tiger farms would have to be to prevent extirpation of wild tigers. The simulated policy combinations are plotted in Figure 5 to form the extinction prevention policy frontier. It indicates that if π = 0.05, for example, then tigers will go extinct in the absence of tiger farming; at the other extreme, an enforcement effort leading to an unrealistic detection rate of more than 80% is required to prevent extinction if no tiger farming is permitted.

The policy frontier enables us to ask how many fewer captive tigers could be sold if enforcement is increased and extinction of wild tigers is to be prevented. If the rate of detection is increased from the current $\pi = 0.03$ to $\pi = 0.15$, something like five fewer tigers (about 865 rather than 870) could be sold annually to prevent extinction, but only for the β = –0.01 scenario and not the β = –0.005 scenario (it would require that the detection rate reach 40%). However, if the rate of detection were already $\pi = 0.50$ and we could raise it to $\pi = 0.65$, some 170 fewer captivity-bred tigers would need to be sold annually to prevent extinction of wild tigers in the β = –0.01 scenario, and nearly 80 tigers in the β = –0.005 scenario.

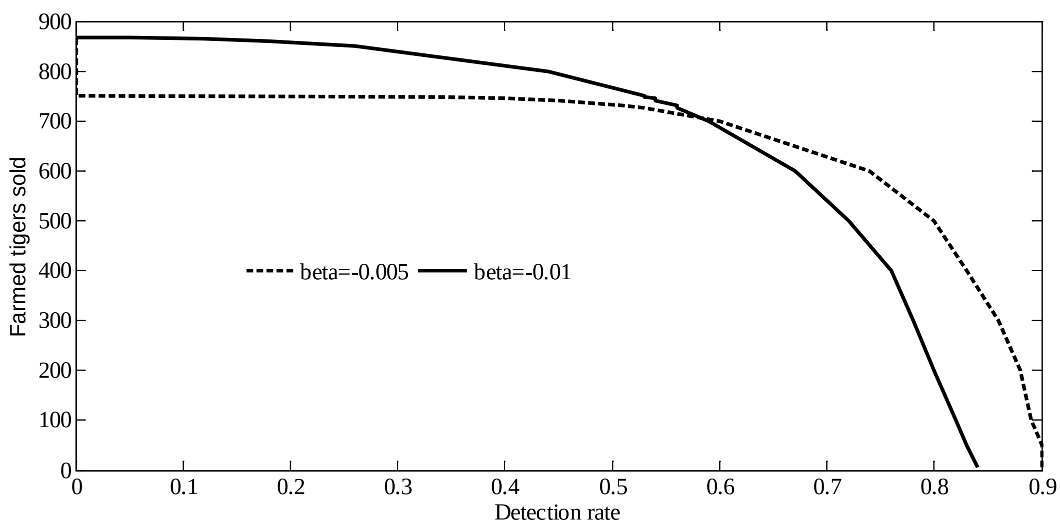


Figure 5: Extinction Prevention Policy Frontier, Base Case Scenario

4. OTHER CONSIDERATIONS: HABITAT AND CONSERVATION PAYMENTS

Along with other factors such as the quality of the ecosystem and quantity of prey, the available habitat determines the maximum number of tigers that can survive in the wild – the ecosystem's carrying capacity. Even the minimum viable population required to ensure that tigers do not go extinct might be affected by the amount of habitat available to tigers. Clearly, quantity and quality of tiger habitat has declined during the 20th century (Dinerstein et al., 2006).

India has taken steps to protect tigers, for example, by setting aside habitat. It protects some 37,000 km^2 of habitat in 27 tiger reserves, although more than 20,000 km^2 of this is included in buffer zones and not actual reserves.[9] It is not clear how many tigers are protected as population counts are sporadic and reliant on the discredited use of pugmarks.[10] Available data indicate that the highest total animal count occurred in 1997, but it found less than 1100 animals, while a failure to find any tigers in the Sariska Tiger Reserve in Rajasthan State in 2005 created quite a stir (Sudir, 2006). With 40 million people now living in India's forested areas, it is little wonder that tigers are disappearing despite efforts since 1973 to protect their habitat – protecting habitat is insufficient if its quality is seriously eroded by the activities of peasants, including illegal logging and taking of wildlife upon which tigers prey.

