Devaluing rhino horns as a theoretical game

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Abstract

The poaching of rhinos has increased dramatically in recent years, creating an ongoing problem and cost to rhino managers. A manager may decrease the reward to the poacher by devaluing the horn such as dehorning so that only a stub is left, or inserting a poison, dye or GPS tracker. However, as it is impossible to remove all value of the horn (a stub remains, poison fades, or GPS trackers can be removed) a poacher may still kill the rhino for the partial gain from the horn, and to avoid tracking this particular rhino in the future. We consider the problem as a theoretical game, where the players are poachers and a rhino manager. By considering the payoff to both manger and poachers we highlight the manager's struggle to discourage poachers to not kill a devalued rhino, despite the loss of time, and increase of risk, to the poacher. Generally, the manager can only influence the situation if virtually all rhino horns are devalued, or the risk involved to the poacher is increased, such as through greater enforcement. However, the cost to devalue the last few rhinos may be very costly due to the sparsity of rhinos, and the rhino manager can easily make a loss by trying to devalue the last, few rhinos. But, whilst a few rhinos remain with their intact horn, a poacher is unlikely to avoid a particular ranch.

Keywords: *Ceratotherium*, *Diceros* , Game theory, poaching, Rhinoceros, wildlife management

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1. Introduction

The illegal trade in rhino horn supports aggressive poaching syndicates and a black market (Nowell et al. 1992). 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 (Smith et al. 2013). In response, rhino conservation has seen increased militarisation with 'boots on the ground' and 'eyes in the sky' (Duffy et al. 2015). 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 (Milner-Gulland & Leader-Williams 1992). Other methods of devaluing the horn that have been suggested include the insertion of poisons, dyes or GPS trackers (Gill 2010, Smith 2013). 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 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 (Ferreira et al. 2014). For wildlife manages law enforcement is often one of the main methods of detering poaching, however rhino managers can remove the poaching incentive by devaluing their rhinos (Milner-Gulland 1999).

A manager does not need to choose 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. Milner-Gulland and Leader-Williams (1992) 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. Further, Milner-Gulland and Leader-Williams (1992) discussed dehorning as a better strategy than anti-poaching protection since the benefits are carried over to subsequent years where the rhino horn length is shorter, whereas anti-poaching protection costs are renewed each year.

We consider one year only, for a single rhino manager. We assume a given amount of resource available for the year, and that all rhinos initially have intact horns. Rhino managers may devalue a proportion of their rhinos. We assume that managers would like to devalue as few as possible, whilst still ensuring the safety of their rhinos. This is a problem of conflicting interests, game theory can provide an appropriate framework. A game theoretic perspective provides insights about (a) the strategies different stakeholders will likely adopt given their objectives when consensus, compromise, or cooperation are feasible, (b) what types of cooperation best reflect stakeholders interests and achieve their objectives (c) which stakeholders are likely to form coalitions, (d) the range of possible outcomes under non-cooperative and cooperative decision-making dynamics, and (e) whether an optimal or satisfactory solution for all stakeholders can be reached simultaneously (Colyvan et al. 2011).

The model we present is similar to the cyclic model used by Bell (1986), where the stakeholders were insects and flowers. Insects and flowers each behaved in one of two ways determined by particular rules, and a cycle of behaviour was formed. With rhino managers and poachers the rules engender a different, non-cyclic, pattern of behaviour where the system settles to one of two states.

Poachers may either only kill rhinos with full horns, ‘selective poachers’, or kill all rhinos they encounter, ‘random poachers’. If all rhinos are left by the rhino manager with their intact horns, it does not pay poachers to be selective so they will become random poachers. Conversely, if all poachers are selective, it pays rhino managers to invest in devaluing his/her 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 devalued and all poachers selective; or all horns intact and all poachers random. Essentially, either the managers win, the top left quadrant of Fig. 1, or the poachers win, the bottom right quadrant of Fig. 1.

2. The model

Consider the situation on one ranch. Let r be the proportion of devalued rhinos (where here, rhino value is only measured by its horn value), and s be the proportion of selective poachers. Assuming a poacher encounters a rhino, there are four scenarios which depend on the strategy of the players. The probabilities of each of these four scenarios are given in Table 1. The actual

	Horn devalued	Horn intact
Selective	rs	$(1-r)s$
Random	$r(1-s)$	$(1-r)(1-s)$

Table 1: The probabilities of each of the four scenarios given that a poacher has encountered a rhino.

probabilities in Table 1 are unknown to the players. They must choose which strategy to take with imperfect information, which is especially relevant to the poachers who can choose their strategy instantaneously, unlike the manager. Furthermore, at any time, the manager can only only choose to either not devalue any further rhinos, or to increase the proportion which are devalued.

