An evolutionary game theory model for devaluing rhinos

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Abstract

Rhino poaching has escalated in recent years due the demand for rhino horn in Asian countries. Rhino horn is used in traditional Chinese medicine and as a status symbol of success and wealth. Wild life managers attempt to secure wild rhinos with approaches such as devaluating the horn. The most common strategy of devaluing horns is dehorning. Game theory has been used before to examined the interaction of poachers and wild life managers. A manager can either 'dehorn' their rhinos or leave the horn attached. Poachers may chose to to behave 'selectively' or 'indiscriminately'. The approach described in this paper builds previous and investigates the interactions between the poachers using evolutionary game theory. The purpose of this work is to discover whether conditions which encourage the poachers to behave selectively exist, that is, they only kill those rhinos with full horns. Notwithstanding, the analytical results prove that poachers will never adopt a selective strategy as long as there is gain from a partial horn. Additionally, poachers behaving indiscriminately was proven to be stable and robust. Thus, we conclude that rhinos are not secured by dehorning and we suggest that resources should be assigned to security.

1 Introduction

The illegal trade in rhino horn supports aggressive poaching syndicates and a black market [11]. This lucrative market entices people to invest their time and energy to gain a 'winfall' in the form of a rhino horn, through the poaching of rhinos. In recent years poaching has escalated to an unpresidented level resulting in concerns over their future existence [13]. In response, rhino conservation has seen increased militarisation with 'boots on the ground' and 'eyes in the sky' [2]. An alternative method is to devalue the horn itself, one of the main methods being the removal so that only a stub is left. The first attempt at large-scale rhino dehorning as an anti-poaching measure was in Damordond, Namibia, in 1989 [10]. Other methods of devaluing the horn that have been suggested include the insertion of poisons, dyes or GPS trackers [4, 13]. However, like dehorning, they cannot remove all the potential gain from an intact horn (poison and dyes fade or GPS trackers can be removed). This paper builds on the work of [7] and considers the general strategy of devaluing horns, which includes dehorning.

Rhino populations now persist largely in protected areas or on private land, and require intensive protection [3]. For wildlife managers law enforcement is often one of the main methods of deterring poaching, however rhino managers can remove the poaching incentive by devaluing their rhinos [10]. In [10] they found the optimum proportion to dehorn using mean horn length as a measure of the proportion of rhinos dehorned. They showed, with realistic parameter values, that the optimal strategy is to dehorn as many rhinos as possible. A manager does not need to choose between law enforcement or devaluing, but perhaps adopt a combination of the two; especially given that devaluing rhinos comes at a cost to the manager, and the process comes with a risk to the rhinos.

A recent paper modelled the interaction between a rhino manager and poachers using game theory [7]. The authors consider a working year of a single rhino manager. A manager is assumed to have standard yearly resources which can be allocated on devaluing a proportion of their rhinos or spent on security. It is assumed that all rhinos initially have intact horns. Poachers may either only kill rhinos with full horns, 'selective poachers', or kill all rhinos they encounter, 'indiscriminate poachers'. This strategy may be preferred to avoid tracking a devalued rhino again, and/or to gain the value from the partial horn. If all rhinos are left by the rhino manager with their intact horns, it does not pay poachers to be selective so they will chose to be indiscriminate since being selective incurs an additional cost to discern the status of the rhino. Conversely, if all poachers are selective, it pays rhino managers to invest in devaluing their rhinos. This dynamic is represented in Fig. 1. Assuming poachers and managers will always behave so as to maximise their payoff, there are two equilibriums: either all rhinos are devalued and all poachers are selective; or all horns are intact and all poachers are indiscriminate. Essentially, either the managers win, the top left quadrant of Fig. 1, or the poachers win, the bottom right quadrant of Fig. 1. The paper [7] concludes that poachers will always choose to behave indiscriminately, and thus the game settles to the top left quadrant, i.e., the poachers win.

The work of [7] did not take in to account the population dynamic effect of these strategies. In a population full of selective poachers would there be a benefit to a single poacher becoming indiscriminate or vice versa? This notion is

		Manager strategies	
		Horn devalued	Horn intact
Poacher strategies	Selective	(M)	
	Indiscriminate		(P)

Figure 1: The game between rhino manager and rhino poachers. The system settles to one of two equilibriums, either devaluing is effective or not.

explored here using evolutionary game theory [12]. The game is not that of two players anymore (manager and poacher) but now the players are an infinite population of poachers. This allows for the interaction between poachers over multiple plays of the game to be explored with the rhino manager being the one that creates the conditions of the population.

