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Towards Sustainability in Resource Sharing: A Game Theory Approach

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Abstract. Over-exploitation of present renewable resources has an impact on future generations unlike in traditional community relationship. Present generations maximize their pay-off by exhausting the resources. However, this minimizes the total pay-off of all generations as a whole. The failure to cooperate with future generations is mainly championed by a few. What policies can aid sustainable inter-generational resource usage? How can this few be deterred from over-exploitation of the present resources? How can those willing to cooperate be encouraged by guaranteeing sustainability? And can all these be achieved without a central authority? Some researchers proposed voting to solve these problems. However, this has a clear limitation in that it must be binding on all for it to work thereby necessitating the need for central authority. In this study, a reputation based model is proposed instead of voting. The model evaluates the reputation of agents based on their willingness to cooperate with the future. The agent's reputation defines other agents it interacts with in the society. Hence, cooperators tend to relate with fellow cooperators and are better off while defectors are worse off. It is shown that reputation is a viable alternative in the attainment of a sustainable society. However, this is only applicable for sustained interactions between the agents.

Keywords: Prisoners' Dilemma, Evolutionary Games, Game Theory, Resource Sharing

INTRODUCTION

The algorithm can be categorized into many classifications, one of its deterministic or stochastic. Deterministic algorithm is an algorithm that produce on the given input, and it will produce same result by following the same computational steps. Deterministic algorithm is quite efficient in finding local optima because of it will do local search.

High deforestation rates, depletion of the ozone layer and high pollution rates of both air and water are some indicators of the current unsustainable use of the Earth's natural resources[1]. Worse still, out of 65 countries regarded as natural-resource rich countries, only a meagre 4 were able to attain a long term investment above 25 percent of the Gross Domestic Product and an average annual per capita Gross National Product above 4 percent. This is for the 1970 – 1998 period [2]. Thus, utilizing natural resources while keeping the interests of future generations in mind poses a challenge. Although an old statement, the words of King Faisal (1964 – 1975) of the oil-rich Saudi Arabia are still relevant today: “In one generation we went from riding camels to riding Cadillacs. The way we are wasting money, I fear the next generation will be riding camels again” [2]. The point is: There is a problem of resource sharing between current and future generations due to over-exploitation.

Various government and other institutional policies aim at addressing the sustainability issue. And to help in policy making, economists and scientists sometimes employ special tools. One such tool is game theory. Game theory is “the study of mathematical models of conflict and cooperation between intelligent rational decision-makers” [3]. It is used in economics, political science, psychology, computer science and biology. An example of games or cases studied in game theory is the Prisoners’ Dilemma. Prisoners’ Dilemma represents a situation of two prisoners caught and kept in separate cells [4]. Each has the option of either confessing while implicating the other, or remaining silent. If one confesses while the other remains silent, the one who confesses stands a better position of getting a less sentence. Hence confessing is the dominant strategy for each prisoner. However, when both confess, they would be worse off than when they both decide to remain silent. Figure 1 shows an illustration.

Another game studied to analyze group interactions is the Public Goods Game(PGG) [5]. In a typical set-up, the experimenter gives a group of people a certain amount of money (for example, five players with 10 AED each). The players are offered to contribute their money to a common pool with knowledge that the amount in the pool would be tripled and shared equally among participants regardless of their contributions. This means that if each player contributes his 10 AED, they will each get 30 AED. Since each dirham yields only 50 fils in return, and everyone benefits from the pull regardless of contribution, players (group members) are tempted to invest nothing and ‘free-ride’ on others’ contributions. This would be the rational and dominating action. Hence, a group with rational players will not be able to increase their endowment since they forego the public good. Public goods (Figure 1b) are available to all when provided regardless of those who contribute or refuse. Cooperators are those who contribute to its provision while free-riders only benefit without contribution.

