[Academic Script]

Game Theory

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1. Introduction

Game theory was developed by mathematician John Von Neumann and economist Oskar Morgenstern (in 1944) to evaluate situations where individuals and firms have conflicting objectives. In oligopoly and duopoly markets firms must consider the effects of their decisions on other firms and anticipate how other firms will respond. Thus the goal of the firms in oligopoly markets is to earn economic profits by outguessing the rival firms. The game theory has helped to understand more clearly how the firms behave in oligopoly markets.

MEANING

Game theory attempts to study decision making in situations where two or more intelligent and rational opponents are involved under conditions of conflict and cooperation. Such situations basic to oligopoly market structure. Game theory seek to determine a rival's most profitable counter strategy to one's own best moves to formulate appropriate defensive measure. For example two firms are involved in a competition to maintain their market share, then a price cut by the first firm will invite similar reaction from the second firm. This will, in turn affect the sales and profits of the first firm, which will again have to develop a counter strategy to meet the challenges from the second firm. The game will thus go on. Game theory helps in determining the best course of action for a firm in view of the expected counter moves from the competitors. The competitors in the game are called players.

A game is thus a competitive situation where the market players pursue their own interest and no player can dictate the outcome. Games that firms/players play can be of two types:

a) Cooperative games: in this type of games players can negotiate a binding contract to plan joint strategies (actions).
b) Non-cooperative games: in this type of games it is not possible to negotiate a binding contract to plan a joint strategy.

ASSUMPTION OF GAME THEORY

1) The possible set of actions (strategies) available to each firm is finite.
2) Each player/firm is aware of the both, the strategies available to himself and to his Opponent.
3) Each player is intelligent and rational thus having complete knowledge preference order of his moves and that of his opponents which he uses to select his best moves.
4) Players aim to maximize gain or minimize loss.
5) Player A's gain is player B's loss and vice-versa. If the gain is exactly equal to loss, it is called zero-sum game.

BASIC DEFINITIONS AND TERMINOLOGY

Every game theory model includes players, strategies and payoffs. Therefore lets us first understand these concepts.

1) STRATEGY: A strategy is the course of action taken by one of the participants (a firm) in a game (market). Each player/firm is a decision making unit who decides about the rules of the game. A strategy is a complete specification of the plan of action by a firm/player after taking into consideration all possible reactions of its competitors as they compete for profits or other

advantages. Since there are only a few firms in the industry, actions of each firm affects the others, and the reactions others must be kept in mind by the first firm while choosing its own best course of action/strategy. There are two types of strategy:

a) **Pure Strategy**: If the player/firm selects same strategy or only one course of action every time in response to his competitor's action, it is called a pure strategy. Use of this type of strategy requires that each player has complete knowledge of the strategy of his opponent.

b) **Mixed Strategy:** In many games pure strategy would be a very poor choice. The use of mixed strategy means that the players do not use a single strategy but a mix of strategies. Each player always keeps the other players guessing about the course of action that the firm is going to select in a particular situation. Mixed strategies involve a player randomly choosing among pure strategies according to given probabilities. A mixed strategy is a strategy in which a player makes a random choice among two or more possible actions, based on a set of chosen probabilities. For example in a cricket match between two countries say India and Australia, an Indian bowler always balls differently each ball in an over than it is said that he is using **a mixed strategy** because he keeps the opponent batsman guessing about the type of ball that he is going to face from the baller. Mixed strategies can be important in many settings and sometimes they are used to reduce the costs. It would be very expensive to audit every income tax return, and therefore the income tax department chooses individuals at random after using some pre-selection criteria, for audits. Although the vast majority of returns are

not audited, the possibility of an audit encourages tax compliance among the general population.

2) **PAYOFF:** It is the result or outcome of the strategy. For each strategy adopted by a firm, there are usually a number of strategies available to a rival firm. The payoff is the outcome or consequence of each combination of strategies by the two firms. The payoff is usually expressed in terms of the profits or losses of the firm that as a result of firm's strategies and the rival's responses. The table giving the payoffs from all strategies open to the firm and the rival's responses is called payoff matrix.

