CS711A: Introduction to Game Theory and Mechanism Design — Fall 2020

Creating game-theoretic models to analyse biodiversity conservation problems

Group number: 6

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Abstract

Biodiversity conservation is central to the idea of sustainable development. In this paper we use game theory to model three situations and to analyse informed group decisions in biodiversity conservation scenarios by modeling conflicts between stakeholders. We develop theoretical models of the problem on the basis of the situation and use NFG and Recursive games to find the most reasonable outcomes and the impact of the characteristic parameters of the game on the outcome. We also propose ways to control the parameters so that the most favourable outcomes adhere to the idea of biodiversity conservation.

1 Introduction

Environmental problems like biodiversity loss, climate change, pollution, resource overuse are becoming increasingly important issues. Regions and peoples worldwide are afflicted with drought, floods, storms, food shortages, air and water contamination and more. Most issues are due to misuse and overuse of resources. Each problem is unique in terms of stakeholders and participants. Policymakers should be able to consider each problem analytically and find effective and implementable solutions. In this paper, we use a game-theoretic [7] approach to analyse and model three such scenarios where motives of stakeholders with conflicting interests and their interactions are analysed so that solutions can be recommended. These are (1) Ecotourism, (2) Trophy Hunting, (3) Dog-Human-Wildlife Conflict.

1.1 Related Work

Many researchers have analysed biodiversity issues, but most of their studies have been qualitative and restricted to analysing problems, their causes and some solutions, and lack a theoretical model on which their solution is based. A few of them have tried game-theoretic point of view, but the application of game theory is limited to understanding the rationale behind the behaviour of agents. In [3], Frank and Sarkar discuss and model three biodiversity related problems as single-stage games and identify Pareto-inefficient Nash equilibria in all of them which led to continued destruction to the ecosystem. They show that such equilibria imply that constructive action (such as cooperation and building of trust between agents) can be taken to achieve more optimal outcomes. We build upon this approach, analysing three different biodiversity conservation problems and analysing them. For the three biodiversity sub-problems we have chosen, we have built upon the ideas of

1. A Game Theoretic Look at Ecotourism [10]: Based on this article, we further analyse The author qualitatively describes how the self-interests of local guides and travel operators cause exploitation of workers and destruction of the environment, and how information flow to tourists about the state of the environment of the region and the ethical practices of tour operators could reduce this destruction. We analyse this solution formally in our project.
2. Banning Trophy Hunting Will Exacerbate Biodiversity Loss [1] and Does Trophy Hunting Support Biodiversity? a Response to Di Minin et al [12] : These two contrasting articles discuss the pros and cons of trophy hunting as a conservation measure. We attempt to apply the effects of trophy hunting discussed here to two different situations and check if it is a feasible solution in each.
3. At IIT Madras, There Is a People-Dog-Wildlife Conflict [2]: In this article, the author discusses the problem of stray dogs in the IIT Madras campus (which was built on the land of Guindy Deer Sanctuary) attacking the local wildlife. Laws against relocating wildlife and strays has created a tricky situation, and animal birth control does not seem to be working. We attempt to analyse this situation to find out what policy changes would be beneficial in this situation.

1.2 Brief Overview of Report

In Section 2, we have modelled each of our three problems separately. We begin with a brief introduction of the problem, followed by defining the agents and their action sets. We also describe the motives of each player which we then use to set a preference order for each strategy set. A detailed reasoning behind the preference order is included in the Appendix. In Section 3, we describe the interpretations for the equilibria observed in the models, and discuss the conclusions.

2 Formal Model of the Problems

2.1 Ecotourism in Andaman and Nicobar Islands

Agents, their motives and roles in ecotourism-

Agents and available actions:

- Locals - They live there, have to make a living, some of them unknowingly damage the ecosystem there via garbage dumping, sanitation, etc. [14]; some might be doing it for money via illegal fishing, poaching for money [6]. Poaching is a serious problem for Indian oceanic resources as marine wildlife in South East Asia is depleting fast [13]
- Tourists-They come to the place to have a nice experience visiting a place with rare beauty. Definitely, the more the tourists, more is the pressure on the ecosystem.
- Tourism Operators- They need revenue. They want to have as many tourists as possible.

Since most of the travel operators are enlisted with the government, it is no harm to assume that they are in a long term business, so they must want the place not to lose its attraction, and the possible way is via the support of locals.

Modelling as recursive games with condition

We now model the ecotourism problem as **recursive** games with condition characterising the game (see appendix A). The players are tourism operators(O) and local people(L). The strategies of both players are exploiting, be it exploiting locals for more money in case of operators or exploiting the environment for money by locals, represented by E and not exploiting represented by $-E$. The condition of the game c will refer to the condition of environment with $C = \{0, 1, \dots, N\}$ where higher values of c denote better environment while a value of 0 denotes worst condition.

We can reason on the basis of data that it's only the locals who impact the environment most, so we can ignore other agents' impact. If locals exploit the environment condition goes down to $c - d$, if not, goes up to $c + h$, for simplicity, we assumed $h = 1$.