2.1. The rhino manager

The rhino manager initially has C resources, which is the cost to devalue the horns from all of his/her rhinos. Then the cost to devalue a proportion of the rhinos is $Cr^{1/\alpha}$, $\alpha > 0$. When $\alpha = 1$ the cost to devalue the first rhino is the same as devaluing the last rhino, the relationship is linear. This would represent a high density of rhinos where there is no time penalty incurred to find each rhino. However if the cost to devalue the last few rhinos is more costly because of the time needed to find the last remaining intact rhinos (Milner-Gulland 1999), then $0 < \alpha \leq 1$, see Fig. 2. As $\alpha \to 0$ the marginal cost to devalue the last few rhinos tends to infinity, representing the difficulty of tracking very sparse rhinos. Note that if devaluing the first rhino is the most expensive, perhaps due to start-up costs, then $\alpha > 1$, however in reality this is unlikely to be the case so we consider $0 < \alpha \leq 1$ only.

Let K be the cost to the rhino manager from rhino killings. Then the expected payoff for a manager under each scenario is given in Table 2, where the payoff is in terms of reducing the loss to C. Therefore, the expected payoff to the manager is the sum of all four expected payoffs in Table 2,

$$E_m = r(sK - Cr^{1/\alpha}). \tag{1}$$

Notice that when $r^{1/\alpha} < sK/C$ the expected payoff is positive, which signifies the savings from unused resources C.

The expected payoff to the manager is linear in s, meaning that for any given proportion of devalued rhinos r, the relationship between the proportion of selective poachers s and the expected payoff to the manager is linear. Therefore for any given r, if there is a maximum expected payoff to the manager, it is at $s = 1$ (all rhino horns are devalued).

Conversely for a varying proportion of selecting poachers s, the expected payoff to the manager is at a maximum when

$$r = \left(\frac{\alpha s K}{C}\right)^{\alpha/(\alpha-1)}, \tag{2}$$

calculated by setting $\partial E_m/\partial r = 0$. Equation (2) often has a maximum larger than 1, meaning

	Horn devalued	Horn intact
Selective	$-Cr^{(\alpha+1)/\alpha}s$	$-K(1-r)s$
Random	$-(K+Cr^{1/\alpha})r(1-s)$	$-K(1-r)(1-s)$

Table 2: Expected payoff to the rhino manager under each scenario.

that the manager can only minimise his or her loss by devaluing all the rhino horns, $r = 1$. For the optimum proportion of rhinos to devalue to be less than one, the manager requires $C/(\alpha K) < s$. Therefore when all the poachers are random $s = 0$, there is not an optimum r less than one; and when all the poachers are selective $s = 1$, there is an optimum less than one provided the cost of a killed rhino is large enough such that $K > C/\alpha$. However, in reality a manager could not choose what proportion to devalue based on (2) as the proportion of selectors s at any given time is unknown.

2.2. *The rhino poacher*

The rhino poacher initially has no resources. Essentially the expected payoff to the poacher is the amount gained from an intact horn, or a devalued horn, less the time and risk to find and kill a rhino, and this is all relative to the salary and lifestyle of the individual poacher. Let H be the gain to the poacher from an intact and γH, $0 \leq \gamma \leq 1$, be the gain from a devalued horn.

We consider the time to kill a rhino T, the time to find a rhino F and, for the selecting poachers, a discerning time D to establish whether the rhino has an intact or devalued horn. The time dependent variables, represent time together with the associated risk per unit of time, so a manager can increase T, D and F by additional policing. The time taken to find a rhino is linked to the density of the rhinos α, so we set $F = f + 1/\alpha$, where f is the time taken to find a rhino if the rhinos are very dense. As $\alpha \to 0$ the time taken to find a rhino F tends to infinity, representing the difficulty of tracking very sparse rhinos. The expected payoff to the poacher

	Hor devalued	Horn intact
Selective	$-(F+D)rs$	$(H-F-D-T)(1-r)s$
Random	$(\gamma H-F-T)r(1-s)$	$(H-F-T)(1-r)(1-s)$

Table 3: Expected payoff to the poacher under each scenario.

