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

INTRODUCTION

Wild tiger populations have declined from about 100,000 in 1900 to perhaps as few as 6000 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, Indochinese, Amur, South China, Malaysian and Sumatran) remain, scattered throughout eastern Russia, Indochina, the Indian subcontinent and Southeast Asia (see Figure 1 and Table 1). Along with tiger poaching and depletion of prey, habitat degradation and destruction caused primarily by illegal logging contribute greatly to the demise of the tiger. Ninety-three percent of the tiger's historic range has disappeared, while the area known to have been inhabited most recently by tigers has declined by 41 percent over the past decade (Dinerstein et al. 2007).

In an effort to stave off extinction, international trade in tigers has essentially been prohibited since 1975 when the species was listed under Appendix I of the UN Convention on International Trade in Endangered Species (CITES), although the Amur tiger was listed only 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. Nonetheless, evidence indicates that illegal trade in wild tigers continues with tiger bone still used in some traditional medicines.[1] Within China, the domestic ban coincided with the establishment of tiger farms that now house some 5000 animals (CATT 2007; Gratwicke et al. 2008). Wildlife groups are concerned that the sale

[1] 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."

of products from tiger farms (which seems inevitable given the number of captive tigers in China) will increase demand for tigers and facilitate the marketing of poached animals.

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 significant source of illegally traded products that contain tiger bone (Novell and Ling 2007; EIA 2007).[2] 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.[3] 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, concluding that wild tigers will likely become extinct if the status quo is maintained (Gratwicke et al. 2008; Nowell and Ling 2007; Dinerstein et al. 2007; Sanderson 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

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[2] In an article in the January 4, 2010 issue of *The Economic Times*, entitled "China wakes up, calls for protection of tigers" (http://www.savethetigerfund.org as viewed January 27, 2010), it is clear that China is the main market for medicines from tigers and that much of it comes from tiger farms.

[3] 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."

facilitates the laundering of illegal tiger parts. The so-called 'stigma effect' (Fischer, 2004), which has not been demonstrated empirically, postulates that the demand for illegal wildlife products falls when trade is banned. 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 wild tigers and preventing their extinction.[4]

Upon examining the issue in a theoretical framework, Damania and Bulte (2007) assume imperfect competition and demonstrate that multiple equilibria are possible in a game between organized purveyors of illegal wildlife products (criminal poaching gangs) and domestic wildlife farms. In their model, it is not possible to determine unambiguously whether products from captive-bred wildlife will increase or decrease harvests of wild animals. If poachers and farmers compete on the basis of quantity (Cournot competition), the solution to the game leads to higher populations of wild tigers; but, if competition is on the basis of price (Bertrand competition), wild stocks are reduced. However, as Singh and Vives (1984) demonstrate, the poacher and farmer are unlikely to compete on the basis of price because they both do better if they compete on the basis of quantity when the goods they market are substitutes. That is, the Cournot outcome (with higher wild stocks) dominates the Bertrand outcome (reduced wild stock) if wild and farmed products are considered substitutes, and especially if the demand structure is linear (as assumed by Damania and Bulte).

Damania and Bulte (2007) also argue that, since the feed costs of raising tigers are considerable, farmers are unable to undercut suppliers of illegal wildlife products. However, they

[4] 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.

assume low costs of processing and marketing wild animals and ignore the potential economies of scale in producing multiple products from farmed tigers, including new products such as tiger bone wine, which may not be possible when activities must be hidden from the authorities. But clearly the existence of tiger farms despite a domestic and international trade ban suggests that costs may not be onerous, that there might be benefits specific to tiger farming (e.g., paid public viewing), that farmed products are somehow circumventing the current trade ban, or some combination of these factors.[5]

Similar arguments have been raised concerning the African elephant and the ivory trade ban. There is fear that CITES-sanctioned intermittent sales of stockpiled raw ivory from southern African states with large elephant herds 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 stigma effect appears to have had little effect in reducing the rate of decline in elephant populations in west and central Africa, although Blanc et al. (2007) find elephants in east and southern Africa to be increasing by 4% annually. Van Kooten argued that the elephant is best protected by effectively protecting its habitat through actual on-the-ground payments tied to elephant numbers. While conservation of tiger habitat is an important policy in range states, as are captive breeding programs designed solely to ensure survival of the various tiger subspecies, economic incentives to prevent poaching and promote tiger protection have seemingly been ignored.

[5] In response to a Wall Street Journal article, Kirsten Conrad, an environmental services consultant from Singapore, notes that, while it is cheaper to kill a tiger in the wild than raise one on a farm, the "wild tiger must be transported across numerous borders … As an illicit good, bribes and payoffs would be required; the rule of thumb is a doubling of price each time the cargo is handed off from one dealer to another. China has imposed the death penalty for trafficking tiger parts, and this strong deterrent further jacks up the price." See http://online.wsj.com/article/SB10001424052748704454304575081042120355402.html?mod=WSJ_latestheadlines (last viewed April 28, 2010).

The present study contributes to the debate about tiger farming by using a mathematical bioeconomic model of wild tiger population dynamics, trade and habitat to analyze the potential of heightened anti-poaching enforcement and/or liberalization of the captive tiger breeding industry to prevent the extinction of wild tigers. A major conclusion of our research is that anti-poaching and trade-ban enforcement must be increased to rates that are seemingly unattainable if extirpation of wild tigers is to be prevented, but that a captive breeding industry and/or effective transfer payments from rich countries to poor ones for protecting habitat 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, available habitat, and other relevant variables to the rate of change in the wild tiger population. Using the survivability function, we determine for any combination of parameters whether the tiger population will reach a stable positive equilibrium or go extinct. The model makes no distinction between poachers and farmers, except that the ability to sell farmed animals increases the supply of tigers while also shifting out the demand function, which is taken to be downward sloping. We estimate the current levels of all of the parameters and then calculate 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 to sell tiger products from captive-bred animals. Then, 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 transfer payments in section 4. We conclude in section 5 with a discussion of the policy issues.