In evolutionary game theory, we assume infinite populations and in our model this will be represented by $\chi = (x_1, x_2)$ with x_1 proportion of the population using a strategy of the first type and x_2 of the second. We assume there is a utility function u_1 and u_2 that maps the population to a fitness for each strategy,

$$u_1(\chi) \qquad u_2(\chi).$$

In evolutionary game theory these utilities are used to dictate the evolution of the population over time, according to the following differential equations,

$$\begin{cases} \dfrac{dx_1}{dt} = x_1(u_1(\chi) - \phi), \\[3mm] \dfrac{dx_2}{dt} = x_2(u_2(\chi) - \phi), \end{cases} \tag{1}$$

where ϕ is the average fitness of the whole population. Here, the overall population is assumed to remain stable thus, $x_1 + x_2 = 1$ and

$$\frac{dx_1}{dt} + \frac{dx_2}{dt} = 0 \Rightarrow x_1(u_1(\chi) - \phi) + x_2(u_2(\chi) - \phi) = 0. \tag{2}$$

Thus the average fitness can be written as,

$$\phi = x_1 u_1(\chi) + x_2 u_2(\chi). \tag{3}$$

By substituting (3) and $x_2 = 1 - x_1$ in (1),

$$\frac{dx_1}{dt} = x_1(1 - x_1)(u_1(\chi) - u_2(\chi)). \tag{4}$$

The equilibria of the differential equation (4) are given by, $x_1 = 0$, $x_1 = 1$, and $0 < x_1 < 1$ for $u_1(\chi) = u_2(\chi)$. These equilibria correspond to stability of the population: the differential equation (4) no longer changes.

The notion of evolutionary stability can be checked only for these stable strategies. For a stable strategy to be an Evolutionary Stable Strategy (ESS) it must remain the best response even in a mutated population χ_ϵ. A mutated

population is the post entry population where a small proportion ϵ starts deviating and adopts a different strategy. Fig. 2 illustrates two potential strategies: without outside stimulation neither marble would move. In Fig. 2b however the stability can be described as "stronger": with a small nudge the marble would return to its stable position. In Fig. 2a any non zero nudge would move the marble out of its equilibria.
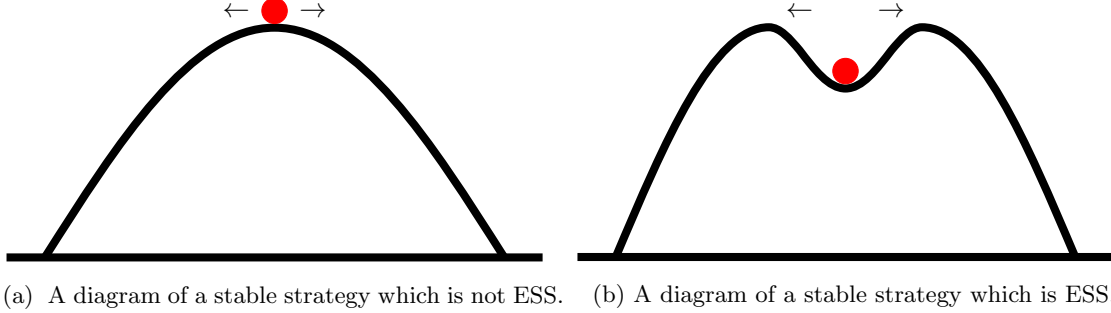

(a) A diagram of a stable strategy which is not ESS. (b) A diagram of a stable strategy which is ESS.

Figure 2: Diagrams of stable strategies.

In Section 2, we determine expressions for u_1, u_2 that correspond to a population of wild rhino poachers and we explore the stability of the equilibria identified in [7]. The results contained in this paper are proven analytically, and more specifically it is shown that:

- all poachers behaving selectively is trivially unstable,

- a mixed population where selective and indiscriminate poachers learn to co exist can not hold,

- all poachers adopting an indiscriminate strategy is an evolutionary stable strategy.

This implies that under almost all conditions, no matter what current proportion of of poachers are acting selectively, the population will eventually turn in to a population of only indiscriminate poachers.

2   The Utility Model

As discussed briefly in Section 1, a rhino poacher can adopt two strategies, to either behave selectively or indiscriminately. To calculate the utility for each strategy, the gain and cost that poachers are exposed to must be taken into account. The poacher incurs a loss from seeking a rhino, and the risk involved. The gain depends upon the value of horn, the proportion of horn remaining after the manager has devalued the rhino horn and the number of rhinos (devalued and not).