Let $0 \leq \delta \leq 1$ be the insight of the players, insight is a parameter that takes into account how much a player realizes the utility in subsequent games, and thus will be affected by it. A player with perfect insight of 1 will realize full utility of subsequent game and one with 0 insight will not be affected at all by what happens in subsequent games.

Let the total profit earned through tourism be T. If operators treat the locals fairly, they will provide their fare share of $(1 - \eta)T$ and will keep a share of ηT, where $0 < \eta < 1$ .If the operators will exploit the locals, then locals will receive negligible share while operators would take almost all the profit. The profit earned by locals if they exploit the environment will be an increasing function of condition of environment, c. For simplicity, we assume this function to be linear in c, αc, where $\alpha > 0$. From the above conditions we can devise the recursive game with condition in the form of following table:

$O \backslash L$	$-E$	E
$-E$	$\eta T + \delta u_1(min(c+h, N))$, $(1-\eta)T + \delta u_2(min(c+h, N))$	$\eta T + \delta u_1(max(c-d, 0))$, $(1-\eta)T + \alpha c + \delta u_2(max(c-d, 0))$
E	$T + \delta u_1(min(c+h, N))$, $\delta u_2(min(c+h, N))$	$T + \delta u_1(max(c-d, 0))$, $\alpha c + \delta u_2(max(c-d, 0))$

(The max and min functions have been used to keep the condition within the limits of 0 and N)

The recursive nature of the game is reflected in the utilities of players.

2.2 Trophy Hunting in Namibia and Kenya

2.2.1 Agents, their motives and actions

- Hunters: Trophy hunters hunt exotic animals mainly for their own pleasure, which can encompass several things [15]. Their action set includes:
  1. H: hunt trophy animals (legally or illegally)
  2. -H: not hunt trophy animals
- Conservationists: Conservationists wish to conserve the biodiversity of the region under consideration. Their action set includes:
  1. B: ban trophy hunting
  2. -B: continue trophy hunting with regulations

  Also, conservationists expect the following:
  1. If hunting is banned, most hunters will not hunt.
  2. If hunting is not banned, most hunters will hunt.

2.2.2 Factors determining the type of Conservationists

- Factors that increase the incentive for the action B
  - V: animals have an intrinsic value [16]
  - D: losing big, healthy individuals of a community affects the gene pool, social structures, and other animals of the community, and the effect is exaggerated in endangered animals
- Factors that increase the incentive for the action -B
  - P: a part of profits collected from trophy hunting fees are put back into conservation
  - L: the economic value of the land used for trophy hunting increases incentive for authorities to conserve natural habitats
  - S: the economic value of the animals of the species being hunted increases incentive for locals and authorities to conserve their numbers

2.2.3 Trophy hunting of blesbok in Namibia

Fact	Effect on Weights
Namibia's economy is based largely on trophy hunting [8]	Increase P, L
Blesbok are not uncommon in Namibia	Decrease D

Interpretation: Conservationists tend towards -B, i.e, -B has a higher utility for them when the hunters act according to expectations.

C \ *H*	H	-H
B	4,3	2,2
-B	1,1	3,4

2.2.4 Trophy hunting of lions in Kenya

Fact	Effect on Weights
Kenya collects a large revenue from its eco-tourism industry	Decrease P, L, S
Lions in Kenya are threatened with extinction [11]	Increase D

Interpretation: Conservationists tend towards B, i.e, B has a higher utility for them when the hunters act according to expectations.

C \ *H*	H	-H
B	2,3	1,2
-B	4,1	3,4

2.3 People-Dog-Wildlife conflict at IIT Madras

According to this article [2], stray dogs at IIT Madras hunt the wild animals, this results in loss of endangered species.To reduce the population of stray dogs the institute can to move the dogs to dog shelters. Dog lovers feed the stray dogs and resisting against removal of stray dogs from the institute. Other way of maintaining control over population of stray dogs is to make the dog lovers themselves responsible for their vaccination and neutering thereby bringing a check on dog population but since it is tedious to take the responsibility they don't want to take it. It was also suggested by the institute to relocate the wild animals to protect them from being a prey to feral dogs but the conservationists argued that institute doesn't monitor the species after relocation when it requires tremendous amount of support to help them survive.

Potential Actions:

1. A_1 = Dog lovers and feeders.
2. A_2 = Institute wanting to control dogs.
3. A_3 = Concerned about impact on wildlife.

Agents in game:

1. s_1 = Just randomly feed stray dogs.

   $-s_1$ = Providing shelter to unknown dogs and have them neutered and vaccinated.

2. s_2 = Moving unowned dogs to shelters.

   $-s_2$ = Not move unowned dogs to shelters.

3. s_3 = Relocate wild endangered animals.

   $-s_3$ = Not relocate wild endangered animals.