MODEL OF TIGER TRADE

An economic model of the interplay between killing of wild tigers and culling of farmed animals is provided in Figure 2.[6] 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^{**}. In the diagram, $q^{**}>q_1$, but it could also be true that $q^{**}<q_1$, which would be the case if the stigma effect was greater and the post-ban demand function intersected the illegal supply curve to the left of *v*. Further, the qualitative analysis in Figure 2 would remain unchanged if the marginal cost of bringing wild tigers to market was lower than the marginal cost for farmed animals – say, the illegal and legal supply functions were interchanged.

In Figure 2, the illegal supply function is upward sloping, while 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 the figure (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 2, the illegal supply function is upward sloping and its intercept lies above p^* (perhaps due to very successful enforcement). If not, then tigers

[6] Similar figures were derived independently by Heltberg (2001) and van Kooten (2008) in conjunction with ivory trade, so only a brief description is provided here.

will always be poached. The question is whether illegal harvests will still cause extirpation of wild tigers.

BIOECONOMIC MODEL OF TIGER EXPLOITATION

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:

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

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 the following production function:[7]

$$(2) \qquad h(x, \tau) = \theta\, x^{1/2}\, \tau^{1/2}\,,$$

where θ is a catchability 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

$$(3) \qquad \tfrac{1}{2}\, \theta\, x^{1/2}\, \tau^{-1/2}\, (1-\pi)\, p = w,$$

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:

[7] This is a square-root variant of the standard constant returns to scale Schaefer production function (Clark 1990). Our production function is required to obtain a varying marginal value product for effort and to solve for the catchability parameter, as indicated in what follows.

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

We can also solve for the catchability parameter:

(5) $$\theta = \sqrt{\frac{2h\,w}{(1-\pi) x p}}\,.$$

TIGER SURVIVABILITY FUNCTION

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

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

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 *p* with *p*(*h*). As discussed below, the case where the output from tiger farms affects the price of tigers is the one of most interest, because, if this is not so, tiger farming has no effect on wild tigers and policy-makers 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) $$\mathrm{S}(p) = \frac{\theta^2 (1-\pi)^2 x p}{2w}.$$

We assume a linear derived demand function for wild tigers, $\mathrm{D}(p) = \alpha - \beta\, p$, with $\alpha, \beta > 0$. Setting $\mathrm{S}(p)=\mathrm{D}(p)$ and solving for price gives:

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

Now substitute (8) into (6) to obtain the following expression for the tiger survivability function:

$$(9) \qquad \dot{x} = \frac{\gamma\, x(x-m)}{x+m}\left(1-\frac{x}{K}\right) - \frac{\alpha(1-\pi)\theta^2 x}{(1-\pi)^2\theta^2 x + 2w\beta}.$$

Anti-poaching enforcement

We can determine that the effect of anti-poaching enforcement is to halt the decline in tiger populations. Upon partial differentiating $\dot{x}$ in equation (6) with respect to π and then substituting for *p*, we get:

$$(10) \qquad \frac{\partial \dot{x}}{\partial \pi} = \frac{\theta^2 x p}{2w} = \frac{\alpha\theta^2 x}{2w\beta + \theta^2(1-\pi)^2 x} > 0.$$

Both the numerator and the denominator in (10) are positive, so $\frac{\partial \dot{x}}{\partial \pi} > 0$, which implies that the effect of increased enforcement, or detection (π), will have a positive effect on the rate of increase in the population of wild tigers, ceteris paribus.

This says nothing, however, about the threshold level of detection π^* required to cause the tiger population to rise, or at least stop declining. Set (6) equal to zero, substitute for *p* from (8) and solve for π^*:

$$(11) \qquad \pi^* = 1 - \frac{1}{2\,g(x)}\left[\alpha \pm \sqrt{\alpha^2 - \frac{8w\beta g(x)^2}{\theta^2 x}}\right].$$

The second term on the right-hand-side of (11) is required to be less than 1.0. The value of θ is obtained from (5) and is constant. For baseline values of the parameters (see below), π^* = 1 – 0.099 = 0.901; that is, higher levels of enforcement are not likely to be sufficient by themselves to prevent extirpation of tigers.

Stigma effect

Upon partial differentiating $\dot{x}$ with respect to the shift parameter on the demand function, we get

$$(12) \qquad \frac{\partial \dot{x}}{\partial \alpha} = -\frac{(1-\pi)\theta^2 x}{(1-\pi)^2\theta^2 x + 2w\beta} < 0 .$$

The sign is negative because both the numerator and denominator are positive. Result (10) indicates that, if a stigma effect reduces α, it leads to an increase in the population of wild tigers.

Sale of captive-bred tigers

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:

$$(13) \qquad S(p) = \frac{\theta(1-\pi)^2 xp}{2w} + \Omega.$$

Again set $S(p) = D(p)$, solve for p and substitute this result in (6). The new expression for the tiger survivability function is:

$$(14) \qquad \dot{x} = \frac{\gamma\, x(x-m)}{x+m}\left(1-\frac{x}{K}\right) - \frac{(\alpha-\Omega)(1-\pi)\theta^2 x}{(1-\pi)^2\theta^2 x + 2w\beta} .$$

Partial differentiating $\dot{x}$ with respect to Ω gives a result identical to (12), except the sign differs:

$$(15) \qquad \frac{\partial \dot{x}}{\partial \Omega} = \frac{(1-\pi)\theta^2 x}{(1-\pi)^2\theta^2 x + 2w\beta} > 0 .$$

The direct effect of permitting sales of farmed tigers is to increase the population of wild tigers over what it would otherwise have been. If wild tigers are declining due to poaching or loss of habitat, the sale of farmed tigers will simply reduce the rate of decline (possibly by enough to prevent extinction).