Let us first consider the gain to the poacher, where θ is the amount of horn taken. We assume rhino horn value is determined by weight only, a reasonable assumption as rhino horn is sold in a grounded form [1]. Referring to Fig. 1, clearly if the horn is intact, the amount of horn gained is $\theta = 1$ for both the selective and the indiscriminate poacher. If the rhino horn has been devalued, and the poacher is selective, the amount of horn gained is $\theta = 0$ as the poacher does not kill. However, if the poacher is behaving indiscriminately, the amount of horn gained is $\theta = \theta_r$ (for some $0 < \theta_r < 1$). Therefore, the amount of horn gained in the general case is

$$\theta(r, x) = x(1 - r) + (1 - x)((\theta_r - 1)r + 1), \tag{5}$$

where r is the proportion of rhinos that have been devalued, and x is the proportion of selective poachers and $1 - x$ is the proportion of indiscriminate poachers. Note that since $\theta_r, r, x \in [0, 1]$, then $\theta(r, x) > 0$, that is, some horn will be taken. Standard supply and demand arguments imply that the value of rhino horn decreases as the quantity of horn available increases [8]. Thus at any given time the expected gain is

$$H\theta(r, x)^{-\alpha}, \tag{6}$$

where H is a scaling factor associated with the value of a full horn, and $\alpha \geq 0$ is a constant that determines the precise relationship between the quantity and value of the horn. Fig. 3, verifies that the gain curve corresponds to a demand curve.
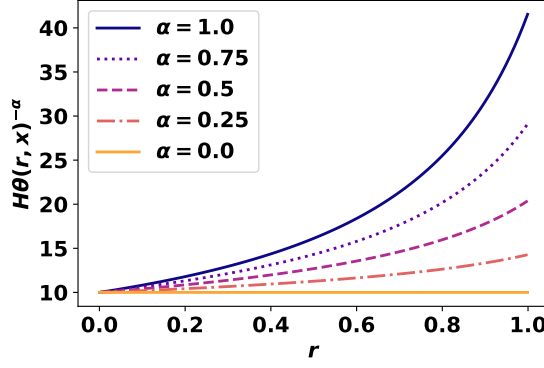
Figure 3: $H\theta(r,x)^{-\alpha}$ for values $H = 10, \theta_r = 0.3$ and $x = 0.2$.

An individual interacts with the population, denoted as $\chi = (x, 1-x)$. For simplicity, from herein the population χ is referred to in terms of the proportion of selective poachers only, x. Therefore, the gain for a poacher in the population x is either

$$
\begin{cases}
\theta(r,1)H\theta(r,x)^{-\alpha} & \text{selective poacher} \\
\theta(r,0)H\theta(r,x)^{-\alpha} & \text{indiscriminate poacher}
\end{cases}
\tag{7}
$$

depending on the chosen strategy of the individual, see Fig. 1.

Secondly we consider the costs incurred by the poacher. Let us denote the number of rhinos that will be considered at risk given r and x as $\psi(r,x)$. The rhinos **not** at risk are the devalued ones that cross the paths of selective poachers. Thus the cost to seek a rhino depends on r and x by,

$$
\psi(r,x) = 1 - rx.
\tag{8}
$$

Additionally, the poachers are also exposed to a risk. The risk to the poacher is the directly related to the proportion of rhinos not devalued, $1 - r$, since the rhino manager can spend more on security if the cost of devaluing is low.

$$
(1-r)^\beta,
\tag{9}
$$

where $\beta \geq 0$ is a constant that determines the precise relationship between the proportion of rhinos not devalued and the security on the grounds. Therefore, at any given time the expected cost for a poacher is,

$$
F\psi(r,x)^\gamma(1-r)^\beta = F(1-rx)^\gamma(1-r)^\beta
\tag{10}
$$

where F and $\gamma \geq 0$ are constants that determine the precise relationship between the proportion of vulnerable rhinos and the probability of finding a rhino, such that γ close to zero indicates very sparse rhinos. Fig. 4, verifies the decreasing relationship between r and the cost.

Note that a selective poacher needs more time to secure an 'available' rhino, if they exist at all. Hence, there is an additional cost that tends to infinity as $r \to 1$,

$$
\begin{cases}
\frac{1}{\psi(r,1)} = \frac{1}{1-r} & \text{selective poacher} \\
\frac{1}{\psi(r,0)} = 1 & \text{indiscriminate poacher}
\end{cases}
\tag{11}
$$

To summarise, the cost incurred by a given individual poacher when interacting with the population x is given by

$$
\begin{cases}
\frac{1}{1-r}F\psi(r,x)^\gamma(1-r)^\beta & \text{selective poacher} \\
F\psi(r,x)^\gamma(1-r)^\beta & \text{indiscriminate poacher}
\end{cases}
\tag{12}
$$

4

(a) For values, $x = 0.7, F = 5$ and $\beta = 0.95$.   (b) For values, $x = 1, F = 5$ and $\gamma = 0.95$.