			A_1	A_2	A_3
s_1	s_2	s_3	5	3	5
s_1	s_2	$-s_3$	6	4	2
s_1	$-s_2$	s_3	1	7	8
s_1	$-s_2$	$-s_3$	2	8	7
$-s_1$	s_2	s_3	7	1	4
$-s_1$	s_2	$-s_3$	8	2	1
$-s_1$	$-s_2$	s_3	3	5	6
$-s_1$	$-s_2$	$-s_3$	4	6	3

Table 1: Ordinal preference order for each agent for each strategy set.

3 Main Results

3.1 Ecotourism in Andamans

Results for the recursive game with conditions

As can be seen in the Appendix B, analysis for recursive game is difficult and only a subset of strategies have been analysed for Nash Equilibrium(NE). It can be seen, in this game also exploiting the locals remains dominant strategy for tourist operators and hence, regardless of condition of environment or the type of function T is . For locals, the choice to exploit the environment remained more favourable when the condition of environment was high and the insight of people was quite low. When the condition steeped quite low (lower than d), then for certain range of δ, the strategy of locals was not exploiting for condition $c \leq k$ and exploiting for other conditions. But even for very small values of k, insight needs to be very close to 1, for ex. $k = 1$ requires $0 < \delta \leq 0.618$, $k = 2$ requires $0.618 \leq \delta \leq 0.81$ and $k = 3$ requires $0.81 \leq \delta \leq 0.888$ and since healing effect of environment is quite less than destruction of environment, implying $d >> h = 1$, hence these values of k are quite small in front of d.

3.2 Trophy Hunting in Namibia and Kenya

1. Trophy hunting of blesbok in Namibia: The Nash equilibria are (-B, H) and (B, H). (-B, H) is a Pareto-efficient solution. (-B, H) is both, a Nash equilibrium and Pareto efficient. Trophy hunting of blesbok is already prevalent in Namibia, and this analysis indicates that this is an optimal outcome for blesbok conservation under the current conditions, and is not likely to change soon unless there is a major change in Namibia's economic model or blesbok populations.

2. Trophy hunting of lions in Kenya: The Nash equilibria are (B, -H). (B, -H) and (-B, H) are Pareto-efficient solutions. (B, -H) is both, a Nash equilibrium and Pareto efficient. Kenya has banned trophy hunting for many decades, and has a stable ecotourism model to make

up for it. This is likely to continue unless other sources of revenue for conservation take a hit or lion populations increase significantly (which is unlikely).

3.3 People-Dog-Wildlife Conflict

Nash Equilibrium is (s_1,s_2,-s_3), which is also Pareto Efficient.
Assuming players will follow the Nash equilibrium, dog lovers will continue to feed dogs instead of being responsible and as a result, institute will be required to transfer the stray dogs to animal shelters and those who are concerned about impact on wildlife will find it favourable to let the wildlife reside in the campus and prevent them from the adverse affect of relocation.

4 Summary and Conclusion

4.1 Ecotourism

From analysis of ecotourism in Andaman & Nicobar, it is seen that, government and stakeholders would have to interfere to penalize operators in case they exploit locals, so that operators see a negative utility in exploiting, fund locals for saving environment, educate them about biodiversity conservation, consequently increasing insight so that the idea of ecotourism is justified.

4.2 Trophy Hunting

We used ordinal preferences to analyse how conservationists and hunters would interact with policies in two different cases. Our analysis showed that different policies regarding trophy hunting can be useful in different cases. We found two equilibria which reflect the current policies in Namibia and Kenya, indicating that these policies would not change in a major way unless other factors change.

4.3 People-Dog-Wildlife Conflict in IIT Madras

In game-theoretic analysis of People-Dog wildlife conflict we used ordinal preference order whose pareto efficient nash equilibrium shows that dog lovers will continue to feed dogs and the institute will have to move the dogs to shelter so that they can protect wildlife from dogs and relocation.

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Appendices

A. Recursive Games with Conditions

Consider two players A and B playing a normal form game characterised by a variable c, called condition of game, repeatedly infinitely many times[4]. Let the insight of players for future games is characterised by variable δ, s.t. $0 \leq \delta < 1$. For, $\delta = 0$, players do not have any insight of future games and will play the game as normal NFG without being affected by utilities obtained in future games. Let such a NFG with $\delta = 0$ and characterised by c be given by the following game table:

A \ B	$-E$	E
$-E$	$a_{00}(c), b_{00}(c)$	$a_{01}(c), b_{01}(c)$
E	$a_{10}(c), b_{10}(c)$	$a_{11}(c), b_{11}(c)$

,where $E, -E$ are the actions available to the players. The strategy pair can also be represented by (i, j) s.t. $i, j \in \{0, 1\}$ where 0 is equivalent to strategy $-E$ and 1 is equivalent to E and i represents the strategy of player 1 and j represents the strategy for player 2.

When the players have played first game with condition c, for the next game the condition of the game changes and depends on the actions (i, j) chosen by players in the previous game and the condition c of the previous game. Let the condition of next game for strategy pair (i, j) be given by c_{ij}.