The overall impact on wild tigers from sales of farmed tigers is uncertain, however. 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. If there is a stigma effect, the demand intercept α would increase, perhaps to what is was prior to the trade ban. To see the overall effect, partial differentiate $\dot{x}$ in (14) with respect to (α–Ω), which gives $\frac{\partial \dot{x}}{\partial(\alpha - \Omega)} < 0$ if $\alpha > \Omega$ and $\frac{\partial \dot{x}}{\partial(\alpha - \Omega)} > 0$ if $\Omega > \alpha$, ceteris paribus. By setting (14) equal to zero, it is possible to derive the critical level of captive-bred sales required to prevent wild tiger populations from declining:

$$\Omega^* = \alpha - \left[(1-\pi) - \frac{2w\beta}{(1-\pi)\theta^2 x}\right]\left[\frac{\gamma\, x(x-m)}{x+m}\left(1-\frac{x}{K}\right)\right]. \tag{16}$$

Critical values depend on the model parameters, and this is investigated in more detail below.

Conservation payments

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.

We do so in roundabout fashion by considering the levels of compensation needed by poachers and consumers of tiger products.

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

$$(17)\qquad p(q^D) = \frac{1}{\beta}\,(\alpha - q),\ \alpha, \beta > 0,\ \text{ and }\ p(q^S) = \frac{2w}{(1-\pi)^2\theta^2 x}\,q\,,$$

where q refers to sales (harvest) of poached tigers. The total consumer plus producer surplus (SS) in the tiger market is given by the area between the demand and supply functions:

$$(18)\qquad SS = \int_0^{q^*}\left(\frac{\alpha}{\beta} - \frac{q}{\beta} - \frac{2w}{(1-\pi)^2\theta^2 x}\,q\right)dq\,.$$

Let $\bar{q} < q^*$ be the number of tigers that would prevent extinction of tigers, that is, the level that just causes $dx/dt > 0$. A payment of amount M is required to protect $q^* - \bar{q}$ tigers. Therefore, we define the marginal surplus value, M, as the surplus created by the last $q^* - \bar{q}$ wild tigers harvested (see Figure 3):

$$(19)\qquad M = \int_{\bar{q}}^{q^*}\left\{\frac{\alpha}{\beta} - \left(\frac{1}{\beta} + \frac{2w}{(1-\pi)^2\theta^2 x}\right)q\right\}dq = \frac{\alpha}{\beta}(q^* - \bar{q}) - \left(\frac{1}{2\beta} + \frac{w}{(1-\pi)^2\theta^2 x}\right)(q^* - \bar{q})^2\,.$$

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

From (19), we can solve for $\bar{q}$ 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:

$$\dot{x} = g(x) - h(x) + \frac{q^*(x) - \bar{q}(x, M)}{1-\pi}. \tag{20}$$

Equation (20) is another form of the tiger survivability function that is similar to equations (6), (9) and (14), but with an added term that is positive because $(q^* - \bar{q}) > 0$ and $(1-\pi) > 0$. Mathematically,

$$\frac{\partial \dot{x}}{\partial M} = \frac{-\frac{\partial \bar{q}}{\partial M}}{1-\pi} > 0, \tag{21}$$

because $\partial \bar{q}/\partial M < 0$ as is evident from Figure 3. Thus, $\dot{x}$ will be greater for all levels of x, which implies that there is greater incentive to preserve tigers. Using (21) and knowledge about the model parameters, 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.

Effect of tiger habitat

The analysis thus far has not directly addressed the issue of habitat loss. The only way in which habitat loss and loss of prey can be taken into account in the current model is through the carrying capacity, K. Partial differentiating (6) with respect to K gives:

$$\frac{\partial \dot{x}}{\partial K} = \frac{\gamma x^2 (x-m)}{(x+m)K^2} > 0, \forall x > m. \tag{22}$$

Not unexpectedly, an increase in K will lead to an unambiguous increase in wild tigers, given all else held constant.

TIGER SURVIVAL PARAMETERIZATION

From the theoretical model, we find that the rate of change in tiger population increases as a result of increased habitat, conservation payments, increased anti-poaching enforcement, and a trade ban on tigers and their products that operates through the stigma effect. However, this says nothing about the survivability of wild tigers. If wild tiger populations are declining, an increase in these parameters might only reduce the rate of decline. Further, the effect of sales of captive-bred tigers is uncertain as it depends on the size of the stigma effect parameter (α) and the sales of farmed tigers (Ω). Therefore, we consider plausible parameter values to provide some notion of the potential impact of various policies on wild tiger populations.

Given that we lack specific data on the demand side, our model cannot take into account subspecies details regarding reproduction, habitat and minimum viable populations, information that is not generally available at the regional level in any case. In rainforests, tigers occur at densities of one to two tigers per 100 km^2 because of low prey densities; in other regions with higher prey densities and/or smaller tiger subspecies, such as the Indochinese tiger, habitat can support an average of as many as five adult tigers per 100 km^2.[8] Thus, dietary requirements, prey densities and other factors determine the size of habitat required to support tigers. In the last column of Table 1, data on currently available habitat are provided. There currently exist approximately 6000 wild tigers (=x) over a range of some 850,000 km^2 (Table 1); this habitat might support 17,000 tigers (at two tigers per 100 km^2), so K = 17,000.

In order to maintain a viable population of a minimum of six breeding females (perhaps as few as 20 animals total), reserves need to be a minimum of about 500 km^2 for Bengal tigers, since prey are generally abundant in their native habitat, to more than 2000 km^2 for the Amur

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[8] http://www.savethetigerfund.org/Content/NavigationMenu2/Community/Distribution/default.htm (as viewed 16 April 2009)

(Siberian) tiger. Thus, habitat and prey availability are important factors affecting wild tiger populations. If we assume 76 tiger conservation landscapes (Sanderson et al. 2006) and a minimum population of approximately 20 animals in each to ensure survival, the minimum viable population would be $m \approx 2000$ (see Reed et al. 2003). 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. One such estimate is provided by Sanderson et al. (2006, pp.21-22) who indicate that only 20% of newborn tigers will have the opportunity to breed, annual reproduction averages 0.61 per young female, and there are 2.5 females per male. Then the growth constant is $\gamma = 0.087$ ($=0.2\times0.61\times2.5/3.5$).

Economic data are even more difficult to find. Nowell and Ling (2007) report that, in 1992 (before the domestic trade ban in China), 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 highly sophisticated criminal gangs receive considerably more (CITES 1999).[9] We choose a price of p=$5,000 per wild tiger, but consider scenarios with lower and higher prices.