E_p is the sum of all four expected payoffs in Table 3,

$$E_p = (T-\gamma H)\,rs - (H-\gamma H)\,r - Ds + H - F - T. \tag{3}$$

An individual poacher can choose his or her behaviour instantaneously, flipping from random $s = 0$ to selective $s = 1$ according to the average state of the rhinos on the particular ranch.

Consider the situation where only one poacher visits the ranch and behaves randomly $s = 0$ then, from (3), the manager needs to devalue

$$r \geq \frac{H-F-T}{H-\gamma H}, \tag{4}$$

to ensure the poacher does not make a profit. Assuming $H > F + T$, the right-hand side of equation (4) is greater than one if $F + T < \gamma H$. That is, if the time and associated risk to find and kill a rhino is less than the gain from a devalued horn, the random poacher cannot make a loss irrespective of the portion of horns devalued, thus the manager has 'lost the game' (the bottom right quadrant of Fig. 1).

Alternatively, if the poacher behaves selectively $s = 1$ then, from (3), the manager needs to devalue

$$r \geq \frac{H-T-D-F}{H-T} \quad \text{where } H > T, \tag{5}$$

to ensure the poacher does not make a profit. Equation (5) is always less than one. That is, if the poacher is selective, there is always a proportion of rhinos a manager can devalue to ensure the poacher would not make a profit on his or her particular ranch, thus the manager has 'won the game' (the top left quadrant of Fig. 1).

The model does not change in time. That is, should the variables for either players change, the expected payoffs need to be recalculated.

3. Examples

3.1. The rhino manager

We consider some examples and examine the expected payoff for the rhino manager in Fig. 3. In all cases, if all poachers behave randomly $s = 0$, there is no gain to be made by devaluing rhino horns, and devaluing only means a further loss of resources are incurred. In fact, for all s, the optimum proportion to devalue is always less than 1. That is, after r defined by equation (2), the extra cost to devalue becomes a waste of resources, and would be better spent on other measures. Nonetheless, as the proportion of selectors increase $s \to 1$, the greater the proportion of rhinos that need to be devalued to minimise loss to resources.

In the case of fairly sparse rhinos, say $\alpha = 0.125$ (Fig. 3d), a larger proportion of selectors are required before it is deemed worthwhile to devalue. However, once devaluing has been deemed a cost saving expense, a significant portion of rhinos need to be devalued. Generally, as $\alpha \to 0$, the optimum proportion to devalue increases.

In the case where the cost of devaluing all rhino horns (the total resource) is equal to the cost of one killed rhino $C = K$ (Fig. 3a), the manager can ensure that no loss is incurred for all proportions of selecting poachers by devaluing at most s^α rhinos (from equation (2)).

The manager can conserve the most resources when $C < K$ (Fig. 3b), despite the optimum proportion to devalue being close to 1. As $C << K$, this optimum proportion increases.

When $C > K$ (Fig. 3c), the manager suffers the biggest loss of resources and devaluing would be an inadvisable strategy. Even when all poachers are selective, it is not beneficial to devalue a significant portion, and this portion decreases as $C >> K$.

3.2. The rhino poacher

We consider some examples and examine the expected payoff for the rhino poacher in Fig. 4. In all cases, if all poachers behave selectively $s = 1$, the manager can choose an optimum number of rhinos to devalue (see equation (5)), albeit this proportion is generally high.

If all poachers behave selectively $s = 1$, the proportion of rhinos to devalue depends upon the relationship between the finding and killing time (and associated risk), $F + T$, and the gain from a devalued horn γH (see equation (4)). When $F + T = \gamma H$, the only deterrent is devaluing all rhinos (Fig. 4a). Should the gain from a devalued horn drop, the necessary proportion of rhinos to devalue drops (Fig. 4b). Conversely, should the gain of a devalued horn increase so that $F + T < \gamma H$, there is not an optimum proportion to devalue since a damaged horn would still prove profitable for the poacher (Fig. 4c). Although the manager has little control over the gain from a devalued horn for a given poacher, he or she can increase the risk involved with finding and killing the rhino, $F + T$, via security measures. This can decease the proportion needed to devalue (Fig. 4d).

4. Discussion

We have developed a model based on game theory where the two players are poachers and a rhino manager. There are two equilibrium states, either the manager devalues all the rhino horns and the poachers behave selectively, that is they do not kill these devalued rhinos so the manager wins, or the manager does not devalue any horns and the poachers behave randomly, that is the poacher wins.