Let for a repeating game with the players having insight δ and starting game having condition c, the optimal strategy pair be given by $(s_1(c), s_2(c))$ and corresponding optimal utility for players be given by $u_1(c), u_2(c)$. Then, the game table for insight of players as (δ) and condition of game as c is given by the following table:

A \ B	$-E$	E
$-E$	$a_{00}(c) + \delta u_1(c_{00}), b_{00}(c) + \delta u_2(c_{00})$	$a_{01}(c) + \delta u_1(c_{01}), b_{01}(c) + \delta u_2(c_{01})$
E	$a_{10}(c) + \delta u_1(c_{10}), b_{10}(c) + \delta u_2(c_{10})$	$a_{11}(c) + \delta u_1(c_{11}), b_{11}(c) + \delta u_2(c_{11})$

The utilities in above table is explained as for example if strategy profile $(-E, -E)$ was the optimal profile then after playing $(-E, -E)$, the condition of game will change to c_{00}. Since the game is being played infinitely many times, the series of games from the second game are also infinite and hence, the optimal strategy and optimal utility for second game will be given by $(s_1(c_{00}), s_2(c_{00}))$ and $u_1(c_{00}), u_2(c_{00})$ respectively. Since, the insight of players is δ, the effect of future games in terms of utility will be given by $\delta u_1(c_{00})$ and $\delta u_2(c_{00})$ for the two players respectively. Hence, the overall utility for the two players is given as in the table.

Let the set of condition of game be C which is a finite set. If we assume that there is strict preference in strategy profile then due to infinitude of game, for intermediate rounds with same condition, players will choose same strategy. Hence, the strategy space of players can be given by the set, $S = \{s \mid s : C \to \{0, 1\}^2\}$.

Nash equilibrium

The condition for strategy $s \in S$ to be optimal strategy or Nash equilibrium is

$$a_{s(c)} + \delta u_1(c_{s(c)}) \geq a_{(1-s_1(c)),s_2(c)} + \delta u_1(c_{(1-s_1(c)),s_2(c)}) \text{ and,}$$

$$b_{s(c)} + \delta u_2(c_{s(c)}) \geq b_{s_1(c),(1-s_2(c))} + \delta u_2(c_{s_1(c),(1-s_2(c))}), \forall c \in C$$

Condition for equilibrium

Consider a sequence of all elements of C given by $< x >_k = x_1, x_2, \ldots, x_k$, where $k = |C|$. Suppose strategy s is N.E., then for game with insight δ, by definition of u_i, for player 1,

$$u_1(x_i) = a_{s(x_i)}(x_i) + \delta u_1(x_{i_{s(x_i)}}) \text{ and } u_2(x_i) = b_{s(x_i)}(x_i) + \delta u_2(x_{i_{s(x_i)}}), \forall i \in [1,k]$$

Let $f_s : C \to C, \bar{f}_s^1 : C \to C$ and $\bar{f}_s^2 : C \to C$ be functions defined as,

$$f_s(c) = c_{s(c)}$$

$$\bar{f}_s^1(c) = c_{(1-s_1(c)),s_2(c)}$$
$$\bar{f}_s^2(c) = c_{s_1(c),(1-s_2(c))}$$

Square matrix F_s of order k corresponding to f_s is given as,

$$(F_s)_{ij} = 1 \text{ , if } x_j = f_s(x_i)$$
$$= 0, \text{ otherwise}$$

Similarly, $\bar{F}_s^1$ and $\bar{F}_s^2$ are the corresponding matrix for functions $\bar{f}_s^1$ and $\bar{f}_s^2$ respectively.
Let us define the following arrays of size k:

$$\begin{aligned} U_i &= \{u_i(x_j)\}_{j\in[1,k]}, i \in \{1,2\} \\ A_s &= \{a_{s(x_j)}\}_{j\in[1,k]} \\ \bar{A}_s &= \{a_{(1-s_1(x_j)),s_2(x_j)}\}_{j\in[1,k]} \\ B_s &= \{b_{s(x_j)}\}_{j\in[1,k]} \\ \bar{B}_s &= \{b_{s_1(x_j),(1-s_2(x_j))}\}_{j\in[1,k]} \end{aligned}$$

It can be easily seen that $(F_sU_i)_j = u_i(f(x_j)) = u_j(x_{j_{s(x_j}})$, for $j \in [1,k]$ and $i \in \{1,2\}$, hence by definition of u,

$$U_1 = A_s + \delta F_s U_1 \text{ and } U_2 = B_s + \delta F_s U_2$$

For player 1,

$$U_1 - \delta F_s U_1 = A_s \implies (I - \delta F_s)U_1 = A_s$$
$$\implies U_1 = (I - \delta F_s)^{-1} A_s \text{ (it is proved below } (I - \delta F_s) \text{ is invertible)}$$

Similarly, for player 2, $U_2 = (I - \delta F_s)^{-1} B_s$

Outline of proof of invertibility of $(I - \delta F_s)$

Since F_s contain only single 1 in a row, F_sY only contains elements of Y without being scaled. Hence, if e_i is an eigen-vector of F_s, and $F_s e_i = \alpha_i e_i$, for some α_i then $|\alpha_i| \leq 1$. If e_i is eigen-vector[5] of F_s, then $(I - \delta F_s)e_i = e_i - \delta(\alpha_i e_i) = (1 - \delta\alpha_i)e_i$. Hence, e_i is also eigen-vector of $(I - \delta F_s)$ with eigen-value, $(1 - \delta\alpha_i) > 0$ as $0 \leq \delta < 1$. Since all eigen-values are greater than zero, $\implies$ $(I - \delta F_s)$ is invertible.