Each tiger produces between 5 kg and 12 kg of dry bone (e.g., see Ng and Nemora 2007, p.8); thus, 200 wild tigers would yield 1000-2400 kg of bone. Over the period 1999-2005, an average of 60 kg of tiger bone was seized annually, or 2.5 to 6.0 percent of the 1992 illegal harvest. We assume a base-line detection rate of $\pi = 0.04$.

To determine the stigma effect, it is necessary to assume an elasticity of demand and know something about the population dynamics of tigers before and after the Chinese domestic

[9] 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.

trade ban (as the earlier CITES ban by itself would be much less effective). Given that 23 tigers were marketed in shops in Indonesia (Ng and Nemora 2007) and that there might be 500 tigers in that country (Table 1), we get a poaching rate of 4.5%. This rate is higher than the nearly 3% rate based on the 200 wild tigers harvested in 1992 and assumed population of some 7000 wild tigers (CITES 1999, 2001; Dinerstein et al. 2007), but perhaps information was easier to obtain prior to the Chinese trade ban. If we use the 4.5% poaching rate as a baseline, this implies that 315 wild tigers would have been taken in the pre-1993 period, and 270 after 1993. This information is used to derive the stigma effect.

Finally, average per capita GDP in Vietnam reached about $US 1000 in 2008, which was still below the average in most other Asian countries. However, peasants are unlikely to earn wages equal to the per capita GDP of the country in which they reside. We simply assume that those actually killing tigers for the organized gangs have an opportunity annual wage w=$450.

A summary of the parameter values employed in the model is provided in Table 2.

NUMERICAL SIMULATION RESULTS

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 4 for parameters associated with four of the scenarios in Table 2. 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.

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 $x(t)$ = 6000. Increased expenditures on enforcement will result in higher rates 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. The critical level of detection π^* required to keep wild tiger populations from declining can be determined from equation (11), and are provided in Table 3. Clearly, levels of enforcement must be dauntingly high to prevent tigers from going extinct.

A second policy option is to introduce farmed tiger products to the market. The presence of captive-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. Results for selected scenarios are provided in Figure 5; these indicate that the critical level of annual sales causing the rate of change in tiger populations to become positive is between 160 and 200 farmed tigers.

We are also interested in a combination of policy options that can prevent extirpation of wild tigers. 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 an extinction prevention policy frontier. Setting $\dot{x}=0$ in equation (14) and solving for Ω gives the following relation for the policy frontier:

$$\Omega = \alpha - \left(1 + \frac{2w\beta}{(1-\pi)^2 \theta^2 x}\right) g(x) . \tag{23}$$

Plotting various combinations of Ω and π gives the extinction prevention policy frontier plotted in Figure 6. Clearly, detection rates (and thereby expenditure on enforcement) must be increased significantly if one wishes to reduce reliance on sales of farmed tigers to protect wild stocks, with the initial tradeoff steeper when poachers receive lower prices.

Finally, we consider a policy option that focuses on habitat to the exclusion of other policies, except the current level of enforcement remains. The effect of protecting or expanding habitat is to increase the ecosystem's carrying capacity (cc) – its ability to support tigers. In Figure 7, we provide an indication of this effect. Notice that, if the population of wild tigers reaches around 7,000, an increase in carrying capacity to 35,000 (from 17,000) will lead to a positive growth in wild stocks. This occurs in the absence of increases in poaching detection rates and sales of farmed tigers. However, it may be necessary to implement some of the other policies in order to increase tiger populations in the short term while efforts to protect and increase habitat and ecosystem carrying capacity are implemented.

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 (or the sale of poached tiger products). 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.[10] 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).

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

REFERENCES

Bhalla, Nita, 2006. Forest People must help Conserve India's Tigers, Reuters, New Delhi, 27 November. [Available at http://www.alertnet.org/thenews/newsdesk/ SP308865.htm as viewed March 27, 2008].

Blanc, J.J., Barnes, R.F.W., Craig, G.C., Dublin, H.T., Thouless, C.R., Douglas-Hamilton, I. and Hart, J.A., 2007. African Elephant Status Report 2007: An Update from the Elephant Database. Occasional Paper Series of the IUCN Species Survival Commission, No. 33. Gland, Switzerland: IUCN/SSC African Elephant Specialist Group. vi + 276 pp.

Bolze, D., Chetkiewicz, C., Mingjiang, Q., and Krakower, D. 1998. The availability of tiger-based Traditional Chinese Medicine products and public awareness about the threats to the tiger in New York City's Chinese communities: a pilot study. Working Paper No. 12. New York: Wildlife Conservation Society. [Available at http://wcs.org/media/file/mime-9967825651.pdf as viewed June 16, 2008].

Boukal, David S. and Ludeck Berec, 2002. Single-species models of the Allee Effect: Extinction boundaries, sex ratios and mate encounters, *Journal of Theoretical Biology* 218: 375-394.

Bulte, E.H. and R. Damania, 2005. An Economic Assessment of Wildlife Farming and Conservation, *Conservation Biology* 19: 1222-1233.

Bulte, E.H., G.C. van Kooten and T. Swanson, 2003. Economic incentives and wildlife conservation. 1-3 December. CITES, Geneva, Switzerland. [Available at http://www.cites.org/eng/prog/economics/CITES-draft6-final.pdf as viewed July 3, 2008].

CATT, 2007. CATT Alert #49. Thousands ask China to keep Tiger Trade Ban. May 16. [Available at http://www.savethetigerfund.org/CATT as viewed June 30, 2008].

Chapron, G., D.G. Miquelle, A. Lambert and J.M. Goodrich, 2008. The Impact of Tigers on Poaching versus Prey Depletion, *Journal of Applied Ecology* (awaiting publication).

CITES, 1999. Issues relating to species Tiger. Technical Missions. Convention on International Trade in Endangered Species of Wild Fauna and Flora, Forty-second meeting of the Standing Committee in Lisbon, 1999. Standing Committee 42, Doc. SC42.10.4. [Available at http://www.cites.org/eng/com/SC/42/42-10-4.pdf as viewed June 9, 2008].