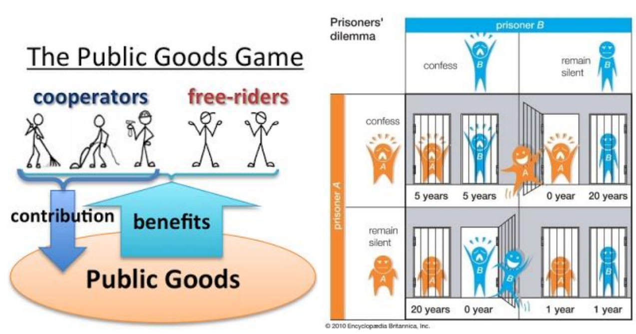

FIGURE 1. (a) The Prisoners’ Dilemma [4] (b) The Public Goods Game [5]

In both games described above, defection or selfishness affects group members or the current generation. Hence, it might not be suitable for studying resource sharing between current and future generations. Hauser et al. [6] developed a modified version of the PGG in which selfishness affects subsequent groups. They called it the Intergenerational Game (IGG). In their IGG experiment, participants formed groups of five called generations. The first generation is given a 100 unit endowment and each participant can take between 0 and 20 units from the pool. If the total percentage of extracted units does not exceed a predefined threshold which is commonly known, the 100 unit pool is renewed for the future generation (next group of players). On the other hand, if the extracted units exceed the threshold, the future generations are left with no payoff and the pool is not renewed. In the IGG as illustrated in Figure 2, the next generation occurs with a probability of δ while the game ends with a probability of $1 - \delta$. The study showed that when extraction decisions are made individually, the extracted resource always exceeds the threshold hence leaving nothing for the future generations. This is usually spearheaded by few individuals who extract more than what is sustainable. However, when extraction decision is reached by voting, the resource pool is sustained and reaches many future generations.

Hauser et al. [6] noted that voting is effective because:

- it allows cooperators to restrain a minority of defectors
- conditional cooperators are reassured that their efforts are not futile

Through a partial voting set-up where two members are free to choose at will while three others decide and vote among themselves, it was proven that voting is successful only when the outcome is binding upon all members. Number of future generations and pools sustained for the three cases (unregulated, partial voting and full voting) is presented in Figure 3. What is there to give the assurance that all members are bound by the voting outcome? In real human interactions between individuals or even governments and nations, all participants might not have the same voting power and there needs to be an institution to enforce the outcome or make it binding. A clear example is seen in the international Kyoto protocol which was not binding upon all members [7]. The result is that it lacked the full power to enact the desired change. Since there is no guarantee for a third party enforcement of voting outcome, Kroll et al. [8] designed experiments to study the effects of punishment on voting. They concluded that voting alone as a tool for cooperation is not enough since subjects are quick in realizing that nonbinding votes are cheap talk; hence they tend to defect from the decision of the majority. They found that voting by itself does not increase cooperation but it increases significantly when voters can punish violators. The study showed that even though punishment comes at a cost, voting-with-punishment was more efficient than voting without punishment.

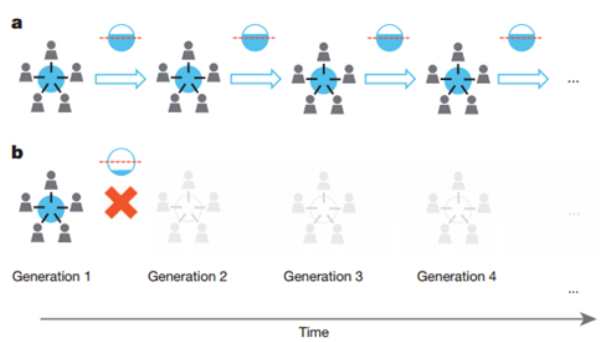

FIGURE 2: The Intergenerational Game

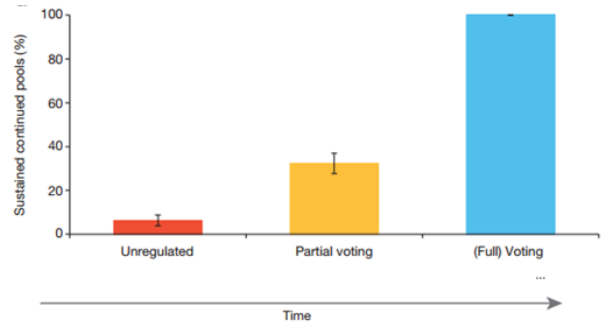

FIGURE 3: Level of sustainability of pools achieved for the case of unregulated extraction as well as extraction with partial and full voting [6].