In China, tiger habitat quality and quantity have also declined as the rural (primarily agricultural) population has grown and a larger proportion of total available land is used in agriculture. However, the population engaged in agriculture has not increased since about 1990, while the decline in woodland area has also been arrested (FAO, 2008). Nonetheless, until very recently, the proportion of land in agriculture continued to increase, although it has now stabilized at about 60% of total land. This slowdown in the growth of agricultural land could simply be due to scarcity of suitable land (FAO, 2008; Fischer et al., 1999). Clearly, in China land suitable for tigers has declined significantly since at least 1960.

The Effect of Tiger Habitat

Given that the simulations reported earlier did not directly address the issue of habitat loss (only taking it into account in determining the potential size of the stigma effect), we

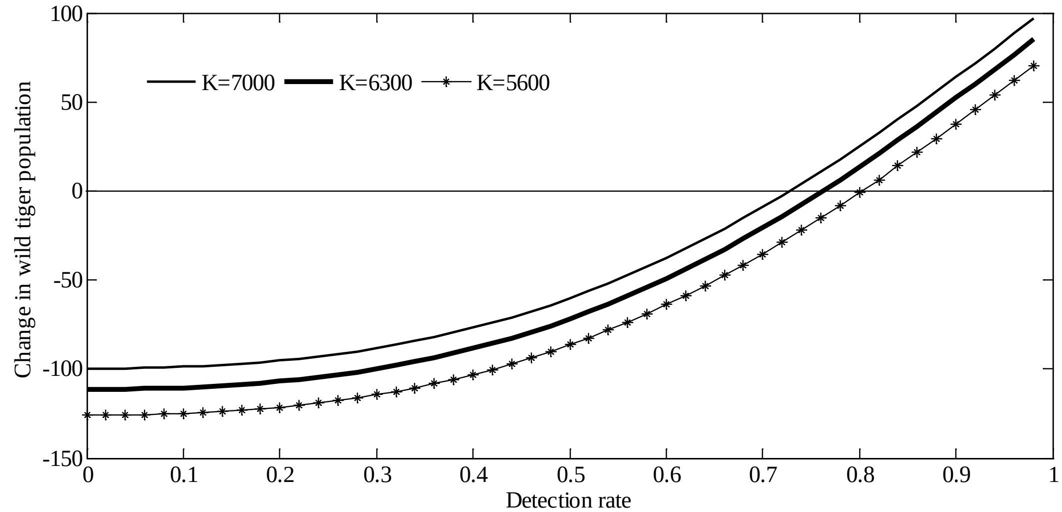
[9] Available at http://www.wpsi-india.org/tiger/tiger_reserves.php (as viewed July 3, 2008).

[10] Pugmarks are paw prints thought to be unique to each tiger. A better method not currently employed is to use fecal samples to extract DNA and identify individual tigers (Sudhir, 2006).