CITES, 2001. Tiger Enforcement Task Force to target criminal networks. Press Release. [Available at http://www.cites.org/eng/news/press/2001/010330_tiger.shtml as viewed June 9, 2008].

CITES, 2006. Interpretation and Implementation of the Convention Species Trade and Conservation Issues: Tiger. SC54 Doc. 25.1. Report of Standing Committee Meeting, October 2-6. [Available at http://www.cites.org/eng/com/SC/54/E54-25-1.pdf as viewed June 9, 2008].

Damania, R. and E.H. Bulte, 2007. The Economics of Wildlife Farming and Endangered Species Conservation, *Ecological Economics* 62: 461-472.

Dinerstein, E., C. Loucks, E. Wikramanayake, J. Ginsberg, E. Sanderson, J. Seidensticker, J. Forrest, G. Bryja, A. Heydlauff, S. Klenzendorf, P. Leimgruber, J. Mills, T.G. O'Brien, M. Shrestha, R. Simons and M. Songer, 2007. The Fate of Wild Tigers, *BioScience* 57(6): 508–514. doi:10.1641/B570608

Dinerstein, E., C. Loucks, A. Heydlauff, E. Wikramanayake, G. Bryja, J. Forrest, J. Ginsberg, S. Klenzendorf, P. Leimgruber, T. O'Brien, E. Sanderson, J. Seidensticker and M. Songer, 2006. Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005–2015. A User's Guide. Washington & New York: WWF, WCS, Smithsonian and NFWF-STF. [Available at http://www.savethetigerfund.org/AM/Template.cfm?Section=Full_Reports as viewed April 22, 2009].

EIA, 2007. Availability of Tiger Bone Wine at Wild Animal Parks in China. Briefing Document. [Available at http://phttp://www.eia-international.org/files/reports164-1.pdf as viewed September 16, 2008].

FAO (UN Food and Agricultural Organisation), 2008. Land use data. [Available at http://faostat.fao.org/site/497/default.aspx as viewed May 15, 2008].

Fischer, C., 2004. The Complex Interactions of Markets for Endangered Species Products, *Journal of Environmental Economics and Management* 48: 926-953.

Gough, Barry, 2007. *Fortunes a River: The Collision of Empires in Northwest America*. Madeira Park, BC: Harbour Publishing.

Gratwicke, B., J. Mills, A. Dutton, G. Babriel, B. Long, J. Seidensticker, B. Wright, W. You and L. Zhang, 2008. Attitudes toward Consumption and Conservation of Tigers in China, *PLoS ONE* 3(7): e2544. doi:10.1371/journal.pone.0002544.

Heltberg, R., 2001. Impact of the Ivory Trade Ban on Poaching Incentives: A Numerical Example, *Ecological Economics* 36: 189-195.

Kaplanov, L.G., 1948. Tigers in Sikhote-Alin. Materialy k poznaniyu fauny i flory SSSR, Obschestva Ispytateley Prirody. Novaya seria, *Otdel Zoology* 14: 18-49. (In Russian).

Karanath, K. Ullas, James D. Nichols, N. Samba Kumar and James E. Hines, 2006. Assessing Tiger Population Dynamics using Capture Recapture Sampling, *Ecology* 87(11): 2925-2937.

Miquelle, D.G., Y.M. Pikunov, V.V. Dunishenko, I.G. Aramilev, V.K. Nikolaev, E.N. Abramov, G.P. Smirnov, I.V. Salkina, V.V. Seryodkin, P.V. Gapanov, M.N. Fomenko, A.V. Litvinov, V.G. Kostyria, V.G. Yudin, K.G. Korkisko and A.A. Murzin, 2007. 2005 Amur Tiger Census, *Cat News* 46: 11-14.

Ng, J. and Nemora, 2007. *Tiger Trade Revisited in Sumatra, Indonesia.* Petaling Jaya, Selangor, Malaysia: TRAFFIC Southeast Asia. 20pp.

Nowell, K. and X. Ling, 2007. *Taming the Tiger Trade. China's Markets for Wild and Captive Tiger Products since the 1993 Domestic Trade Ban*. Hong Kong: TRAFFIC East Asia. 64pp. [Available at http://www.ifaw.org/ifaw/dimages/custom/2_Publications/Wildlife/MadeinChina_farmingTigersToExtiction.pdf as viewed June 30, 2008].

Rao, Jaithirth, 2008. How to kill a tiger, *The Indian Express*, Monday, March 17.

Reed, David H., Julian J. O'Grady, Barry W. Brook, Jonathan D. Ballou and Richard Frankham, 2003, Estimates of Minimum Viable Population Sizes for Vertebrates and Factors Influencing those Estimates, *Biological Conservation* 113: 23-34.

Sanderson, E.W., J. Forrest, C. Loucks, E. Dinerstein, J. Ginsberg, J. Seidensticker, P. Leimgruber, M. Songer, A. Heydlauff, T. O'Brien, G. Bryja, E. Wikramanayake and S. Klenzendorf, 2006. Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005–2015. The Technical Assessment. Washington, DC: WCS, WWF, Smithsonian and NFWF-STF. [Available at http://www.savethetigerfund.org/AM/Template.cfm?Section=Full_Reports as viewed April 22, 2009].

Scully, M., 2002. *Dominion. The Power of Man, the Suffering of Animals, and the Call to Mercy*. St. Martin's Press, New York.

Shepherd, C.R. and N. Magnus, 2004. *Nowhere to Hide: The Trade in Sumatran Tiger*. Petaling Jaya, Selangor, Malaysia: TRAFFIC Southeast Asia. 98pp.

Singh, Nirvikar and Xavier Vives, 1984. Price and Quantity Competition in Differentiated Duopoly, *Rand Journal of Economics* 15(4 Winter): 546-554.

Sudhir, T.S., 2006. Tiger census: AP scientists develop new method. Hyderabad, NDTV, Tuesday, November 21. [Available at http://www.ndtv.com/environment/ Wildlife.asp?id=96744&callid=1 as viewed March 27, 2008].

van Kooten, G.C., 2008. Protecting the African Elephant: A Dynamic Spatial Price Equilibrium Model of Ivory Trade, *Biological Conservation* 141(8): 2012-2022.