Punishment could be incorporated in several ways one of which is reputation [9]. The evolution of punishment through reputation could be applied to the Intergenerational Game instead of voting. This is the approach of the current work. A decrease in reputation is used as a punishment for defectors.

In this study, we start by reviewing reputation and how it is used to incorporate punishment. Next, we present our model which is a two-game approach incorporating punishment through reputation. Code parameters are presented and explained, results of various cases and sensitivity of model parameters are presented and expounded upon. The relevance and applications of the study are also highlighted.

RELATED WORK

Consider a monitoring device placed in student's rooms in Masdar Institute - the first graduate university dedicated to research in sustainability. It reads water and electricity usage of the student occupying the room. Assume that reputation points are assigned such that the more of these resources a student uses, the more his reputation points are cutoff. At the end of every month, each room will choose two other rooms to partner with on condition that they both belong to the same floor. The five best groups with the lowest cumulative usage (highest reputation points) get varying but attractive prices monthly. Every room has a meter outside showing the inmate's reputation points to guide in group selection. Will this make students more conscious of water and electricity usage? Perhaps yes, if the prices are attractive enough.

The afore-mentioned example is an example of reputation as a means of punishment. There are various studies along this line. Fu et al. [10] studied how reputation affects partner choice in an evolutionary game. Two strategies were employed in partner switching:

- Ordering in partnership
- Randomness in partnership

In the former, individuals can switch from partners with lowest reputation to partners who have the highest reputation. For randomness in partnership, individuals replace lowest reputation partners with some randomly chosen partners from the entire population. Results showed that cooperation is much more favored when reputation is involved in the partner switching process. While individuals with good reputations attract new partnerships, those with a low reputation are at risk of losing existing partnerships.

To study the role of reputation, a memory-decaying effect on individual's reputation updating was introduced. A decaying rate δ was used such that when δ → 0, the influence of reputation from previous games vanishes and partners are chosen from the current game's result. On the other hand, as δ → 1, choice is totally based on the partner's accumulated reputation. Results are shown in Figure 4. When the decaying rate is introduced δ → 0.5, a lower cooperation level is reached compared to the case without decaying effect of reputation δ → 1. This highlights the importance of reputation in promoting cooperation since under social selection pressure, generosity is forced upon individuals in search of a good reputation.

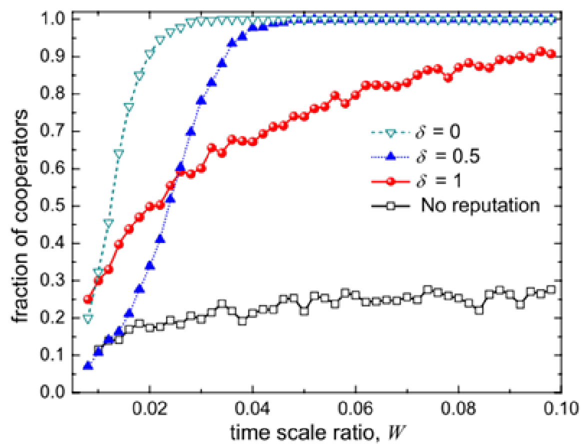

FIGURE 4: Effect of reputation on the evolution of cooperation. δ represents a decaying effect of reputation [10].

In another study by dos Santos et al. [9], the reputation of being a punisher was explored through a helping game. They introduced a game in which a donor can choose to either help or refuse to help a receiver who has the ability to punish in return. This is assumed to affect the punishment score of an individual and others are able to decide whether he is a punisher or non-punisher by looking into how much he has punished in the past (his punishment reputation). Reputation was based on:

- Punishment of defectors
- Punishment of cooperators
- Punishment of both defectors and cooperators

Punishing defectors and always cooperating with punishers emerged as the dominant strategy. Results showed that although punishment comes at a cost to punishers, it still serves as a deterrent to stop observers from refusing to help. The benefits that come from additional donations (due to the reputation as a punisher) outweigh the immediate cost of punishment. Some limitations of this model are that all individuals were assumed to have the same ability to punish and there was no retaliation from punished individuals.