By definition of Nash equilibrium (in matrix form), for player 1,

$$\begin{aligned} A_s + \delta F_s U_1 &\geq \bar{A}_s + \delta \bar{F_s^1} U_1 \\ \implies A_s + \delta F_s (I - \delta F_s)^{-1} A_s &\geq \bar{A}_s + \delta \bar{F_s^1} (I - \delta F_s)^{-1} A_s \\ \implies (I - \delta F_s)(I - \delta F_s)^{-1} A_s + \delta F_s (I - \delta F_s)^{-1} A_s &\geq \bar{A}_s + \delta \bar{F_s^1} (I - \delta F_s)^{-1} A_s \\ \implies (I - \delta F_s)^{-1} A_s &\geq \bar{A}_s + \delta \bar{F_s^1} (I - \delta F_s)^{-1} A_s \\ \implies (I - \delta \bar{F_s^1})(I - \delta F_s)^{-1} A_s &\geq \bar{A}_s \end{aligned}$$

Similarly, we can obtain $(I - \delta \bar{F_s^2})(I - \delta F_s)^{-1} B_s \geq \bar{B}_s$

Hence, the necessary conditions for NE to exist are

1. $(I - \delta \bar{F_s^1})(I - \delta F_s)^{-1} A_s \geq \bar{A}_s$
2. $(I - \delta \bar{F_s^2})(I - \delta F_s)^{-1} B_s \geq \bar{B}_s$

Also, it is true in backward direction also as if for some $s \in S$, above two conditions are true then utility functions u_1 and u_2 given through matrix $U_1 = (I - \delta F_s)^{-1} A_s$ and $U_2 = (I - \delta F_s)^{-1} B_s$ respectively, it can be easily shown that they satisfy the condition of Nash equilibrium as well as the recursive definition of u_i.

Hence, above conditions are necessary and sufficient conditions for Nash Equilibrium of recursive games with conditions.

B. Special cases for equilibrium

(Note: Same terminology will be used as in Appendix A and report).

Consider the following recursive game with condition as discussed in report for ecotourism:

$O \backslash L$	$-E$	E
$-E$	$\eta T + \delta u_1(min(c+h, N))$, $(1-\eta)T + \delta u_2(min(c+h, N))$	$\eta T + \delta u_1(max(c-d, 0))$, $(1-\eta)T + \alpha c + \delta u_2(max(c-d, 0))$
E	$T + \delta u_1(min(c+h, N))$, $\delta u_2(min(c+h, N))$	$T + \delta u_1(max(c-d, 0))$, $\alpha c + \delta u_2(max(c-d, 0))$

Since, $c_{00} = c_{10} = min(c+h, N)$ and $c_{01} = c_{11} = max(c-d, 0)$, $f_s = \bar{(}f_s^1), \forall s \in S \implies F_s = \bar{F_s^1} \implies (I - \delta F_s) = (I - \delta \bar{F_s^1})$. Hence, for first condition for NE,

$$\begin{gathered} (I - \delta F_s)(I - \delta \bar{F_s^1})^{-1} A_s \geq \bar{A}_s \\ \implies A_s \geq \bar{A}_s \\ \implies a_{s_1(c), s_2(c)} \geq a_{(1-s_1(c)), s_2(c)}, \forall c \in C \\ \implies s_1(c) = 1, \forall c \in C \end{gathered}$$

Hence, for NE, player 1 or operator must always choose exploiting as its strategy.

For player O, we will only check condition on δ for some specific strategies to be NE as it turns out to be quite a difficult task to calculate in general inverse of matrix as given in question. As it has been already shown for $\delta = 0, (E, E)$ is NE, we will only find condition for $0 < \delta < 1$. The strategies for player 2 to be checked are:

$$s_2(c) = \begin{cases} -E, & \text{if } c \leq k \\ E, & \text{otherwise} \end{cases}, \text{ where } k \in C$$

