How To Achieve Cooperation in Three Game Theory Models

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Abstract: In situation like social interaction and company operation, cooperation can bring profitable and beneficial results, but sometimes cooperation is hard to reach if individual unit want to max their own payoff, such as price war and the arms race, so it is valuable to investigate how to maintain cooperation. This article explained the reason of non-cooperative behavior through three classical models: prisoner's dilemma, stag-hunt game, and snowdrift game, and reviewed game theory approaches to increase cooperation in them. It is found that changing the payoff matrix, and trust and communication could help reaching cooperation. This article can help researcher with what was studied and provide suggestions on stimulating cooperation in real-life application.

1. Introduction

"Cooperate" refers to action providing a benefit to a group while sacrificing single individuals [1]. Cooperation is a common and vital action that can bring more profit among people, companies, and countries [2, 3]. For examples, citizens can cooperate to follow the social contract and laws for greater protection and balance, or if everyone break the law and do what they want, there will be chaos [4]; when two or more companies sell the same product, they can cooperate on the price set up, or having a price war: keep lowering their price to attract customers and get profit but end up with the least profit for all of them [5]; among countries, no cooperation may cause arms race and slow down the economy on each side, like the cold war [6]. None of these detrimental results will happen if there are cooperation. So, it is important and meaningful to find out how to achieve and maintain cooperation.

Game theory serves an essential role when researchers attempt to explain and investigate why cooperate and how to maintain cooperation [7]. It is the study of strategic interaction and optimal decision-making among players assumed to be rational and acting in self-interest. Dominant strategy and Nash equilibrium are crucial concepts to analyze player's strategy and game outcome. Dominant strategy describes the optimal action for individual player regardless of what the other's action; Nash equilibrium is the outcome state once reached that no player has the incentive to shift their choices for better payoffs and each player choose their dominant strategy [7, 8]. So, the conflict between individual optimal and group optimal become the focus problem on cooperation investigation.

From a game-theoretical perspective, corporative behavior consists of both players paying a cost to maximize the joint payoff instead of their own payoff [8]. In this article, three classical models would be used to study cooperation: stag-hunt game [4], prisoner's dilemma game [5], and snowdrift game [6]. Here is their brief introduction:

Prisoner's dilemma game (PDG) was first framed in 1950 by Merrill Flood and Melvin Dresher [5]. In standard PDG, each rational player should always defect because this brought a higher individual payoff no matter what the opponent did. But if both players cooperated, this led to a highest sum-up payoff.

Stag-hunt game (SHG) was originated with philosopher Jean-Jacques Rousseau in his Discourse on Inequality [4]. Players might not always cooperate depend on the belief about the others' choices, while choosing cooperation result highest joint payoff.

Snowdrift game (SDG) was also known as the game of chicken [6]. Both players could cooperate to solve the problem as soon as possible. But player worried that he might be the only working one

without knowing the other's choice and decided to not work. If both players decided not to work, it would lead to the worst result which the sum-up payoff was zero.

All three games represent situation that cooperation will bring higher total payoffs, but cooperation is not guaranteed. The article is to review these three models and analyze and synthesize the investigation and studies on game theory approaches to lead and maintain cooperation in them then summarize the strength and weakness of each solution. By doing so, it can help understand which method is useful to lead cooperation in the model and in real life, such as company operation, government policy decision, and direction of further cooperation investigation.

For the rest of the articles: section 2 briefly introduces the three models and review the current solution. Some discussion and weakness will be shown. Section 3 concludes the findings and provides future research suggestion.

2. Game Theory Approaches on how to achieve cooperation

This section is divided into three parts with: prisoner's dilemma, stag-hunt game, and snowdrift game. In each part, different studies and research on methods to achieve cooperation is reviewed.

2.1 Prisoner's Dilemma

Table 1 provides a standard PDG model's payoff matrix, each player has dominant strategy to play defection, and (D, D) is the Nash equilibrium [9]. So, cooperation between players is not reach because it is not the Nash equilibrium.