Figure 4: $F(1 - rx)^\gamma (1 - r)^\beta$.

Combining (7) and (12) gives the utility functions for selective poachers, $u_1(x)$, and indiscriminate poachers, $u_2(x)$,

$$u_1(x) = \theta(r,1)H\theta(r,x)^{-\alpha} - \frac{1}{1-r}F\psi(r,x)^\gamma(1-r)^\beta, \tag{13}$$

$$u_2(x) = \theta(r,0)H\theta(r,x)^{-\alpha} - F\psi(r,x)^\gamma(1-r)^\beta. \tag{14}$$

Let $\sigma = (s, 1-s)$ denote an individual where $\sigma = (1,0)$ represents a selective poacher, and $\sigma = (0,1)$ represents an indiscriminate poacher. For simplicity, from herein the individual σ is referred to in terms of the probability of behaving selectively, $\sigma = s$. Thus the general utility function for an individual poacher in the population with a proportion of $0 \leq x \leq 1$ selective poachers is

$$u(s,x) = su_1(x) + (1-s)u_2(x). \tag{15}$$

Substituting (13) and (14) into (15) gives,

$$u(s,x) = H(\theta_r r(1-s) - r + 1)\theta(r,x)^{-\alpha} - F\left(1 - s + \frac{s}{1-r}\right)(1-rx)^\gamma(1-r)^\beta. \tag{16}$$

In Section 3, the notions of stability and evolutionary stability of these two strategies as well as a potential mixed strategy will be investigated.

3   Evolutionary Stability

By definition, for a strategy to be an ESS it must first be a best response to an environment where the entire population is playing the same strategy. In our model there are three possible stable distributions based on the equilibria of equation (4):

- all poachers are selective;

- all poachers are indiscriminate;

- mixed population of selective and indiscriminate poachers.

Each of the equilibria will be examined in the following subsections.

5

3.1 All poachers are selective

Theorem 1. *Using the utility model described in Section 2, a population of selective poachers is unstable.*

Proof. For $s = 1$ to be a best response to itself the utility of behaving selectively in a population of selective poachers must be greater than the utility of a poacher behaving indiscriminately in a population of selective poachers,

$$u(1,1) > u(0,1), \tag{17}$$

where

$$u(1,1) = H(1-r)^{1-\alpha} - F(1-r)^{\beta+\gamma-1} \tag{18}$$

and

$$u(0,1) = H(\theta_r r + 1 - r)(1-r)^{-\alpha} - F(1-r)^{\beta+\gamma}. \tag{19}$$

Setting (18) to be greater than (19) gives the condition,

$$H\theta_r < -F(1-r)^{\gamma+\beta+\alpha-1} \tag{20}$$

The right-hand size will always be negative for any r, on the other hand the left-hand side is always positive. Thus, (20) can never hold. $\qquad\square$

This implies that whilst [7] identified the individual poachers acting selectively as an equilibrium it is an extremely week equilibrium from the point of view of population stability: a slight change and the population will change.

3.2 All poachers are indiscriminate

Theorem 2. *Using the utility model described in Section 2, a population of indiscriminate poachers is evolutionarily stable.*

Proof. In order for $s = 0$ to be an ESS it must remain the best response in a mutated population χ_ϵ, where $\chi_\epsilon = (x_\epsilon, 1-x_\epsilon)$. Following the same notation, the mutated population will be denoted as x_ϵ from herein. Thus,

$$u(0, x_\epsilon) > u(x_\epsilon, x_\epsilon), \tag{21}$$

must hold. From (16),

$$\tag{22}$$

$$u(0, x_\epsilon) = H(\theta_r r - r + 1)\theta(r, x_\epsilon)^{-\alpha} - F(1 - rx_\epsilon)^{\gamma}(1-r)^{\beta}, \tag{23}$$

$$u(x_\epsilon, x_\epsilon) = H(\theta_r r(1 - x_\epsilon) - r + 1)\theta(r, x_\epsilon)^{-\alpha} - F(1 - rx_\epsilon)^{\gamma}(1-r)^{\beta}\left(1 - x_\epsilon + \frac{x_\epsilon}{1-r}\right). \tag{24}$$