Table 1. Remaining Tiger Species, Location and Estimated Populations, 2008

Tiger species	Location[a]	Estimated population	Estimated habitat (km^2)
Amur tiger *Panthera tigris altaica*	Russia (Siberia), China	431-529	156,000
Bengal tiger *Panthera tigris tigris*	India, Nepal, Bangladesh, Bhutan, Myanmar, China	3500-4700	210,000[c]
South China tiger *Panthera tigris amoyensis*	China	20-30[b]	10,000[c]
Indochinese tiger *Panthera tigris corbetti*	Cambodia, Laos, Burma, Thailand, Myanmar, Vietnam, China	750-1300	300,000[c]
Malayan tiger *Panthera tigris jacksoni*	Malaysia (Malayan peninsula)	>500	45,000
Sumatran tiger *Panthera tigris sumatrae*	Indonesia (Sumatra)	400-500	130,000[c]

[a] Although four species of tiger were historically found in China, evidence suggests that numbers of any species would now be extremely small (see Figure 1).
[b] Some sources indicate that the South China tiger may even be extinct (see, for example, http://www.medbib.com/South_China_Tiger as viewed 3 April 2009).
[c] Own calculations based on data from www.savethetigerfund.org. Sanderson et al. (2006) provide information by region for effective potential habitat (land cover with low human influence), although this is potential and not current habitat. For Sumatran tiger, information is from Shepherd and Magnus (2004).
Source: http://www.savethetigerfund.org/AM/Template.cfm?Section=Community (as viewed 14 April 2009)

Table 2. Model Parameters: Summary

Item	Parameters and their values		
Population dynamics	$\gamma = 0.087$	$K = 17{,}000$	$m = 2020$
Harvest levels	$h = q = 315$ (trade)	$h = q = 270$ (ban)	
Economic parameters	$w = \$450$	$\pi = 0.04$	$p = \$5000$
Demand parameters[a]			
• Baseline	$\beta = 0.01$	$k = \alpha = 365$	$s = \alpha_{\text{stigma}} = 320$
• More elastic	$\beta = 0.005$	$k = \alpha = 335$	$s = \alpha_{\text{stigma}} = 295$
• Less elastic	$\beta = 0.02$	$k = \alpha = 415$	$s = \alpha_{\text{stigma}} = 370$
• $p = \$1500$	$\beta = 0.01$	$k = \alpha = 330$	$s = \alpha_{\text{stigma}} = 285$

[a] Demand function: D(p)=(1/β)(α – q). Slope parameters (β) are assumed values, with remaining parameters derived assuming linear demand function. Price is assumed to remain constant at $5000/tiger unless otherwise indicated, while pre- and post-Chinese trade ban illegal harvests are assumed to be 315 and 270, respectively. The ‘no stigma’ and ‘stigma’ values of the demand intercepts correspond to k and s respectively in Figure 2.

Table 3: Critical Detection Rates to Prevent Extirpation of Wild Tigers

Price = $5,000 per tiger			Price = $1500 per tiger		
$\beta = 0.005$	$\beta = 0.01$	$\beta = 0.02$	$\beta = 0.005$	$\beta = 0.01$	$\beta = 0.02$
0.948	0.901	0.823	0.984	0.968	0.938

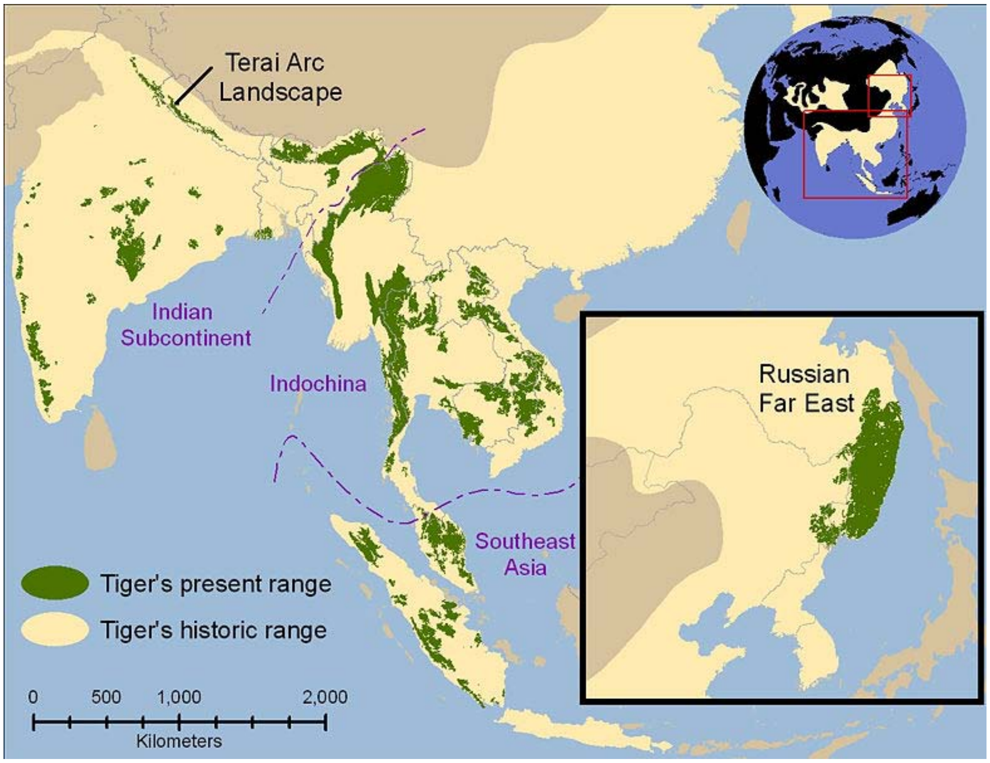

Figure 1: Current and Historic Range of Wild Tigers (Source: Dinerstein et al. 2007)