Boyd et al. [11] studied punishment and cooperation in the context of group selection. They explained that group selection would only lead to cooperation as a dominant strategy when migration in groups is sufficiently limited to sustain some level of differences between groups in the frequency of defectors. They argued that unless the group is small, group selection is not effective in making cooperation evolve as the dominant strategy. The effect of the cost of punishment was also studied. As shown in

Figure 5, punishment does not aid in ensuring that cooperation dominates when the punishment costs are fixed and independent of the number of defectors. Punishment only helps when the reverse is the case (Variable Cost in Figure 5).

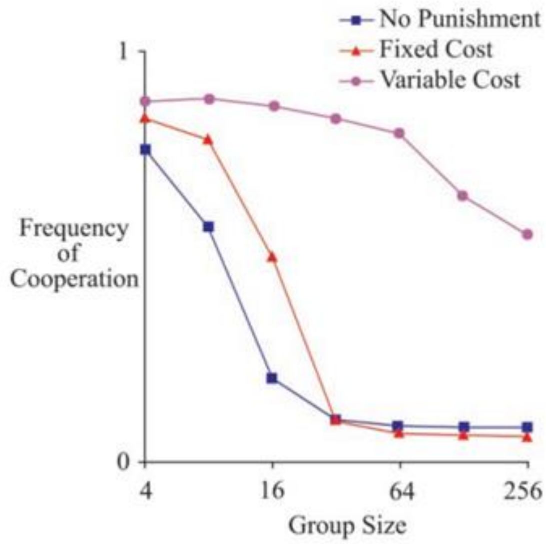

FIGURE 5: Frequency of cooperation when there is no punishment (No Punishment) and when there is punishment either at a fixed cost equal to cost of cooperating (Fixed Cost) or proportional to the frequency of defectors (Variable Cost) [11].

It might also be interesting to know what happens when individuals have the choice of opting out of the group selection process. Studies have shown that if individuals have the option of staying away from the group or joint venture, cooperation is favoured [12]. In other words, joint ventures that are voluntary rather than compulsory are more likely to lead to cooperation based on punishment of defectors.

This brief review presents some methods and findings of scientists regarding punishment, reputation and evolution of punishment through reputation. Based on these studies, we adopted a two-game approach incorporating reputation as a modification or analogue in studying the Intergenerational Game.

METHODOLOGY

Hauser et al. [6] suggested the use of voting to achieve a sustainable future. This has an inherent problem: the need for a constituted authority. This may not be possible in some cases and it might also be too costly. Thus there is need for a viable alternative that can help rein in defectors without the need of a central authority. Reputation as a way of enforcing cooperation has been widely studied in the game theory parlance. Though some people might not care about their reputation, it might be a concern if others decide to avoid them based on it. Our model tries to measure the effect of reputation in the Intergenerational Game. People are often concerned about the reputation of those they interact with. Our model assumes that people’s reputations are shaped mainly by their cooperation with the future.

People are modeled as agents with various strategies. Thereafter a pool of agents is created and made to play two sets of games iteratively - The Intergenerational Game and

Prisoners' Dilemma. Each iteration represents a particular generation. In the Intergenerational Game, agents can either defect or cooperate. If an agent defects, its reputation is decreased by a factor R. Each agent then chooses a number of other agents to interact with i.e. play a game of Prisoners' Dilemma. The reputation plays a great role in the choice of an agent. An agent with reputation **A** chooses **A** percent of its interacting agents from those with higher or equal reputation while the rest are chosen from those with less reputation.

Agents then play games of Prisoners' Dilemma with those in their network. Again, agents can either defect or cooperate. The reputation of a defecting agent is also decreased albeit with a smaller decaying factor as compared to the Intergenerational Game. At the end of the Prisoners' Dilemma game, the total payoff of each strategy and average reputation of each agent are calculated. The percentage of cooperators (those that cooperated in the Intergenerational Game) is also noted. The percentage of each strategy in the mix for the next generation is strictly determined by the strategy's total payoff. The game is said to have converged when the percentage of cooperators after a particular iteration is greater than a given threshold.

The various parameters were then varied and the simulations were run for a large number of times to remove any element of randomness. A random strategy was also inputted into the mix.