Let the difference of (22) and (24) be denoted as,

$$\delta = u(0, x_\epsilon) - u(\underline{\chi x_\epsilon}, x_\epsilon), \tag{25}$$

$$= H\theta(r, x_\epsilon)^{-\alpha}\theta_r r x_\epsilon - F(1 - rx_\epsilon)^{\gamma}(1-r)^{\beta}x_\epsilon\left(\frac{-r}{1-r}\right) \tag{26}$$

all indiscriminate will be an ESS only if $\delta > 0$ for any small value of ϵ. Thus only if,

$$H\theta(r, x_\epsilon)^{-\alpha}\theta_r r x_\epsilon > F(1 - rx_\epsilon)^{\gamma}(1-r)^{\beta}x_\epsilon\left(\frac{-r}{1-r}\right) \tag{27}$$

The right-hand of inequality (27) is always negative since $(\frac{-r}{1-r}) < 0$ for all r. On the contrary, the left-hand side is always positive for all r, thus the inequality always holds. Therefore, it is proven that all indiscriminate poachers is an evolutionary stable strategy. $\qquad\square$

This shows that a population of indiscriminate poachers not only corresponds to the equilibrium of the individual based game identified in [7] but also is a very robust and an attractive equilibrium at the population level.

3.3 Mixed population of selective and indiscriminate poachers

Theorem 3. *Using the utility model described in section 2, a mixed stable strategy $(s = s^*)$ never exists for $0 < r < 1$.*

Proof. A mixed strategy $s = s^*$ is said to be stable for a given s^* only if,

$$u(1, s^*) = u(0, s^*). \tag{28}$$

The left-hand side is,

$$u(1, s^*) = H(1 - r)\theta(r, s^*)^{-\alpha} - F\frac{1}{(1 - r)}(1 - rs^*)^\gamma(1 - r)^\beta$$

The right-hand side is

$$u(0, s^*) = H(\theta_r r + 1 - r)\theta(r, s^*)^{-\alpha} - F(1 - rs^*)^\gamma(1 - r)^\beta.$$

Substituting these into (28) gives

$$-(H\theta_r r\theta(r, s^*)^{-\alpha} + Fr(1 - r)(1 - rs^*)^\gamma(1 - r)^{\beta-1}) = 0. \tag{29}$$

Condition (29) can never hold for $0 < r < 1$. Thus a mixed stable equilibrium is never stable. $\square$

In this section we have studied analytically the stability of all the possible equilibria. We have proven the instability of any population with selective poachers and the evolutionary stability of the indiscriminate behaviour. All of these theoretic results have been verified empirically, the data for this has been archived at [].

Theorems 1, 2, 3 are illustrated in Fig. 5 which shows the numerical solutions to (4) using (13) and (14) with $x_1 = x$. This is done using numerical integration implemented in [6]. As is evident from the scenarios considered, all populations converge to being all indiscriminate.
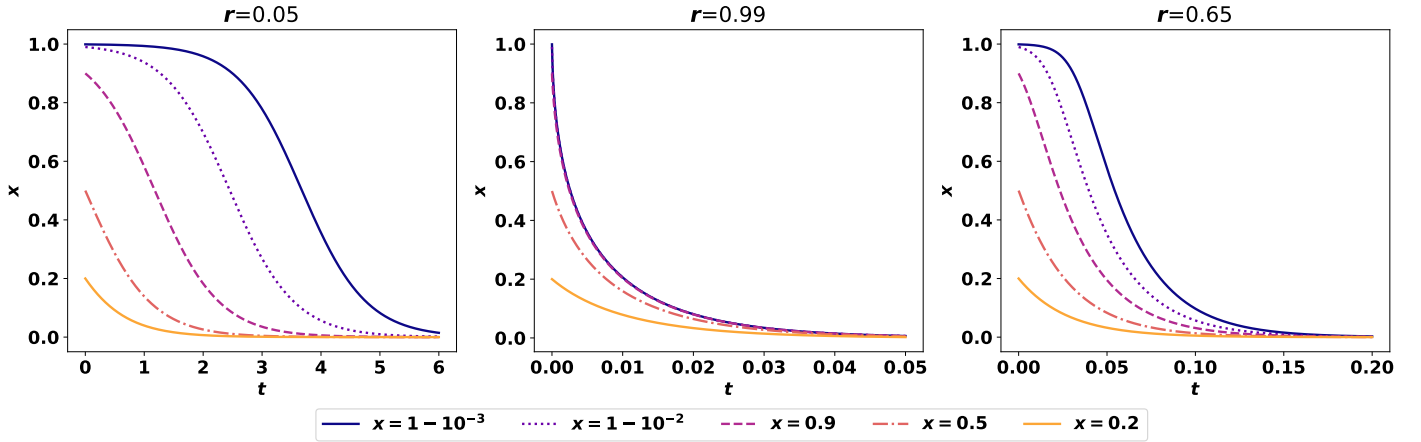

Figure 5: The change of the population over time with different starting populations. For $F = 5, H = 50, \alpha = 2, \beta = 2, \gamma = 1, \theta_r = 0.6$.