We will represent F_s as O and $\bar{F_s^2}$ as $\bar{O}$ as shorthand for notation. Since, eigen-values of δO are less than 1 (proved in Appendix 1), we can use the following identity[5]:

$$(I - A)^{-1} = I + A + A^2 + A^3 + \dots$$

Hence, the condition for NE is:

$$(I - \delta\bar{O})(I - \delta O)^{-1} A_s \geq \bar{A}_s$$

$$\text{or, } (I - \delta\bar{O})(1 + \delta O + \delta^2 O^2 + \delta^3 O^3 + \dots) A_s \geq \bar{A}_s$$

$$\text{or, } (I + \delta(O - \bar{O}) + \delta^2(O^2 - \bar{O}O) + \dots) A_s \geq \bar{A}_s$$

$$A_s = \begin{bmatrix} \alpha 0 \\ \alpha 0 \\ \vdots \\ (k\text{-times}) \\ \vdots \\ 0 \\ k+1 \\ k+2 \\ \vdots \\ \alpha N \end{bmatrix} = \alpha \begin{bmatrix} 0 \\ 0 \\ \vdots \\ (k - \text{times}) \\ \vdots \\ 0 \\ k+1 \\ k+2 \\ \vdots \\ N \end{bmatrix}, \bar{A}_s = \begin{bmatrix} \alpha 0 \\ \alpha 1 \\ \vdots \\ \alpha k \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} = \alpha \begin{bmatrix} 0 \\ 1 \\ \vdots \\ k \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

Let us define some special matrices

$$\mathbf{0}_{m,n} = \begin{bmatrix} 0 & \dots & 0 \\ \vdots & \ddots & \\ 0 & \dots & 0 \end{bmatrix}_{m \times n}$$

$$P^s_{m,n} = [p_{i,j}]_{m,n} \text{ s.t. } p_{i,j} = \begin{cases} 1, & \text{if } (j - i) \equiv (s - 1) \mod n \\ 0, & \text{otherwise} \end{cases}$$

$$C^s_{m,n} = [c_{i,j}]_{m \times n} \text{ s.t. } c_{i,j} = \begin{cases} 1, & \text{if } j \equiv s \mod n \\ 0, & \text{otherwise} \end{cases}$$

case 1: $0 \leq k \leq d$

When the dimensions of the matrices are deducible, they are not written to avoid cluttering. Using the above matrices we can represent O and $\bar{O}$ as,

$$O = \begin{bmatrix} P^2_{(k+1),(k+1)} & \mathbf{0} \\ C^1_{(d-k-1),(k+1)} & \mathbf{0} \\ L_1 & \end{bmatrix}, \bar{O} = \begin{bmatrix} C^1 \\ L_{k+2} \end{bmatrix}$$

where L_i is a shorthand for filling the matrix with diagonal 1s starting at index i and continuing while it first reaches bottom or if it reach right most column the continue filling 1s in the downward direction.

It can be observed after repeated multiplication,

$$O^m = \begin{bmatrix} P^m_{(k+1),(k+1)} & \mathbf{0} \\ C^{m-1}_{(d-k-1),(k+1)} & \mathbf{0} \\ P^{m-1}_{(k+1),(k+1)} & \mathbf{0} \\ C^{m-2}_{(d-k-1),(k+1)} & \mathbf{0} \\ \vdots & \vdots \\ P^2_{(k+1),(k+1)} & \mathbf{0} \\ C^1_{(d-k-1),(k+1)} & \mathbf{0} \\ L_1 & \end{bmatrix}$$

Hence, by direct matrix multiplication we obtain the expression,

$$\bar{O}O^m = \begin{bmatrix} C^m_{k,(k+1)} & \mathbf{0} \\ C^{(}_{(d-k-1),(k+1)} m-1) & \mathbf{0} \\ P^{m-1}_{(k+1),(k+1)} & \mathbf{0} \\ C^{m-2}_{(d-k-1),(k+1)} & \mathbf{0} \\ \vdots & \vdots \\ P^2_{(k+1),(k+1)} & \mathbf{0} \\ C^1_{(d-k-1),(k+1)} & \mathbf{0} \\ L'_1 & \end{bmatrix}$$

where L'_i is same as L_i except the last line in L'_i is same as the second last line. Now we can calculate LHS of the inequality

$$\text{or, } (I + \delta(O - \bar{O}) + \delta^2(O^2 - \bar{O}O) + \dots)A_s \geq \bar{A}_s$$

and compare with the RHS. First consider the special case of $k = 0$. For $k = 0$, by inequality from 1st row, $(-\delta)\alpha \geq 0.\alpha$, no value of $\delta > 0$ satisfy the inequality. For $k > 0$, consider the following inequalities in row i:

case: $1 \leq i \leq k$

$$(k\delta^k - k\delta^{(k+1)} + k\delta^{(k+(k+1))} - k\delta^{(k+1+(k+1))} + \dots)\alpha \geq (i-1)\alpha$$

$$\implies \delta^{(k+1-i)}\frac{1-\delta^i}{1-\delta^{k+1}} \geq \frac{i-1}{k}$$

$$\implies \frac{\delta^{-i}-1}{i-1} \geq \frac{\delta^{-(k+1)}-1}{k}, \forall 1 < i \leq k \text{ (It is trivially true for } i-1 \text{)}$$