There are clear tipping points which influence which equilibrium the model tends towards, based on the assumption that poachers can select their behaviour instantaneously. However, for these tipping points to work in the favour of the manager, the time and involved risk to find and kill a rhino need to be considerably more than the gain from a devalued horn. Furthermore, if the cost of a killed rhino is less than the cost to devaluing all the rhino horns, devaluing rhinos proves to be a waste of resources.

The examples demonstrate that generally a large portion of rhinos need to be devalued to cause poachers to switch to selective behaviour to avoid loss. However, devaluing a large portion of rhinos is not optimal for the rhino manager. Devaluing all rhinos means that rhino manager has exhausted all of his/her resources. Nonetheless, when devaluing the horn by dehorning, investing in dehorning rhinos one year means that the benefit will last for the following years whilst the horn is still below full length. In subsequent years, the value of the partial horn increases, but no further expenditure is required by the manager.

The values presented in the examples are perhaps unrealistic. In reality, the value of a rhino horn is so great - greater per unit weight than gold, diamonds or cocaine (Biggs et al. 2013) - that the risk and time penalties for the poacher have little influence on the final payoff. Even if rhino horn were to decrease in value enough to make our model realistic, we have shown that devaluing rhinos is a difficult game for the rhino manager to win. This is in line with current findings (Lindsay & Taylor 2011). We showed that even in a best case scenario, say Fig. 4d, where the value of a devalued horn is less than the time and associated risk to find and kill a rhino, a rational poacher would still behave randomly to maximise his or her payoff, making devaluing a waste of a manager's resources.

Thus, the conservation of rhinos requires a different approach, which is likely to involve radical innovation. One controversial option that has been used and is still proposed is a 'shoot to kill' policy (Duffy et al. 2015, Messer 2010), however while being potentially effective it raises ethical concerns. Furthermore, it is ultimately still playing the theoretical game proposed here, where the risk associated with time is increased. This raises a dependency that the model has not explicitly incorporated: as the risk increases, or the quantity of horn decreases, the value of the horn would increase, making the game virtually impossible for a manager to win.

To conclude, the game proposed here is challenging for the rhino manager to win unless rhino horn lost nearly all its value. Therefore, anti-poaching measures should not seek to tilt the game in the manager's favour, but instead change the game, for example, legalising trade, or campaigns aimed at changing behaviour, although the latter may take some time to impact on rhino populations ('t Sas-Rolfe 2016).

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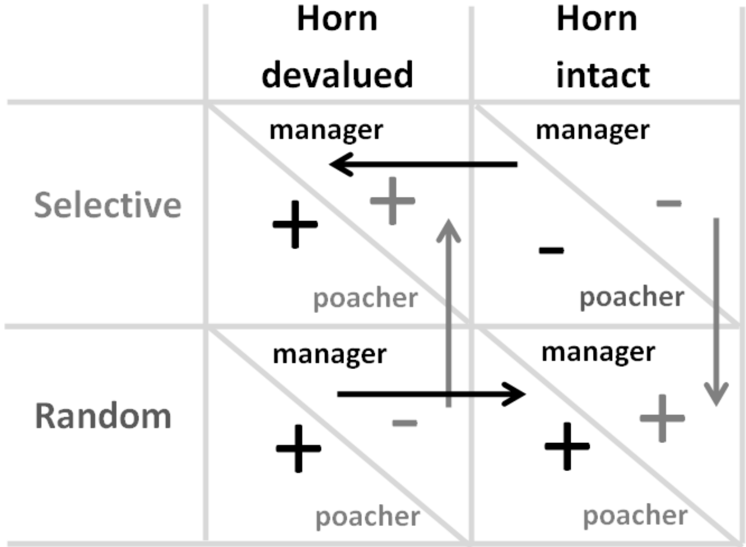


Figure 1: The dynamic between rhino managers and poachers. The arrows indicate the direction that either the manager (black) or poacher (grey) would move to minimise loss. For example, if poachers are selective, the manager would choose to devalue rhino horns.