In the **table-1** below first number in each cell always refers to firm 'A' and the second number always refers to firm 'B'. If firm 'A' advertises but firm 'B' does not, 'A' makes a profit of 30 and 'B' makes no profit. If firm 'B' advertises but 'A' does not advertise, 'A' and 'B' make profit of 12 and 16 respectively.

Table 1

Payoff Matrix for an Advertising Game(Profit)

		Firm B	
		Advertise	Don't Advertise
Firm A	Advertise	20 ; 10	30 ; 0
	Don't Advertise	12 ; 16	10 ; 5

3) **OPTIMAL STRATEGY:** A course of action or plan which puts the player (firm) in the most preferred position, irrespective of strategy of his competitors is called its optimum strategy. Any deviation from it results in a decreased payoff for the player.

2. Dominant Strategy

How can a firm decide about the choice of its optimal strategy? A particular strategy may be successful or more profitable if competitors make a particular choice or decision but will not be successful or more profitable if they make other choices.

However a **dominant strategy** is one which will be successful or optimal for a firm regardless of what other firms do. It is that strategy which will be most beneficial to a firm no matter what strategy the rival firms adopt. Thus dominant strategy is the optimal choice for a player no matter the opponent does.

To understand the concept of dominant strategy we will take one example given in **table-2** below. Suppose there are two firms 'A' and 'B'. There two strategies for each firm-to advertise or not to advertise. Firm 'A' expects to earn higher profits if he advertises than if he doesn't. Four possible outcomes are shown in the payoff matrix given below.

Table 2

Payoff Matrix for an Advertising Game(Profit)

		Firm B	
		Advertise	Don't Advertise
Firm A	Advertise	4 ; 3	5 ; 1
	Don't Advertise	2 ; 5	3 ; 2

What strategy should each firm choose? Let us consider firm 'A' first: If firm 'B' advertises, firm 'A 'will earn a profit of 4 if he also advertises and 2 if he does not. Therefore firm 'A 'should advertise if firm 'B' does. If firm 'B' does not advertise, firm 'A' will earn a profit 5 if he does advertise and profit of 3 if he does not. This shows that 'A' should advertise irrespective of whether firm 'B' advertises or not. Firm 'A' profit will be higher if it advertises rather than if he does not regardless of what firm 'B'

does. Therefore it is said that the dominant strategy for firm 'A' is to advertise.

Similarly if we analyze firm 'B's strategies given strategies of firm 'A', we will find that firm 'B' has a dominant strategy "to advertise" irrespective of what strategy firm 'A' adopts.
Thus in this case 'A' and 'B', both firms have a dominant strategy of advertising. Here final equilibrium exists for both firms irrespective of whether firm 'A' or firm 'B' chooses its strategy first or if both firms decide on their best strategy simultaneously.

3. Nash Equilibrium

Not all games have a dominant strategy for each player (firm). In fact, in real life it is more likely that one or both players do not have a dominant strategy. This is shown in the **table-3** below. Here firm 'B' has a dominant strategy but firm 'A' does not have a dominant strategy. The dominant strategy for firm 'B' is to advertise irrespective of whether firm 'A' advertises or not.

Table 3
Payoff Matrix for an Advertising Game(Profit)

		Firm B	
		Advertise	Don't Advertise
Firm A	Advertise	4 ; 3	5 ; 1
	Don't Advertise	2 ; 5	6 ; 2

For example if firm 'B' advertises, firm 'A' earns profit of 4 if he advertises and profit of 2 if it does not. Thus if firm 'B' advertises, firm 'A' should also advertise. On the other hand if firm 'B' does not advertise, firm 'A' earns profit of 5 if advertises and 6 if it does not. Thus firm 'A' should advertise if firm 'B' does and should not advertise if firm 'B' does not. Thus firm 'A' no longer has a dominant strategy. What firm 'A' should do depends

on what firm 'B' does. In order for firm 'A' to determine what whether to advertise or not, firm 'A' must try to determine what firm 'B' will do and advertise if firm 'B' does and not advertise if firm 'B' doesn't. As the firm 'A' knows the payoff matrix, it can find out that firm 'B' has a dominant strategy of advertising. Therefore the optimal strategy for firm 'A' is also to advertise. This is Nash equilibrium named after John Nash, the Princeton University mathematician and 1994 noble prize winner in economics.