Note that these results essentially ~~following~~ follow by comparing equations (13) and (14~~which shows~~), which show that $u_1(x) \leq u_2(x)$ for all x~~:~~. Consider the reverse scenario,

$$u_1(x) > u_2(x) \tag{30}$$

$$0 < \theta(r,1)H\theta(r,x)^{-\alpha}\left(\theta(r,1) - \theta(r,0)\right) + F\psi(r,x)^{\gamma}(1-r)^{\beta}\left(1 - \frac{1}{1-r}\frac{r}{1-r}\right) \tag{31}$$

$$0 < H\theta(r,x)^{-\alpha}-\theta_r r + F\psi(r,x)^{\gamma}(1-r)^{\beta-1} < -H\theta(r,x) - \frac{r}{1-r}\alpha\theta_r \tag{32}$$

which gives the required contradiction. This shows that the utility model used implies that given the choice of acting selectively or indiscriminately, in any given environment it will always be a rational deviation to act indiscriminately.

In the following section a disincentive to acting indiscriminately will be introduced. This can be interpreted in many ways:

- more severe punishment for indiscriminate killing of rhinos;

- educational interventions that highlight the negative aspects of indiscriminate killing;

- the possibility of a better alternative being on offered to selective poachers.

4 Disincentive for indiscriminate behaviour

Let us consider the following modification of the utility to an indiscriminate poacher:

$$\tilde{u}_2(x) = u_2(x) - \Gamma \tag{33}$$

where $\Gamma > 0$ is some constant representing a disincentive only applied to indiscriminate poachers.

This leads to the following modified form of (15):

$$\tilde{u}(s,x) = u(s,x) + (1-s)\Gamma \tag{34}$$

This leads to the following theorem:

Theorem 4. *Using the modified utility model described a population of selective poachers is stable if and only if:*

$$\theta_r H - F(1-r)^{\gamma+\beta+\alpha-1} < \frac{\Gamma(1-r)^{\alpha}}{r} \tag{35}$$

Proof. Following a similar structure to that of Theorem 1,

$$\tilde{u}(1,1) > \tilde{u}(0,1), \tag{36}$$

where

$$\tilde{u}(1,1) = H(1-r)^{1-\alpha} - F(1-r)^{\beta+\gamma-1} \tag{37}$$

and

$$\tilde{u}(0,1) = H(\theta_r r + 1 - r)(1-r)^{-\alpha} - F(1-r)^{\beta+\gamma} - \Gamma. \tag{38}$$

Setting (37) to be greater than (38) gives the condition,

$$\theta_r H - F(1-r)^{\gamma+\beta+\alpha-1} < \frac{\Gamma(1-r)^{\alpha}}{r} \tag{39}$$

$\square$

This immediately leads to the following important remark:

Theorem 5. *Using the modified utility model described, if all rhinos have been dehorned a population of selective poachers is not stable.*

Proof. All rhinos being dehorned implies that $r = 1$. Substituting this into (35) gives,

$$\theta_r H < 0 \qquad\qquad\qquad (40)$$

which is not possible. $\qquad\square$

~~This is mainly~~ Theorem 5 is due to the fact that given two options, if all rhinos have been dehorned then all poachers will need to act indiscriminately to have any source of utility.

~~As opposed to the result of~~ A mixed population can be stable with a disincentive, as opposed to Theorem 3 ~~a mixed population can be stable with this disincentive~~ which states that a mixed stable strategy does not exist for $0 < r < 1$. This is illustrated in Fig. 6 where the evolutionary dynamics are represented for a number of scenarios.

~~The change of the population over time with different starting populations with a disincentive. For $F = 50, \alpha = 2, \beta = 2, \gamma = 1, \theta_r$~~

Note that now the manager has control over the point of convergence by controlling r, as shown on Fig. ~~6 indicates that having a large~~ 7. This is evident in the first two plots of Fig. 7, where a difference in the value of r ~~pushes poachers to behave indiscriminately.~~ can change the point of convergence from a mixed to a selective one. Moreover, the manager can also manipulate how fast the population convergences, as shown in the last two plots of Fig. 7. Fig 8 shows the equilibrium for x for a number of different values of r, and indicates that having a large r pushes poachers to behave indiscriminately. As demonstrated in Fig 9, a higher value of H also has an non-ideal effect on the poachers. Thus, high values of H and r lead to more indiscriminate poachers.