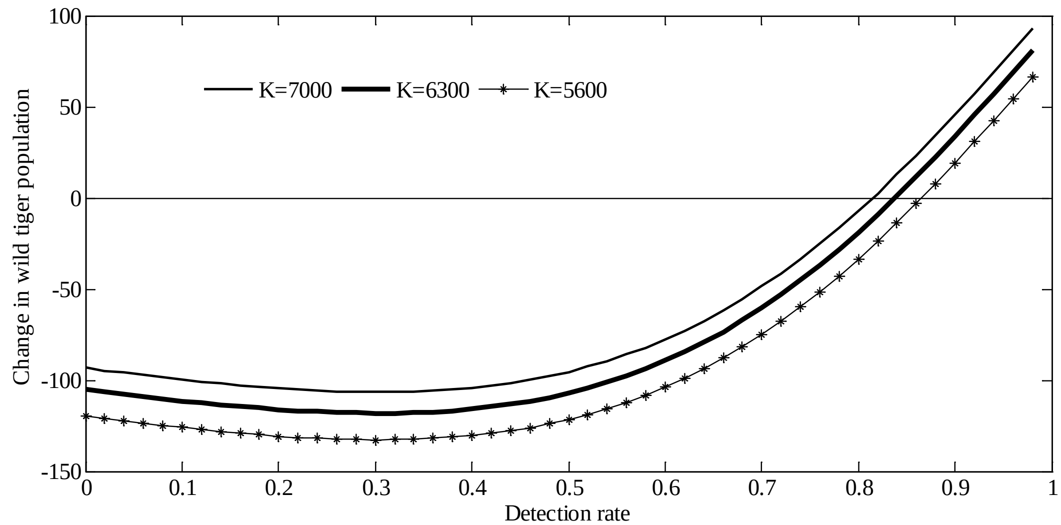
simulate the impact that further habitat degradation will have on the policies necessary to prevent extinction of wild tigers. This is done by varying the carrying capacity in the simulations from K=7000 to K=6300 and K=5600, representing approximate habitat losses of 10% and 20%, respectively. The simulation results are provided in Figures 6a and 6b for the base case scenario, with $\beta = -0.01$ and $\beta = -0.005$, respectively. These indicate that substantial policy adjustments are required – the level of enforcement must be increased so that the detection rate rises from some 74% to slightly more than 80% in one scenario (Figure 6a), and from nearly 80% to more than 85% in another (Figure 6b), when respective habitat losses of 10% and 20% are experienced. Alternatively, the number of captivity-bred tigers marketed annually could be increased by some 200 ($\beta = -0.005$) to 240 animals ($\beta = -0.01$) as indicated by the policy frontier in Figure 5.

Conservation Payments and Tiger Poaching

It is theoretically possible that poachers and consumers of tiger products are compensated so as not to undertake these activities. It is theoretical only because, lacking many essential governance institutions (e.g., rule of law), it is likely impossible to enforce contracts with tiger poachers and consumers in much of Asia. Alternatively, rather than compensating poachers and consumers of tiger products, it might be possible to protect wild tigers by compensating resource (habitat) owners and others who might be negatively impacted by tigers or have the incentive to poach or help poachers (perhaps only by not reporting their activities). Here we seek to answer the question of how much compensation might be required to prevent extirpation of wild tigers in roundabout fashion by considering the levels of compensation needed by poachers and consumers of tiger products.



(a) $\beta = -0.010$, α_{stigma}=806



(b) $\beta = -0.005$, α_{stigma}=589

Figure 6: Impact of Reduced Habitat on Detection Rate Needed for Survival of Wild Tigers

We can rewrite the supply and demand functions for tigers as:

(12) $$p(q^D) = \frac{1}{\beta}(q - \alpha),\ \alpha \geq 0,\ \beta < 0,$$

(13) $$p(q^S) = \frac{2w}{(1-\pi)^2 \theta^2 x} q\ .$$

The total consumer plus producer surplus (*SS*) in the tiger market is then given by:

(14) $$SS = \int_0^{q^*} \left(\frac{q}{\beta} - \frac{\alpha}{\beta} - \frac{2w}{(1-\pi)^2 \theta^2 x} q \right) dq .$$

Let $\overline{q} < q^*$ be the number of tigers that would prevent extinction of tigers, that is, the level that just causes d*x*/d*t*>0. A transfer or conservation payment of amount M is required to protect $q^* - \overline{q}$ tigers. Therefore, we define the marginal surplus value, *M*, as the surplus created by the last $q^* - \overline{q}$ tigers consumed (see Figure 7):

(15) $$M = \int_{\overline{q}}^{q^*} \left\{ \left(\frac{1}{\beta} - \frac{2w}{(1-\pi)^2 \theta^2 x} \right) q - \frac{\alpha}{\beta} \right\} dq = \left(\frac{1}{2\beta} - \frac{w}{(1-\pi)^2 \theta^2 x} \right) (q^* - \overline{q})^2 - \frac{\alpha}{\beta} (q^* - \overline{q}) .$$

The number of tigers that could theoretically be saved per year if side payments were possible is $(q^* - \overline{q})/(1-\pi)$. The divisor (1–*π*) accounts for the fact that tigers are no longer confiscated from poachers because poaching is assumed to cease when conservation payments are made.