Explanation of Strategies:

- **Tit for Tat (TFT):** It repeats the last action of its opponent.
- **Pavlov:** Pavlov repeats the last action only if it is good. It plays a strategy of win-stay, lose-switch.
- **Always Cooperate (AC) :** As the name implies it always cooperates.
- **Always Defect (AD) :** It is the major defector in the pack. It always defects.
- **Random:** It selects an action randomly.
- **Tit for Two Tats (TF@2T) :** It behaves similar to tit for tat except that opponent must defect twice in a row before it is reciprocated.
- **Grudge:** It cooperates until the opponent defects then it always defects unforgivingly.

RESULTS AND DISCUSSION

Repetitive interactions in Prisoners' Dilemma tend to favor the cooperators. This is because they are able to model their opponent and play against them accordingly. However, with limited interactions, defectors have been proven to always win. This is because the dominant strategy is to defect in such cases. With the introduction of reputation factor, this study proves that cooperators are able to rein in defectors even with limited interactions.

Figure 6 shows the effect of the percentage of defectors in the mix. As expected, the more the number of defectors, the higher the chances of the defectors reining in on the cooperators. However as stated earlier, defectors are generally less than cooperators, thus the study is still very relevant.

FIGURE 6: Effect of Number of defectors on the evolution of cooperation. The number of agents in each network is 100 and the reputation decaying factor is 0.8. The result shows that the higher the number of defectors, the more the chances of converging to defection.

Figure 7 shows the effect of the increase in the number of interactions an agent has in the Prisoners' Dilemma. At the cross-point of 4 games in the Prisoners Dilemma, an increase in the number of interactions produces the required effect. The plot clearly shows that smaller values cause a convergence to defection.

The rate at which the reputation is decreased also affects the place of convergence. A faster rate of decrease tends to empower the cooperators over the defectors while with a lower rate, the defectors grow quickly and dominate the game. This effect is illustrated in Figure 8.

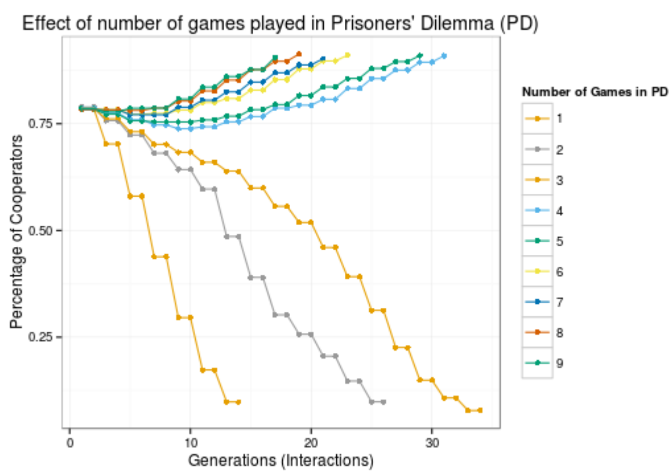

FIGURE 7: Effect of number of interactions in Prisoners' Dilema. The strategies are in equal proportion. The number of interactions in the Prisoners' Dilemma is varied and the number of agents in each network is 100. Reputation decaying factor is 0.8.

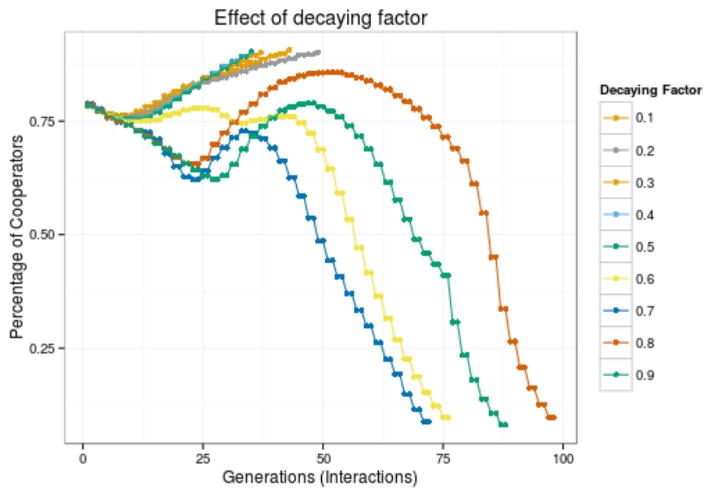

FIGURE 8: Effect of reputation decaying factor on the evolution of cooperation. The strategies are in equal proportion. The number of interactions in the Prisoners' Dilemma is 4 and the number of agents in each network is 100. Reputation decaying factor is however varied from 0.1 - 0.9. The result suggests a faster convergence rate for lower factors.