The insights gained from the results are discussed in Section 5.
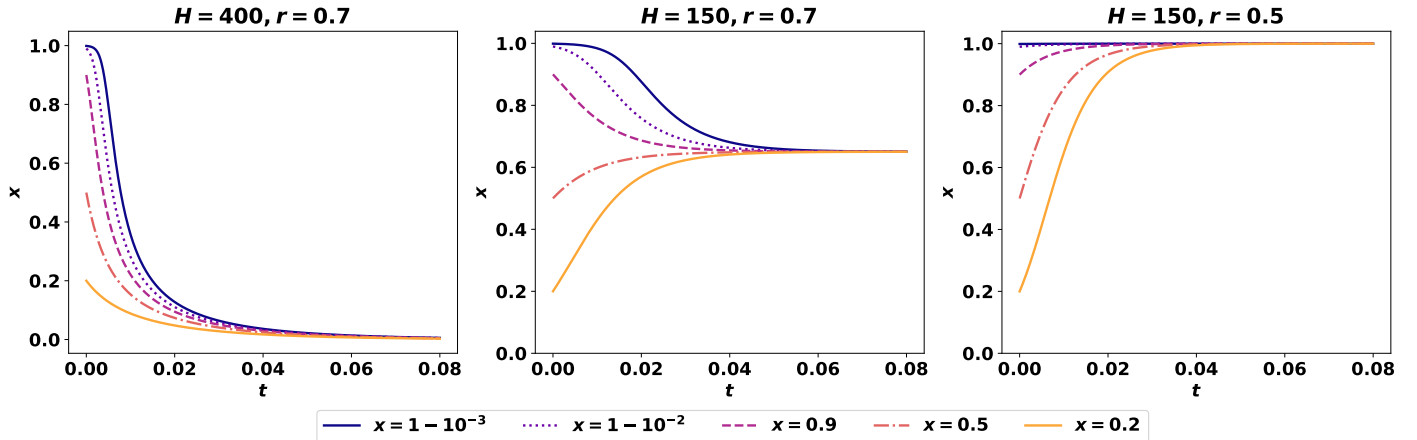

Figure 6: The change of the population over time with different starting populations with a disincentive. For $F = 50, \alpha = 2, \beta = 2, \gamma = 1, \theta_r = 0.5, \Gamma = 300$.

~~In Section 5, we discuss some of the insights we gain from the results of this section.~~

5   Discussion and Conclusions

~~In this section we discuss the insights of our findings~~ Dehorning wild rhinos was introduced in 1989 as a mean of securing the safety of the animal. Our results question the effectiveness of ~~a~~ this key strategy used by wild life managers to deter poachers for more than 20 years.

~~Dehorning wild rhinos was introduced in 1989 as a mean of securing the safety of the animal. However, dehorning~~ Dehorning can be effective if and only if poachers chose to behave in a selective manner. ~~Exploring~~ By exploring the dynamics of a selective population it was proven than being selective is not a best response even in a population where everyone is behaving selectively. More specifically, even a mixed population with a small percentage of the population behaving selectively will not persist. Thus, a poacher would never adopt a selective strategy.
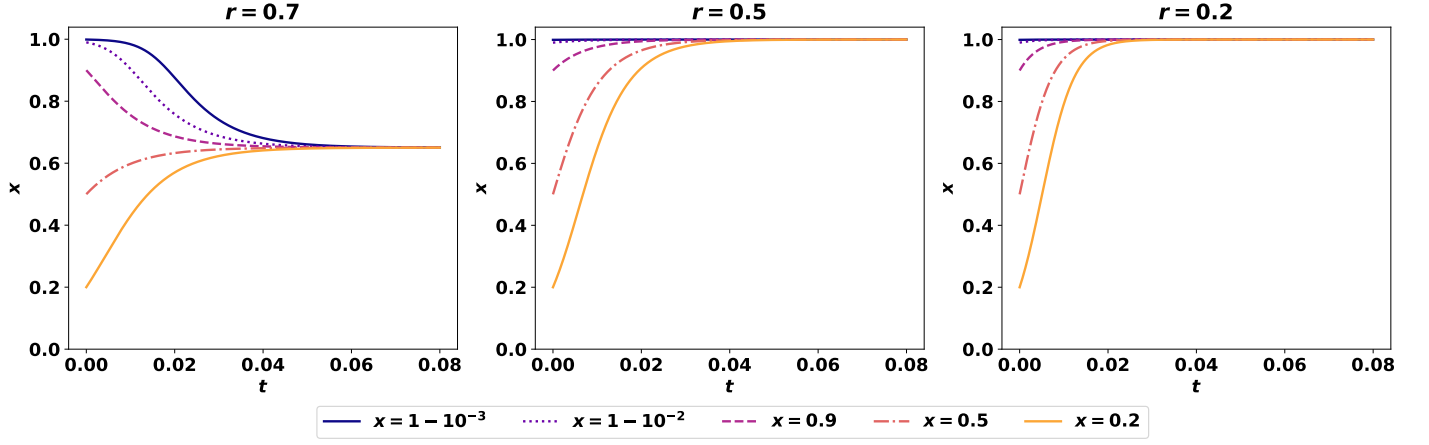
Figure 7: The change of the convergence point with different values of r with different starting populations with a disincentive. For $F = 50, H = 150, \alpha = 2, \beta = 2, \gamma = 1, \theta_r = 0.5, \Gamma = 300$.
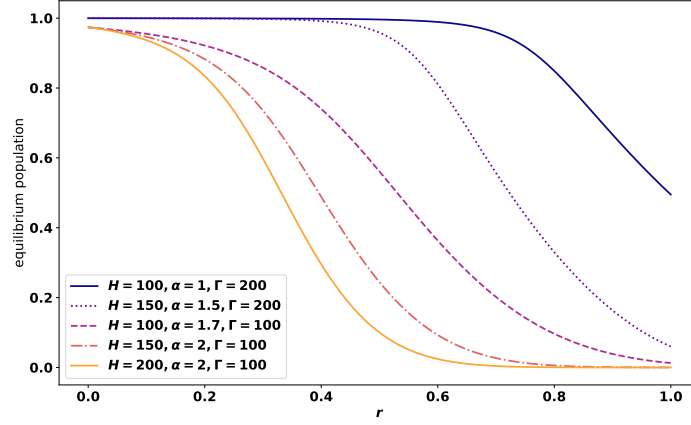