Table.1. Payoff matrix for Prisoner's Dilemma [9]

	C	D
C	(3, 3)	(0, 5)
D	(5, 0)	(1, 1)

（1）**One-round Prisoner's Dilemma**

The most used method to increase cooperation in one-round PDG was to change the value of payoff matrix. In 1963, Lester investigated the effect of payoff on cooperation in PDG using matrix with different temptation to defect and punishment for cooperation failure [10]. The result showed that subjects were more willing to cooperate when punishment for taking the other's defection is low and temptation to defect is low.

In 1965, further investigation manipulated more changing in payoff, including reward to cooperate, punishment and temptation to defect [11]. The study suggested the PDG with higher reward to cooperate and punishment to defect and lower the temptation to defect will have higher rate of cooperation.

Researchers also investigated payoff's effect from perspective of average payoff [9]. The average payoff (AP) of a player is the sum of four possible payoff divided by four (1). Using standard PDG as an example (table 1), the AP is 2.25. The experiment result indicated higher AP leads to higher cooperation.

$$AP = (3 + 0 + 5 + 1) / 4 = 2.25 \tag{1}$$

In [9], the experiment also used money as incentive: each payoff number means gaining corresponding amount in cents, so it concluded that gaining payoff will also stimulate greater cooperation then losing payoff. This was consistent with the finding of Gallo and Charles's study in 1965 that subjects playing for real money were far more cooperative than subjects playing imagery money [9, 12].

(2) Iterated Prisoner's Dilemma Game

There was a big gap between one-round PDG and real-life because, in many situations, the interaction between players does not end in one round and they need to make decisions many times in a row. So, researchers shift focus from one-round PDG to Iterated Prisoner's Dilemma (IPD) and seek methods that lead cooperation.

In 1980, Axelrod studied the result from his finitely Iterated Prisoner's Dilemma (IPD) tournament [13, 14]. A strategy named Tit for Tat (TFT) won both competitions named TFT. This strategy displayed that cooperated at first then copied every previous move of the opponent player. Analyzing all the strategies with higher payoff gained, Axelrod concluded that: niceness (do not defect first); forgiveness (cooperate again after defection); and PROVOCABILITY (defect back to exploitation) were crucial to cooperation.

However, TFT was vulnerable to noise (due to technology or machine error, sometimes there is mistaken choice be sent or received), and TFT never exploit the other by defecting while the other cooperate. Various strategies were investigated aiming on improving TFT. Pavlov strategy was a strategy that deal with the noise and sometimes exploited others [15]. That was a strategy that cooperated unless in the previous move it is a sucker, or the opponent is a sucker. Sucker is the player cooperates while the other defects.

In 1998, Manfred and Claus studied how Pavlov strategy and TFT fit for human reality by testing working memory's constraints on the use of Pavlov and TFT in IPD [16]. The result indicated TFT-like strategy had been fit for short-term working memory and more human-like than Pavlovian strategy.

In addition to these improvements, GTFT and CTFT were introduced. GTFT allowed some defection by cooperating 10% of time when it should defect. CTFT would not defect back after its own unintended defection. The experiment found that GTFT (highest scorer) and CTFT perform well with noise and CTFT was slightly better as noise percent increase [17]. The research also did an ecological simulation and CTFT clearly dominate the population after generations.

2.2 Stag-Hunt Game

Table 2 provides SHG model's payoff matrix, players either choose to play risk (hunt stag) or safe (hunt hare). In this case, there are two Nash equilibrium, (R, R) and (S, S), so the cooperation is not guaranteed because both Nash equilibrium are possible results depend on the player's belief about the other's choice [4].

Table.2. Payoff matrix for stag-hunt game [4]

	C	D
C	(4, 4)	(0, 3)
D	(3, 0)	(1, 1)

Early studies and investigation focused on the effect of value of payoffs matrix on the cooperation. In 2005, Rydval and Ortmann's experiment showed that "loss avoidance" had been a key factor for cooperation [18]. That was a situation where the players tended to avoid safe play and increase cooperation if safe play might yield a negative payoff.