The Nash equilibrium is the situation in which each player chooses his optimal strategy, given the strategy chosen by the other firm. In the above example, the strategy to advertise for both the firms is Nash equilibrium. This is because the given that firm 'B' chooses his dominant strategy of advertising, the optimal strategy for firm 'A' is also to advertise. Here it is important to note that when both the firms had dominant strategy, each firm was able to choose its own optimal strategy regardless of strategy adopted by its rival firm. In this case only firm 'B' a dominant strategy and firm 'A; does not have any dominant strategy. Therefore firm 'A' is not in a position to choose its optimal strategy independently of firm B's strategy.

4. Prisoner's Dilemma

Oligopoly firms often face a problem called 'Prisoner's Dilemma'. This refers to a situation in which each firm adopts its dominant strategy but could do better (i.e. each can earn larger profits) by cooperating. Prisoner's dilemma is an example of a non-cooperative game. A game is considered non-cooperative if it is not possible to negotiate with other participants and enter into some form of binding agreement. When firms in the oligopoly

markets use pricing strategies to compete with each other for profits, they are said to be engaged in non-cooperative games because they are legally prohibited by competition laws for coordinating their prices. In some cases non-cooperative games can result in outcomes that are undesirable for the participants and the society. One such example is prisoner's dilemma. This model takes its name from the story of two persons who were jailed for the crime they allegedly committed. Two suspects are arrested for an armed robbery, and if convicted, each can receive a maximum sentence of 10 years imprisonment. However, unless one or both suspects confess, the evidence is such that they could be convicted only for one year for possessing stolen goods. These suspects are separated and interrogated by the police and no communication is allowed between them. Each is told by the police that if he does not confess and other suspect does confess than he will be convicted and put in jail for 10 years. But if he does confess and implicates his friend, then his jail sentence will be only for 1 year. If both suspects confess, each will get imprisonment for 5 years. The payoff matrix in terms of years of imprisonment is shown in table-4.

Table 4

Negative Payoff Matrix(years of detention) for suspects A and B

		Suspect B	
		Confess	Don't Confess
Suspect A	Confess	5 ; 5	0 ; 10
	Don't confess	10 ; 0	1 ; 1

The table above shows that the dominant or the best strategy for the suspects is to confess. Thus if suspect B confesses, suspect A gets 5 years in jail if he confesses and 10 years in jail if he does

not confess. If suspect B does not confess, suspect A goes free if he confesses and gets one year imprisonment if he does not confess. Thus irrespective of the strategy adopted by suspect B, the dominant or the optimal strategy that A can adopt is to confess. Similarly for suspect B also, the dominant strategy is to confess. If suspect A confesses and suspect B also confesses then B gets jail term of 5 years and if B does not confess he gets jail term for full 10 years. On the other hand if suspect A do not confess and suspect B confesses, B does not go to jail but if B does not confess he gets jail term for 1 year. Therefore confessing is also the best or dominant strategy for suspect B. Both suspects thus adopting their dominant strategy of confessing ends up into jail for 5 years. However if both suspects do not confess than they both will go to jail only for 1 year for possessing the stolen goods and not for full 10 years as the evidence is only circumstantial. But each suspect is afraid that if he does not confess and the other suspect does confess, he will get jail term for 10 years. Only if each suspect was sure that he will not confess and other suspect will also not confess, they will go to jail only for 1 year. However as it is not possible for them to somehow meet or communicate and enter into an agreement of not confessing each suspect adopts his dominant strategy of confessing and thus ending up with 5 years of imprisonment. It is important to note that even if they enter into an agreement of not confessing it cannot be enforced and hence both convicts end up with 5 years in jail. Although not confessing is the best joint strategy, because they are involved in non-cooperative game and cannot influence what other suspect does, they end up with a decidedly non-optimal outcome.