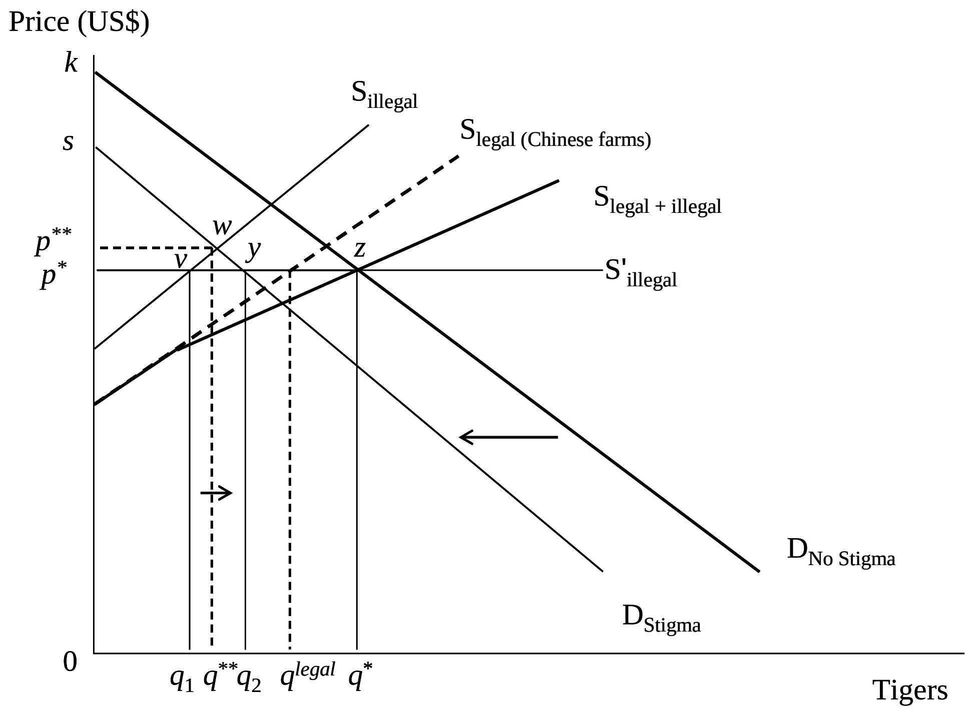

Figure 2: Tiger Market

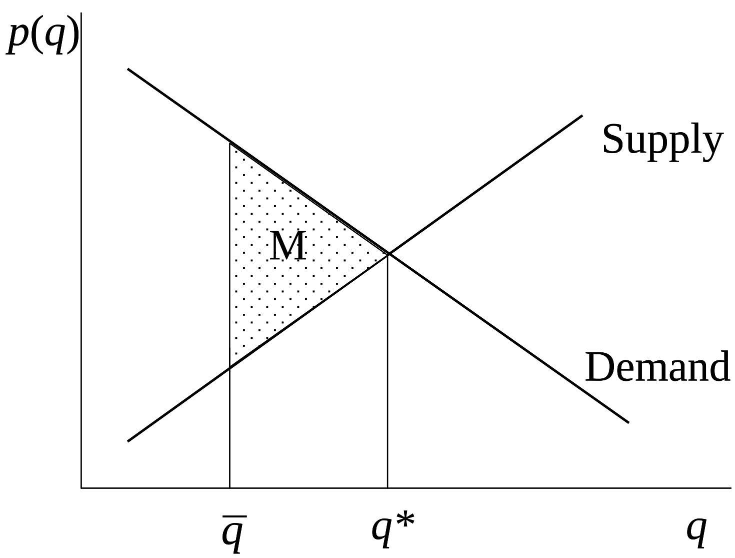

Figure 3: Non-market Values Transfer Framework

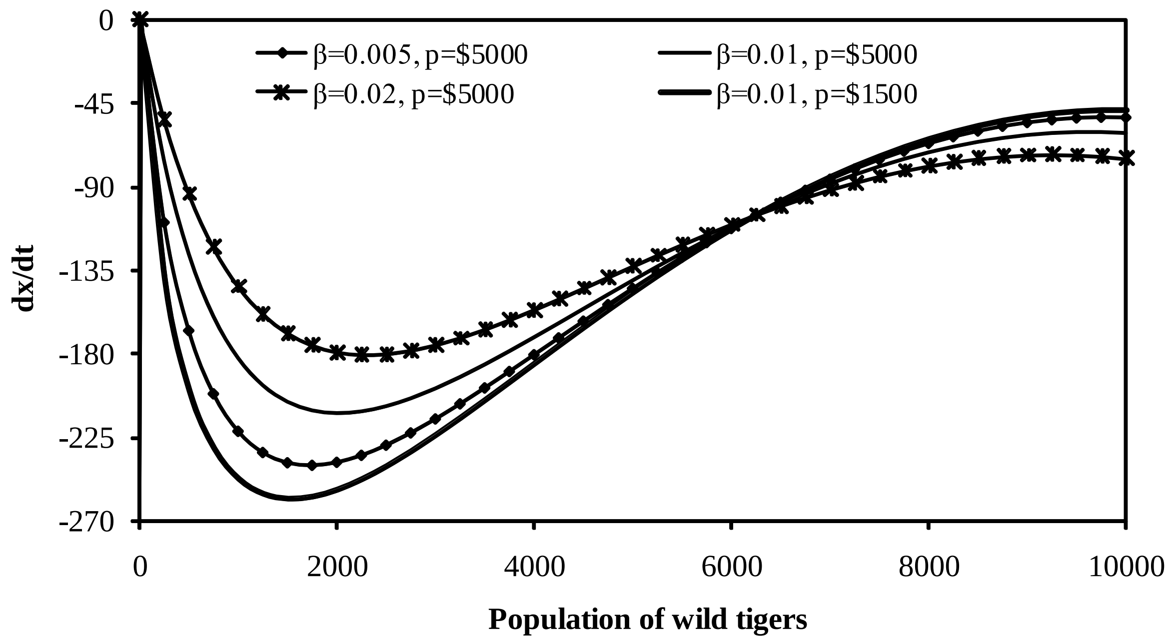

Figure 4: Rate of change in wild tiger populations for various population levels under a trade ban, x_0=6000, π=0.04, different values of β, and prices of \$5,000 and \$1,500