From (15), we can solve for $\overline{q}$ as a function of *M* and the solution will be quadratic with two real roots. One of the roots will be less than *q** and the other greater than *q**; we select the smaller value of *q**. We can simulate the effect of conservation (side) payments on the tiger survivability function by writing the tiger growth function as:

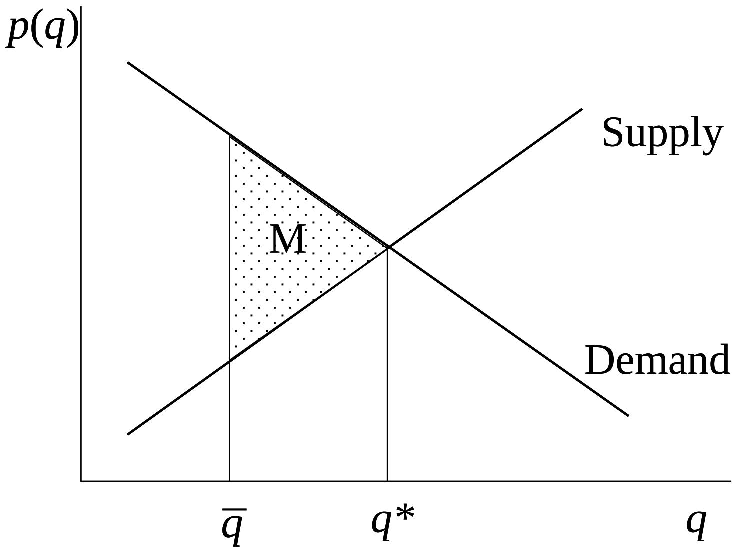


Figure 7: Non-market Values Transfer Framework

(16) $$\dot{x} = \frac{dx}{dt} = g(x) - h(x) + \frac{q^*(x) - \bar{q}(x, M)}{1-\pi}.$$

Equation (16) is similar to equation (6) but with an added term that is positive because $(q^* - \bar{q}) > 0$ and $(1-\pi) > 0$. Mathematically, dx/dt will be greater for all levels of x, which implies that there is greater incentive to preserve tigers. Using (16), we can determine how large M must be to prevent extinction – that is, the size of the conservation payment required to make dx/dt positive somewhere in the interval [0, $x(0)$]. The results are provided in Figure 8.

Results indicate that, if a trade ban is in place (and thus a stigma effect), the minimum required conservation payments are \$7.7 to \$22.0 million for $\beta = -0.01$, depending on the price scenario used to determine θ, with the lower compensation level associated with the lower price for poached wild tigers. The comparable conservation payments required if $\beta = -0.005$ are between \$14.5 and \$28.5 million per year. If there is no trade ban (no stigma effect), annual conservation payments would have to increase to \$52-\$66 million for the $\beta = -0.005$ scenarios, and \$105-\$115 million for the $\beta = -0.01$ scenarios. Even the latter are relatively small amounts for protecting wild tigers. That is, the compensation required in our model to ensure that poaching of wild tigers will not lead to their extirpation does not constitute an obstacle to the conservation of tigers.