It can be shown easily that the set of above inequations are equivalent to the inequation

$$\frac{\delta^{-k}-1}{k-1} \geq \frac{\delta^{-(k+1)}-1}{k}$$

$$\implies (k-1) - k\delta + \delta^{k+1} \leq 0$$

case: $k < i \leq d$

$$((i-1) - i\delta + k\delta^{k+1} - k\delta^{k+2} + k\delta^{k+1+(k+1)} - k\delta^{k+2+(k+1)} + \dots) \geq 0$$

$$\implies (i-1)(1-\delta) - \delta + k\delta^{k+1}\frac{1-\delta}{1-\delta^{k+1}} \geq 0$$

As can be seen from above inequality, as i increases LHS increases. Hence, if the above inequation is valid for minimum value of i, it will remain valid for other values of i. $\therefore$ Above set of inequation are equivalent to inequation with $i = k+1$ or,

$$k(1-\delta) - \delta + k\delta^{k+1}\frac{1-\delta}{1-\delta^{k+1}} \geq 0$$

$$\implies k - (k+1)\delta + \delta^{k+2} \geq 0$$

By calculating inequalities for other rows, it can be shown that if above inequalities are satisfied they are also satisfied.

If we take function $g_k(x) = k - (k+1)x + x^{k+2}$, then the conditions on insight of game for NE, for strategy with k, are $g_{k-1}(\delta) \leq 0$ and $g_k(\delta) \geq 0, \forall 1 \leq k \leq d$. $g_k(x)$ intersects x-axis between $[0, 1)$ only once, say at r_k and remains positive for $x < r_k$ and negative for $x > r_k$. Also, $r_k > r_{k-1}$, hence for different value of k, we have disjoint sets,$[r_{k-1}, r_k]$ for δ to satisfy condition for existence of NE.

case 2: $d < k$

Similarly as above, we can calculate O^m and $\bar{O}O^m$, and so the inequalities obtained for row i are:

case: $1 \leq i \leq d$

$$((k\delta^{k+1-i} - k\delta^{k+1})(1 + \delta^{d+1} + \delta^{2(d+1)} + \dots))\alpha \geq (i-1)\alpha$$

$$k\delta^{k+1}\frac{\delta^{-i}-1}{1-\delta^{d+1}} \geq i-1, \forall 1 \leq i \leq d$$

case: $d < i \leq k$

$$((k\delta^{k+1-i} - k\delta^{k+2+d-i})(1 + \delta^{d+1} + \delta^{2(d+1)} + \dots))\alpha \geq (i-1)\alpha$$

$$k\delta^{k+1-i}\frac{1-\delta^{d+1}}{1-\delta^{d+1}} \geq i-1$$

$$k\delta^{k+1-i} \geq i-1$$

These set of inequalities are subset of set of inequalities of previous case.

case: $k < i < k+d+1$

$$((i-1) - i\delta)\alpha \geq 0\alpha$$

$$\implies \delta \leq \frac{i-1}{i}, \forall k < i < k+d-1$$

Above set of inequalities are equivalent to single inequality with $i = k+1$,

$$\delta \leq \frac{k}{k+1}$$

Similarly for other rows inequalities can be found but analysing these inequalities is quite difficult though there exist some consistent solution but they require δ quite close to 1 and k sufficiently larger than d.

C. Explanation of Preferences

We have modelled the problems through ordinal games [9] and hence provided 'priorities' to each strategy profile for each user s.t. if $x > y$, then y has greater priority than x with 1 being the highest priority.

1. Ecotourism in Andaman and Nicobar Islands

Active Agents:

- Locals - They live there, have to make a living, some of them unknowingly damage the ecosystem there via garbage dumping, sanitation, etc. [14]; some might be doing it for money via illegal fishing, poaching for money [6]. Poaching is a serious problem for Indian oceanic resources as marine wildlife in South East Asia is depleting fast [13]
- Tourists-They come to the place to have a nice experience visiting a place with rare beauty. Definitely, the more the tourists, more is the pressure on the ecosystem.
- Tourism Operators- They need revenue. They want to have as many tourists as possible.

Passive agents(these agents do not have an active participation in the game, but they affect the utilities of the active players):

- Government- wants sustainable socio-economic development of the islands and acts as a policymaker. We assume a perfect response from the government.
- Conservationists- Want the resources to be conserved, and the ecosystem to be always healthy.

Some approximations that are fair to make the analysis easier.

1. Tourists don't indulge in any illegal activity. This assumption can be made safely to a large extent since their indulgence in any illegal activity can be easily observed by the government and may lead to severe punishment.
2. Actions available to the locals are to save the environment actively or to exploit it.
3. Actions available to tourism operators are to betray the locals or to pay them fairly.

Since most of the travel operators are enlisted with the government, it is no harm to assume that they are in a long term business, so they must want the place not to lose its attraction, and the possible way is via the support of locals.

The tourism operators have two options of treating locals fairly and paying them properly, let this strategy be represented by -E, or exploiting them represented by E . The locals can either exploit the environment by dynamite fishing, illegal activities, etc while doing tourism-related work represented by E or they can only do tourism-related work instead of harming the environment with such activities represented by -E.