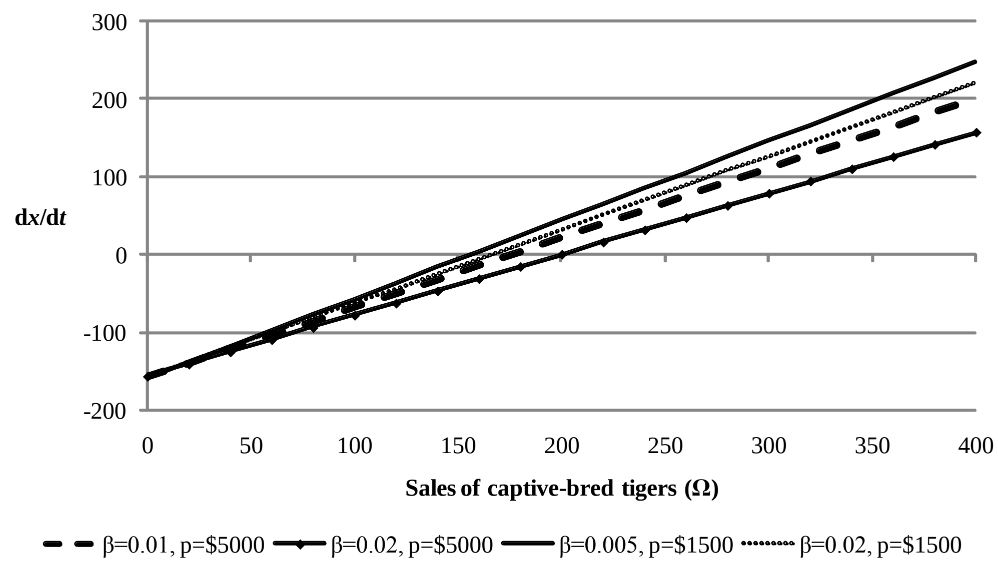

Figure 5: Effect that sales of captive-bred tigers have on rate of change in wild tiger population, x_0=6000, π=0.04, different values of β, and prices of \$5,000 and \$1,500

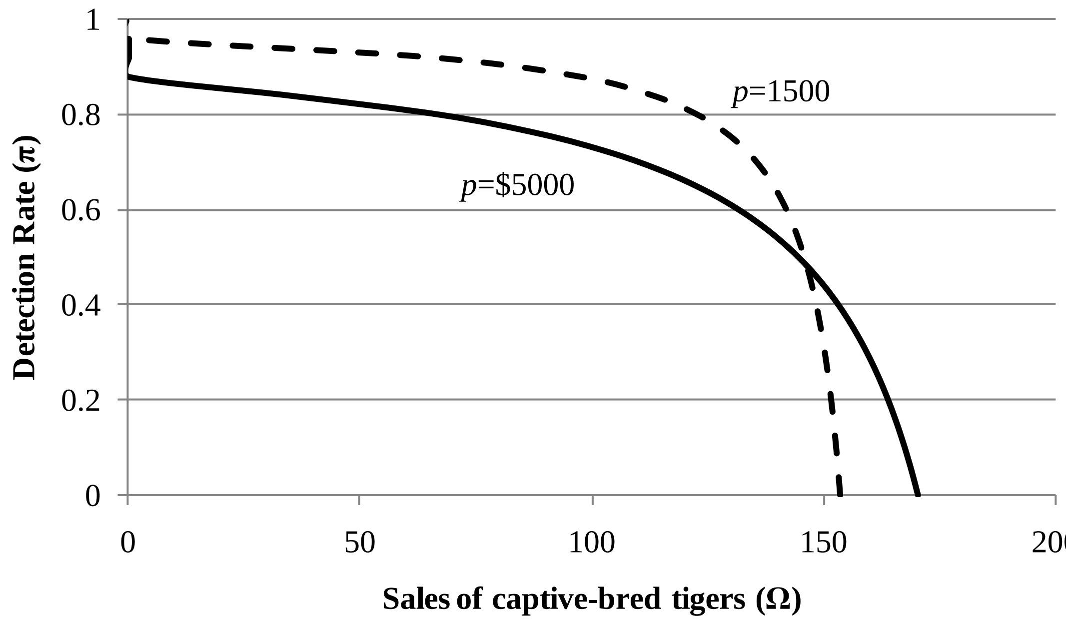

Figure 6: Extinction Prevention Policy Frontier, x_0=6000, β=0.01

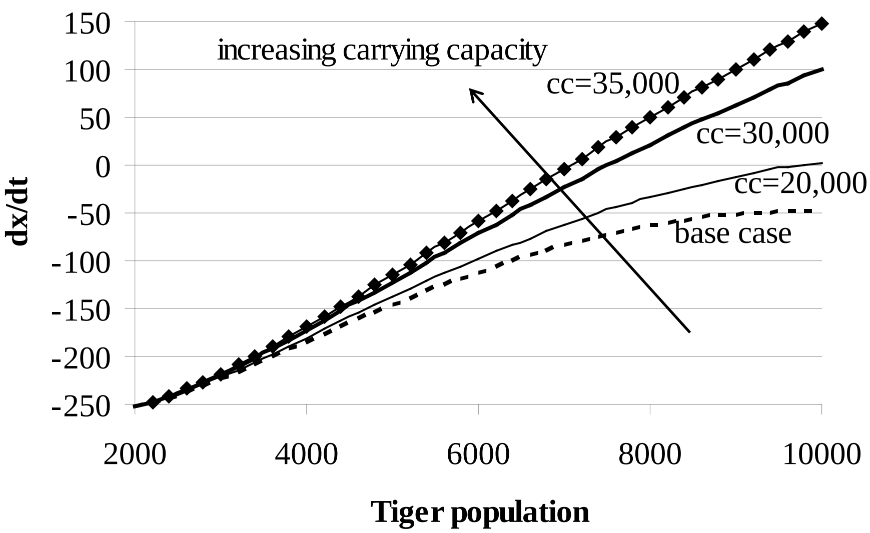

Figure 7: Effect of Increased Habitat Availability on the Tiger Survivability Function, Base Case Parameters, Varying Carrying Capacity