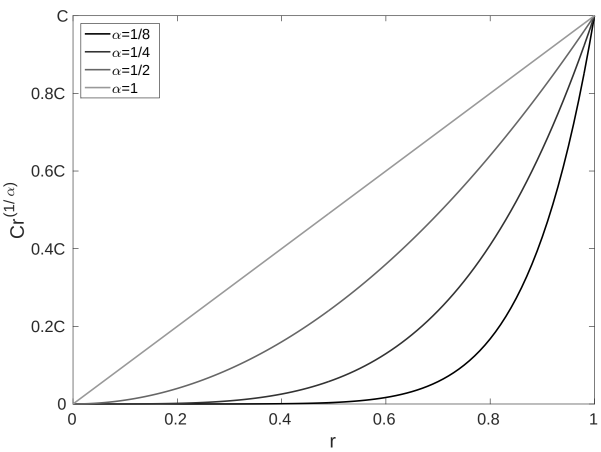
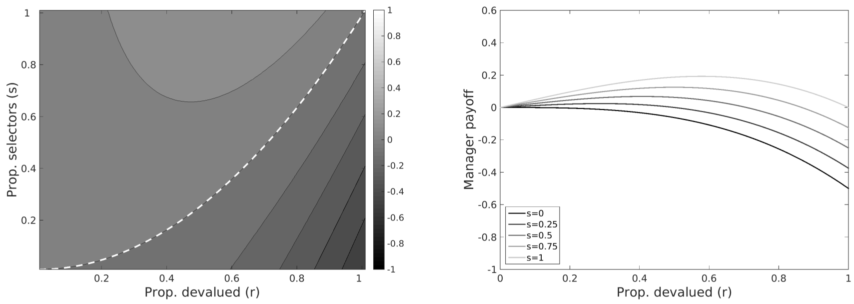
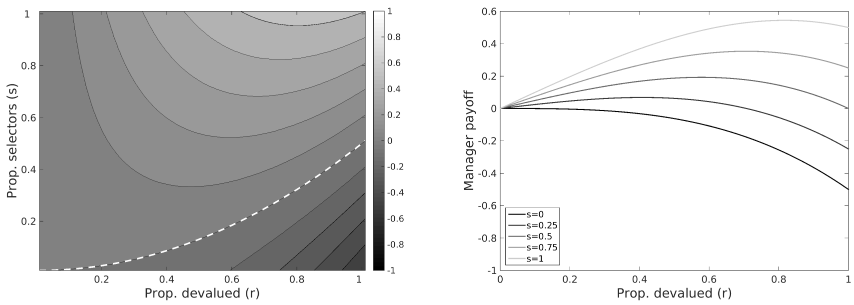


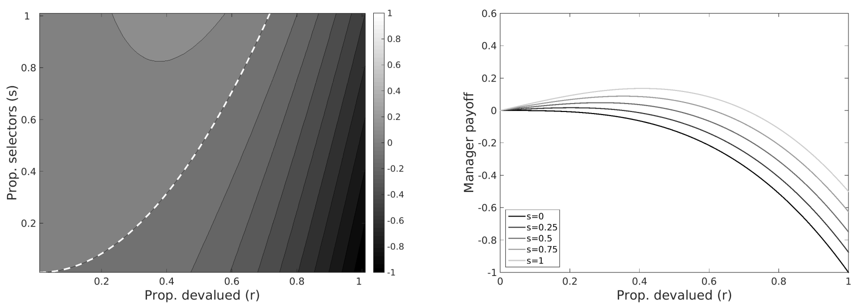
Figure 2: The cost to devalue the proportion r of the rhinos for varying α. The cost to devalue all rhinos ($r = 1$) is C.



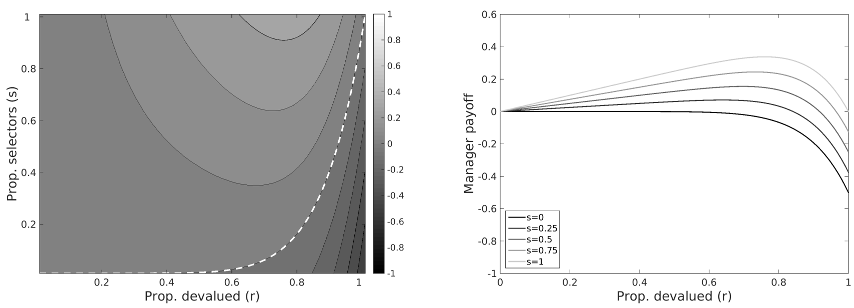
(a) $K = 0.5$, $C = 0.5$ and $\alpha = 0.5$.



(b) $K = 1$, $C = 0.5$ and $\alpha = 0.5$.