This was consistent with research in 2006. Research also tested the effect of players' "loss avoidance" and found that player would cooperate and had higher trust on the other when playing safe might yield a negative payoff [19]. Both studies demonstrated that changing payoff levels, less punishment for taking risk and negative payoff for playing safe could increase the rate of cooperation.

Other than payoff, whether to cooperate in SHG also depended on the trust between players. In 2014, researcher introduced "index of risk aversion" (IRA): the percentage of cooperation that one player would accept the other to have to cooperate [20]. The experiment showed that cooperation increases significantly with the players knowing the opponent's IRA.

Another experiment was conducted to investigate the cooperation rate of human players facing different agents of risk (human player, lottery in social context, and lottery). Like idea of IRA, the result demonstrated that players have lower "minimal acceptable probability" (MAP) and cooperated more when the uncertainty is from human or social context [21].

Besides that, researchers conducted experiment and studied the influence of pre-game suggestion on cooperation. The result showed that players with pre-game trust-other audio cooperated more than the players with pre-game trust-self audio, so the positive suggestions lead to higher cooperation [22].

2.3 Snowdrift Game

Table 3 is payoff matrix in SDG, two players tried to remove the snowdrift between them, the player either choose to cooperate or defect. The expected results are one of the two Nash equilibrium, (C, D) and (D, C), but cooperation is neither of them, so there is no cooperation [23].

Table.3. Payoff matrix for game of Chicken [23]

	C	D
C	(1, 1)	(-2, 2)
D	(2, -2)	(-3, -3)

In 1966, researchers investigated relationship between players' first choice and their latter cooperation [24]. The research found out that double cooperation (C, C) and double defection (D, D) on the first trails would increase player's tendency to cooperate, but both (C, D) and (D, C) outcome on the first trails would make the player non-cooperative in the later game.

There were also some studies focused on the effects of payoff levels. Researchers conducted experiments using different payoff levels in SDG and found out that maximizing the joint payoff for (C, C), or increasing the reward to cooperate, is conducive to cooperation rate [25].

From the perspective of players, there were also findings. In 1975, researchers studied the effect of players' communication's effect on cooperation in PDG and SDG [26]. The experiment allowed some subjects to send message to their partners after certain round of game, and the result indicated that communication between players can increase the cooperation rate in both PDG and SDG.

Some researchers experimented the effect of mood in SDG [27]. The result showed that feeling state has indirect effect on players' choices of cooperation: positive feeling made players easier to be guided by heuristic cues then increase cooperation rate; negative feeling could also increase cooperation if the subjects were put in a serious background.

In 2008, the idea of heterogeneity was introduced. Researchers investigated the structure of population of different types of players' effect on cooperation [28], [29]. The experiment manipulated the population structure of two types of players (unconditional cooperators and strategic cooperators) and found out that strategic cooperators tended to cooperate more when their population increase.

3. Discussion

Based on the studies, changing the payoff matrix were investigated in all three models to achieve cooperation. The increase of the reward to cooperate, and the decrease of the temptation to defect and the negative payoff were the principle behind this method. In real life, companies and government could setup corresponding reward system to simulate cooperation and aim to reduce risk first to maintain cooperation. Besides payoff matrix, the property of niceness and communication also stood out as two key factors, which were a long-term cooperative interaction usually begun with a cooperation choice instead of a defection choice. So, it would be helpful and efficient to communicate and express the willingness to cooperate at the beginning to achieve and preserve the long-term cooperation.

4. Conclusions

This article reviewed game theory approaches to achieve cooperation in three classical game theory models: Prisoner's dilemma, stag-hunt game, and snowdrift game. In each model, the cooperation is not reached either because Nash equilibrium is not cooperative state or there are two Nash equilibria, so the cooperation is not guaranteed. According to the review, changing payoff matrix served an important role in all three models to reach cooperation. Besides that, trust and communication between players also increase the probability to cooperate. The synthesis of this article on the game theory approaches in the model can serve as an efficient guide on further investigation and provide suggestions on how to achieve cooperation in real-life situations.

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