PRICE COMPETITION AND PRISONER'S DILEMMA

The concept of prisoner's dilemma is useful to analyze price and non-price competition in oligopoly markets as well as incentive to cheat (i.e. the tendency to secretly cut price or sell more than its allocated quota. In **table-5** an example of price competition is given which is similar to the example of prisoner's dilemma.

Table 5

Payoff Matrix for Pricing Game

		Firm B	
		Low price	High price
Firm A	Low price	2 ; 2	5 ; 1
	High price	1 ; 5	3 ; 3

The payoff matrix above shows that if firm B charged low price (say Rs.6), firm A would earn a profit Rs.2 if it also charged low price (Rs.6) and 1 if it charged high price (say Rs.8). Similarly, if firm B charged a high price (Rs.8), firm A would earn a profit of Rs.5 if it charged low price and Rs.3 if it also charged high price (Rs.8). Thus firm A would adopt dominant strategy of charging low price. From firm B's point of view, if firm A charged low price, firm B will earn a profit of 2 if also charged low price and profit of 1 if it charged high price. If firm A charged high price and firm B charged low price it will earn a profit of 5 and profit of 3 if it also charged high price. Thus firm B would also adopt its dominant strategy of charging low price. Thus the firms are in prisoner's dilemma: each firm will charge low price and earn a lower profit because if it charged higher price it cannot trust its rival to also charge the high price. Therefore the net result is that both firms by charging lower price end up with lower profits compared to what they can earn by cooperating and thus making an agreement about their respective pricing policy and overcoming the dilemma.

The concept of Prisoner's Dilemma can be to explain with the help of other phenomena of resource waste from advertising in oligopoly markets. For simplicity it is assumed that there are two firms with two strategies regarding advertisement expenditure: low level of advertising or high level of advertising. The payoff matrix for four possible combinations of strategies is shown in table-6 below.

Table 6

Payoff Matrix of Advertising & Resource Waste

		Firm B	
		Low level advertising	High level advertising
Firm A	Low level advertising	30 ; 30	10 ; 40
	High level advertising	40 ; 10	20 ; 20

If firm A advertises at a low level, its profit is Rs.30 crores if firm B also advertises at a low level and Rs.10 crores if firm B advertises at a high level. If firm A advertises at high level it earn a profit of Rs.40 crores if firm B advertises at low level and Rs.20 crores if firm B advertises at high level. Thus the minimum profit from low level advertising is rs.10 crores. The table shows that a high level of advertising will guarantee firm A at least Rs.20 crores profit. Therefore the best strategy for firm A is to advertise extensively. Similar logic applies to firm B also for whom high level of advertising earns him more profit. Thus both firms opt for high level advertising and earn profits of Rs.20 crores each. However a joint decision of not advertising or low advertising through cooperation can lead to higher profits of Rs.30 crores for each firm. But neither firm dares to select his strategy of low advertising because if the other firm selects the strategy of high advertisement he will end up with a profit of

Rs.10 crores. The result is that both the firms earn less profit and waste resources on mutually offsetting advertising.

5. Summary

The above discussions on game theory have explained how this concept can be used to explain the behavior of the firms in oligopoly and duopoly markets. It shows that it is easy to understand the behavior of the firms when it is put into game theoretical situations. The players in the game are the competing firms and their actions are the strategies that they may adopt depending on the action of their rival firms. The firms may or may not have an optimal strategy. If they have an optimal or the best strategy irrespective of the strategy followed by their rivals they are said to have a dominant strategy. If the firm do not have a dominant strategy they can still have an optimal strategy depending on the strategy adopted by the other firm this is called Nash Equilibrium. The behaviors of the firms where they cannot jointly decide their best or most profitable strategy are known as non-cooperative games. These types of games or behavior can be explained by the concept of "Prisoner's Dilemma.