Figure 8: Equilibrium behaviour with a disincentive. For $F = 50, \beta = 2, \gamma = 1, \theta_r = 0.6$.
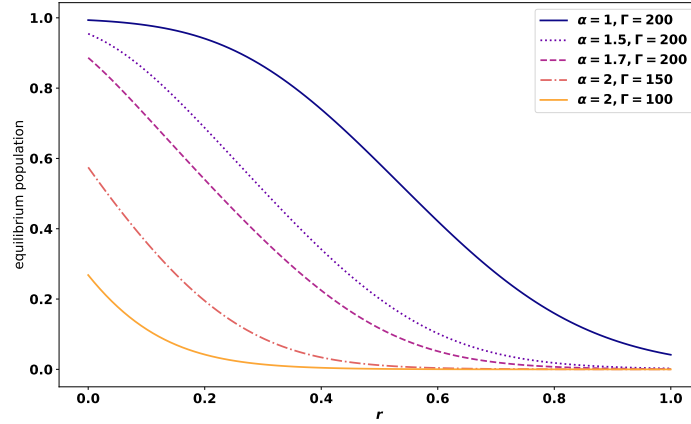

Figure 9: Equilibrium behaviour with a disincentive with different values of H. For $F = 50, r = 0.6 \beta = 2, \gamma = 1, \theta_r = 0.6$.

For a realistic and generic utility model it was found that the only strategy that was proven to be stable is the indiscriminate one. Moreover, it was proven to be evolutionary stable as well. Meaning, that for any given starting population, the poachers would evolve to adopt an indiscriminate behaviour.

Our results indicate however that it is possible for a population of selective poachers to exist, but for this to occur a disincentive must be applied to the utility of indiscriminate poachers. Numerical results indicate that even in this case, the more rhinos are dehorned, the less selective poacher will be in the population.

The disincentive factor can have several interpretations. The government could either force a more severe sentence for rhino poaching~~or likewise could offer some sort of financial reward to selective poachers~~, or through education. Through education we can instill an appreciation for the animal to the future generation of 'possible' poachers. Likewise, a financial incentive for selective behaviour would be an incentive for poaching.

~~The need for poachingis due the poverty levels in African countries.~~ It was displayed that behaving indiscriminate is more profitable than behaving selectively. Thus, it is an easy decision for the poachers. We suggest that a new strategy has to be introduced to the game. A strategy that would allow poachers to have an income without killing an animal or risking their freedom. This can either be opportunities from the government, or even a different income for wild life, such as tourism.

Poachers behaving indiscriminately is an undesirable case and these results indicate that the life of wild rhinos cannot be secured by dehorning. Our results disagree with the claim of [10] that managers should dehorn as many rhinos as possible. We believe that the resources should be assigned to security. By applying a disincentive the tables have been turned ~~. A selective population~~ such that a population of selective poachers is now feasible.

Acknowledgements

A variety of software libraries have been used in this work:

- The Scipy library for various algorithms [6].

- The Matplotlib library for visualisation [5].

- The SymPy library for symbolic mathematics [9].

- The Numpy library for data manipulation [14].

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