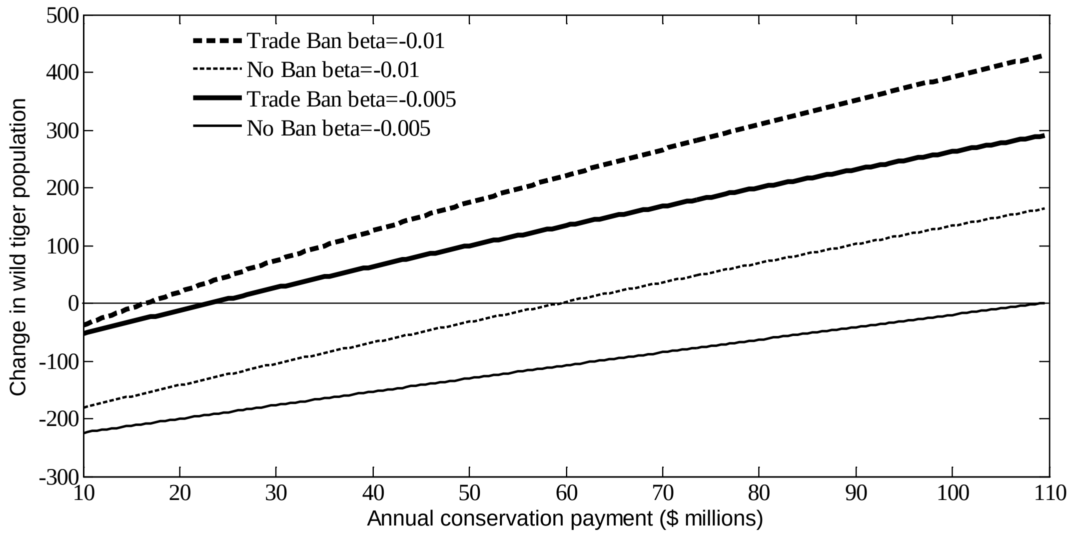


Figure 8: Conservation Payments (M) and Potential to Prevent Extirpation of Tigers, Base Case Price Scenario

In reaching this conclusion, we focused only on the size of payments required to offset the benefits to consumers and producers of wild tiger products. We neglect the issue of habitat and the value of habitat in other uses. However, to the extent that countries such as India and China have set aside land as wildlife (tiger) reserves, the problem of habitat conversion should be less an issue than that of poaching. Nonetheless, even if conservation payments were to increase by an order of magnitude, they would not constitute an onerous obstacle to tiger preservation.

5. DISCUSSION

Given the complexity of tiger protection, our results suggest that, because habitat is being eroded, neither legitimizing trade in products from captive bred tigers nor increased enforcement are likely able to prevent the tiger from going extinct in the wild. Rather, a cocktail of policies will be needed to give wild tigers a chance of surviving. Clearly, if governance institutions found in developed countries (rule of law, low levels of corruption, etc.) also characterized range states, the tiger would survive in the wild (see Bulte et al., 2003). These kinds of institutions lead to rates of detection that exceed those required to preserve wild tigers. Our results also indicate that conservation payments from rich countries to poor range states can be effective in protecting tigers, as was shown to be the case for elephants (van Kooten, 2008), and that such payments need not be onerous. But again, lack of adequate institutions precludes the ability to write enforceable contracts that protect habitat and prevent poaching of tigers.

In the absence of the required institutions or effective community-based natural resource management regimes that inhibit illegal takings, our results indicate that the sale of tiger products from tiger farms in China might reduce poaching sufficiently to enable wild tigers to reproduce faster than they are killed. Some combination of increased enforcement and sale of products from captive-bred animals might also work. However, the loss of quality habitat makes it even more difficult to design an effective policy for saving wild tigers.

Our simulation results assume that anti-poaching enforcement efforts and the demand for poached tigers will be unaffected if tiger farming is legitimized, other than through a stigma effect that causes demand to shift outwards if trade is permitted. These assumptions are certain to generate debate, as there are several arguments against them. Most commentators have argued against legalization of tiger farming on the following grounds (CITES, 2001; Nowell and Ling, 2007):

1. Legalization will increase the demand for poached tigers because farmers will purchase them to increase their captive stocks.

2. Legalization will increase poaching because it is much cheaper to poach a tiger than to raise one in captivity; thus, producers of tiger products will purchase poached animals and sell them as if they were bred in captivity. This is one means by which a legalized activity facilitates an illegal one.
3. Because there will be a legitimate supply of tigers as well as an illegal supply, it will be harder to recognize poached tigers and the effectiveness of anti-poaching efforts will be reduced.