These results are compared with cases with no reputation effect. At the cross-point of four, defectors dominate. However the introduction of reputation aids the cooperators. Figure 9 and 10 show the difference between the two scenarios.

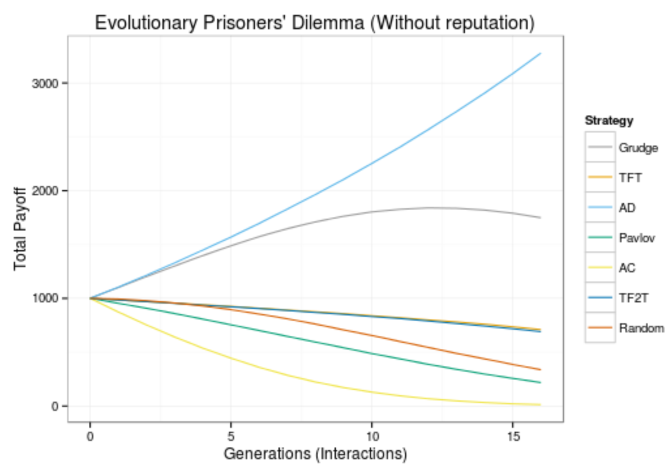

FIGURE 9: Without reputation, defectors prevail. The strategies are in equal proportion. The number of interactions in the Prisoners Dilemma is 4 and the number of agents in each network is 100. However they are chosen randomly because of the absence of reputation.

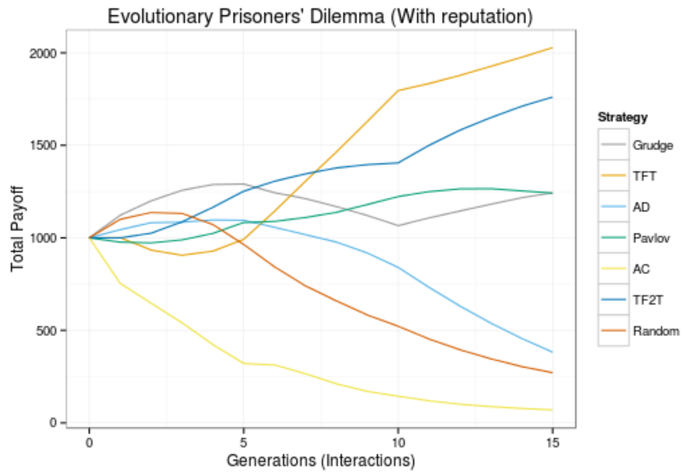

FIGURE 10: Inclusion of reputation aids the cooperators. The strategies are in equal proportion. The number of interactions in the Prisoners Dilemma is 4 and the number of agents in each network is 100. Reputation decaying factor is 0.8.

CONCLUSION

Reputation is a viable alternative in the attainment of a sustainable society. This is effective if people's reputation can be defined by their willingness to cooperate with the future thereby affecting their interactions in the society. A very important aspect is that an agent's reputation must be known to other members of the society. However, this is only effective for long interactions. In one shot interactions, defectors are sure to win.

In the real world, these can be achieved through the use of the media by gradually changing the culture of the people. More interestingly, it is a long term solution to the problem. It is noteworthy that this study has the following limitations:

- The number of interactions in the Prisoners Dilemma' must be large enough.
- The media can be bought over in cases involving big nations or corporations.
- Knowledge of every other agent's reputation might be difficult.

A clear limitation of this model is that it is not efficient in limited interactions. Future work can thus include trying to cater for limited-interactions scenario. However, with all factors affecting human society, the reputation factor can be successfully skewed to favor the defectors. Interestingly, this would come at a cost to the defectors also. Therefore, if the skewing cost can be made more than the gain from defecting, defectors can finally be pressurized to cooperate.

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