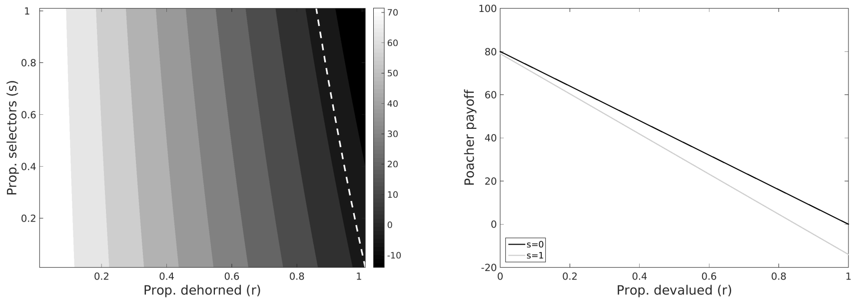


(c) $K = 0.5$, $C = 1$ and $\alpha = 0.5$.

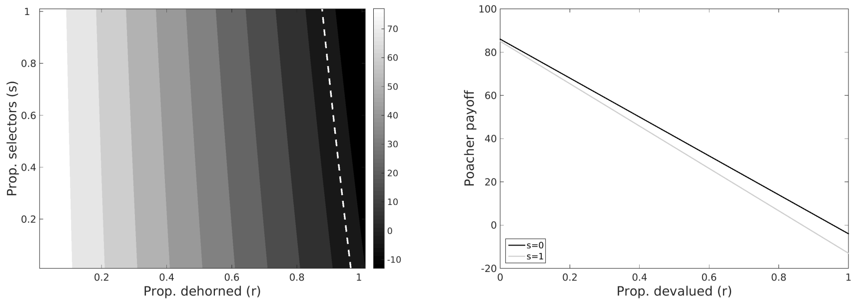


(d) $K = 0.5$, $C = 0.5$ and $\alpha = 0.125$.

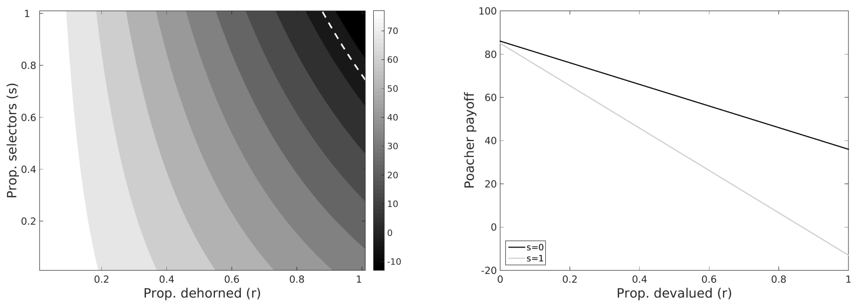
Figure 3: The expected gain to a rhino manager for various parameter values. On the contour plot, to the right of the white dashed line indicates the manager's savings from not devaluing all the rhinos, to the left indicates loss to the manager, hence negative values. Specific scenarios for varying s are highlighted by the plot presented alongside the contour plot.



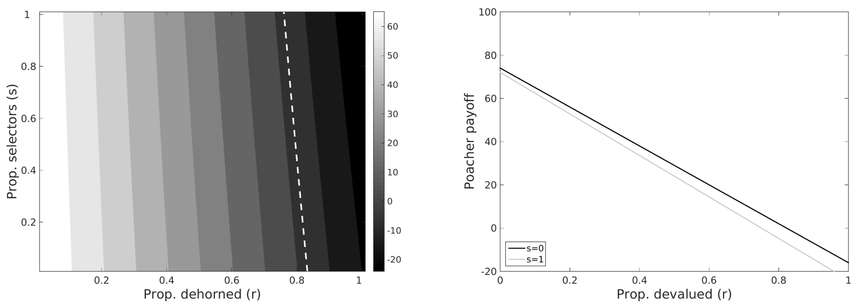
(a) $H = 100$, $\gamma = 0.2$, $T = 7$, $f = 11$, $D = 1$, and $\alpha = 0.5$ ($F + T = \gamma H$).



(b) $H = 100$, $\gamma = 0.1$, $T = 2$, $f = 10$, $D = 1$, and $\alpha = 0.5$ ($F + T > \gamma H$).



(c) $H = 100$, $\gamma = 0.5$, $T = 2$, $f = 10$, $D = 1$, and $\alpha = 0.5$ ($F + T < \gamma H$).



(d) $H = 100$, $\gamma = 0.1$, $T = 4$, $f = 20$, $D = 2$, and $\alpha = 0.5$ ($F + T > \gamma H$).

Figure 4: The expected gain to a rhino poacher for various parameter values. The right of the white dashed line indicates the poacher making a loss. Specific scenarios for varying s are highlighted by the plot presented alongside the contour plot.

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