O \ L	$-E$	E
$-E$	3,3	4,1
E	1,4	2,2

The preferences of players can be seen in the above table. Obviously, it is most beneficial for operators to exploit the locals, and locals also work truthfully to the job without involving in side-activities which may harm tourism business, hence (E, -E) is given 1 priority. As discussed in the article most tourists are less knowledgeable and even when locals are harming the natural spots they may not know that and hence, it may not affect the tourism business much. Hence, even if locals are exploiting this does not affect business much and so operator can also exploit the locals. Hence, based on this rest priorities of operators are given. Since, it is most beneficial for the locals to gain fair payment from operators as well as exploit the natural resources, (-E,E) is there 1st priority. Since, the resources are not over exploited till now in Andaman and Nicobar islands, exploitation of resources is not resulting in scarce resources instead they are gaining more profit from fishing than from tourist job. Hence, (E, E) has higher preference than (-E, -E). And it is obvious that being exploited by operators and not using natural resources will leave locals worse off. Hence, (E, -E) is worst choice.

Nash equilibrium : (E, E) Pareto Efficient: (-E, E), (E, -E) and (E, E) Since (E, E) is both a Nash equilibrium and Pareto efficient, it is highly likely that operators and locals will follow this strategy of operators not fairly paying the locals and locals exploiting nature to achieve the best utility and hence compromising environment which may result in serious damage to the environment.

2. Trophy Hunting in Namibia and Kenya

Hunters like to hunt, so their first preference would definitely be if hunting was allowed and they hunted. If hunting was banned, the risk of getting caught hunting and being punished (through fines or legal action) makes not hunting preferable to hunting in this case. Cases of illegal hunting everywhere indicate that hunters are willing to risk punishment for the pleasure of hunting if it was banned, and they would prefer this option to not hunting even if they were allowed to. This reasoning produces the following table of preference orders in both cases:

C \ H	H	-H
B	3	2
-B	1	4

Preference Order for Conservationists in the Namibia case

As shown in Table 2.2.3, conservationists put more weight on factors that push them to prefer the action -B. So, conservationists would prefer if their expectations (as enumerated in section 2.2) are followed, since policies are based around these expectations. So, we have the preference order as displayed in the table.

Preference Order for Conservationists in the Kenya case

As shown in Table 2.2.4, conservationists put more weight on factors that push them to prefer the action B. Also, since Kenya has a booming ecotourism industry, we assume that they have the resources to detect illegal hunting and take strict measures to prevent it in case of a ban. So, B is a dominant strategy for them. Further, because lions are endangered, they would strictly prefer if they are not hunted to if they are hunted. So, we have the preference order as displayed in the table.

3. People-Dog-Wildlife conflict at IIT Madras

We reproduce the preferences table here for convenience.

For A_1, $< s_3 >$ relocating wild animals will not be of much interest as it is mostly concerned with wild animals and has little effect on the welfare of dogs. But since with less wild animals, dogs will have more space to live and less competition with wild animals, $< s_3 >$ is given slightly

			A_1	A_2	A_3
s_1	s_2	s_3	5	3	5
s_1	s_2	$-s_3$	6	4	2
s_1	$-s_2$	s_3	1	7	8
s_1	$-s_2$	$-s_3$	2	8	7
$-s_1$	s_2	s_3	7	1	4
$-s_1$	s_2	$-s_3$	8	2	1
$-s_1$	$-s_2$	s_3	3	5	6
$-s_1$	$-s_2$	$-s_3$	4	6	3

Table 1: Ordinal preference order for each agent for each strategy set.

higher preference than $-s_3$. It is obvious that the dog lovers would prefer more to just feed the dogs as it is easier than responsibly having the dogs vaccinated and neutered to control their population and also they will not want the street dogs to be separated from them by relocating to dog shelters. Since it is more difficult for dog lovers to get permanently separated from dogs instead of taking up responsibility for them, $< -s_1, -s_2, s_3 >$ has a higher preference than $< s_1, s_2, s_3 >$.

For A_2, Institute gives more preference to it moving stray dogs to shelter, if the dogs are moved to sheltered then it doesn't want concerned authorities to move the wild animals, as it would be bad for animals as well as the reputation of institute,and it that case action of A_1 will have least priority, but still institute would always prefer $< -s_1 >$ because then it would have to spend less money on dogs. If dogs aren't moved then priority of action of A_1 will be more than that of A_3 as in that case security of wild animals is dependent on A_1, but priority of action would remain same.

For A_3, It is best for wild animals that the dog population remains checked to prevent hunting, $< -s_1, s_2, -s_3 >$ is given 1^{st} priority followed by $< s_1, s_2, -s_3 >$ followed by $< s_1, -s_2, -s_3 >$ as moving stray dogs to dog shelters is more effective than their neutering. Then if A_3 has to move the endangered species they would prefer that they have to take as less animals as possible, so next 3 preferences are based on how much control of dog is there, more the stray dogs are remained checked, lesser number of wild animals would be needed to be transported. last 2 preferences are based on the fact (mentioned in article) that relocating wild animal would be worse option as a lot of animals would be need to relocated with a lot of care, and still it may lead to their loss of life.