These claims would certainly be warranted if the legal sector (tiger farming) was unregulated with many competitive firms. However, if tiger farming is concentrated in a single or a very small number of well regulated monopolistic firms, these concerns may not materialize, as we demonstrate using an historical example.

For 200 years spanning almost the entire length of the colonial North American fur trade, the Hudson's Bay Company (HBC) held a monopoly over most of what is now Canada, east of the continental divide (Rocky Mountains). The HBC aggressively self-policed the region they controlled to ensure that their full monopoly rights were upheld (Gough, 2007). As a consequence, the HBC was able to restrict the flow of beaver pelts out of North America. This had two important effects: First, the price of beaver pelts was much higher than it would otherwise be, leading to large profits for the HBC. Second, and perhaps more important in the current context, the population of beavers remained viable because of the conservation effect of restricted trade.

The lands to the west of the North American continental divide were not controlled by any form of monopolistic company until 1824. In fact, during the late 18th and early 19th centuries, many companies from Great Britain, the United States, Spain and Russia competed for furs along the northwest coast of North America. The prize of the fur trade in this region was the sea otter, and, as a consequence of an unrestricted competitive fur trade, the sea otter population plummeted rapidly from perhaps 300,000 to less than 2000. Even today, the sea otter remains an endangered species.

The lesson to be learned is that the structure of the tiger farming sector could have a tremendous effect on the fate of the tiger. To the extent that China is the sole or primary market for tiger products and that tiger products are not in high demand in other countries, the granting of a monopoly charter would ensure that tiger products are sold at a price high enough to cover the costs of a captive breeding program while also providing monopoly rents. In this case, the granting of a monopoly charter could lead to greater anti-poaching enforcement and reduce the demand for poached products.

It would be in the interest of a monopoly firm to take actions against poachers to protect their profits. A high monopolistic price can only be maintained if poaching is prevented and, as a consequence, the monopolist will be interested in preventing poaching. The monopoly charter should give the firm the right to police poachers, and possibly even provide additional incentives for them to do so. Given that the current detection rate is only some 3%, it is clear that extant methods of anti-poaching enforcement are ineffective, perhaps because government officials and police officers are susceptible to corruption. Those involved in anti-poaching activities are not impacted financially by the success of poachers, except to the extent that they can be bribed. A monopolist, on the other hand, would have great incentive to prevent poaching because poaching threatens monopoly rents.

To help ensure that poached wild tigers are not ‘laundered’ into the stock of captive bred tigers, an animal registration program similar to that used for cattle in Europe and North America could be adopted. In the cattle sector, animals are registered with the government at birth, identified by ear tags, frequently branded, and so on. All captive bred tigers could similarly be registered at birth with the registration system monitored for compliance not only by the Chinese government but also by a credible international organization such as CITES that would certify products. Only animals born in captivity to registered parents could be culled to produce medicines and other goods, with monitoring again performed by an outside certifier. Such a scheme would address the three concerns raised by various wildlife protection groups. Monopolistic power, regulatory restrictions and monitoring are all required to give wild tigers their best chance of survival, although other policies (e.g., conservation payments) would need to address the problem of habitat loss and depletion of the tiger's prey.

Ethical and ideological considerations are important factors not taken into account in the forgoing analysis. Clearly, one can object to the slaughter of tigers or other wildlife, but it occurs despite our objections. One can also object on ethical grounds to the sale of products from tiger farms, except that it is difficult to argue against tiger farms while accepting the production of beef, poultry, pig and other commodities from what are best described as animal manufacturing facilities.[11] Unfortunately, about all that we can conclude from our analysis is that, if wild tigers are to be preserved, we must adopt a pragmatic strategy that includes efforts to protect habitat, enforce bans on poaching and international trade, and enable countries to develop and implement institutions that reduce opportunities for illegal activities of all kinds. But we must also be prepared to adopt approaches that might be difficult to accept from an ethical and ideological perspective, and that could well include the sale of products from tiger farms in China (Rao, 2008).

[11] For an excellent and even-handed discussion about animal welfare, hunting and large-scale animal production facilities, see Scully (2002).

ACKNOWLEDGEMENTS

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