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The Application and Limitations of Game Theory in Economics

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Abstract: This article aims to understand the impact, application, and limitations of game theory on microeconomics and macroeconomics in economics. Game theory outlines the situation where players make rational decisions in order to surpass their opponents. Game theory plays a crucial role in the buying and selling parties in different markets. This article provides an overview of the concept of game theory, not only explaining its applications in market analysis, resource allocation, price auctions, and cooperative behavior in economics, but also analyzing the limitations of game theory in its application. By reviewing these cases, this study not only demonstrates how game theory plays a role in economic games such as market competition, international trade, and finance, but also demonstrates how to apply game theory reasonably. The significance of this study includes further discussion on the specific applications of game theory and the limitations of its application in economics, to help people maximize their benefits.

Keywords: Game theory, Nash equilibrium, market analysis.

1. Introduction

Game theory is an advanced mathematical model aimed at studying the strategic behavior of rational decision-makers among players. The earliest history of game theory can be traced back to over 2000 years ago when King Qi of China, Tian Ji, raced horses. However, it was not until the 1980s that game theory began to enter the field of mainstream economics [1]. In 1928, von Neumann proved the fundamental principles of game theory, thus announcing the formal birth of game theory. In 1944, von Neumann and Morgenstein's groundbreaking work "Game Theory and Economic Behavior" extended two player games to n-player game structures and systematically applied game theory to the field of economics, laying the foundation and theoretical system for this discipline. The equilibrium point proposed by Cournot for resolving conflicts between oligopolies through output decisions, which maximizes the interests of all parties, can be introduced into the indicator comprehensive weighting model. The optimal solution can be found among various weighting methods, and the deviation between the optimal solution and each weight is minimized [2].

The game model has three main factors: player, information, and strategy [3]. Nash equilibrium is a classic solution in game theory. It is widely believed that Nash equilibrium refers to a combination of strategies that enable each participant to respond to the best possible response from other participants. Games include both cooperative and non cooperative games. The biggest difference between these two is whether there is a binding agreement on the other party. If there is, it is a

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cooperative game; if not, it is a non cooperative game. From the time series of behavior, gGame theory can be divided into two types based on the chronological order of behavior: static games and dynamic games. Static games refer to games where participants choose simultaneously, or where later participants do not know what specific actions the previous participant took even though they did not choose simultaneously [4, 5]. Dynamic game refers to a game where participants' actions are ordered, and the next participant can observe the action chosen by the previous participant. Simply put, situations like the prisoner's dilemma where all participants make decisions simultaneously belong to static games; A game with a series of decisions or actions, belonging to dynamic games. In addition to dynamic and static, games can also be divided into complete information games and incomplete information games based on the level of understanding of decision-makers. Complete game refers to the process in which each participant has accurate information about the characteristics, strategy space, and payoff function of other participants. Incomplete information game refers to the situation where all of this information is in an unknown state. Nash equilibrium is essentially a non cooperative game state.

Game theory is crucial in economics, especially in the game between consumers and producers, and between countries. These interactions can be modeled as strategic games. The basic starting point of game theory is the pursuit of economic interests, mainly studying the decision-making of behavior and interests, as well as market equilibrium issues, involving the principles, methods, benefits, equilibrium, and results of decision-making. This method can maximize both personal and total benefits. Similarly, game theory can reveal the laws of market economy and provide useful insights for government economic management [6]. In addition, this article will focus on the practical application of game theory in economics and how it affects the market through case studies and explanations. The key research questions include: How effective is game theory for real-world economic markets? What are the limitations of these models?

2. Theorical Foundations

2.1. Definition and Types

The study of the interaction between formulaic incentive mechanisms is the main research direction of game theory, which is studied using mathematical methods and theory. Game theory considers the predictive and actual behavior of individuals in games, and studies their optimization strategies. The advantage of game theory models is that, based on their specific structure, many economic, political, international relations, military strategy, and other issues can be explained under one model [7].

The game theory discussed by economists generally refers to non cooperative games. Due to the complexity of cooperative game theory compared to non cooperative game theory, it is theoretically more difficult to study non cooperative games. Non cooperative game theory also has different classifications. The first is a complete information static game, usually played by Nash equilibrium searching for equilibrium points. The second type is complete information dynamic game, and the most common solution is subgame perfect Nash equilibrium. The third type is incomplete information static game, usually using Bayesian Nash equilibrium to find the equilibrium point. The fourth type is incomplete information dynamic game, where perfect Bayesian equilibrium results in the death of its corresponding equilibrium concept. There are many classifications in game theory, such as: the number of games can be divided into finite games and infinite games. Its manifestation can also be divided into general or expanded types. It can also be divided into traditional games and evolutionary games. The difference between traditional game theory and evolutionary game theory is that their logical foundations are different. These different approaches can help classify game theory into different types.

2.2. Development History of Game Theory

Game theory is the process of two individuals using each other's strategies to transform their own adversarial strategies in an equal game, in order to achieve victory. The history of game theory can be traced back thousands of years, such as in China's "The Art of War" by Sun Tzu. Game theory was initially applied to games such as chess, and people's understanding of games is mostly based on experience rather than theory. Game theory predicts future development by predicting individual behavior. The study of game theory in modern times began with Zermelo, Borel, and von Neumann. The formal birth of game theory theory originated from Feng in 1928 Neumann's proof. In 1944, von Neumann and Morgenstein extended two player games to n-player game structures and systematically applied game theory to the field of economics, providing a theoretical foundation for this discipline. In the early 1950s, by utilizing the fixed point theorem, the equilibrium point of a game was determined, which became a milestone in the development of game theory in later generations. Similarly, Nash's later research papers further promoted the development of game theory, which gradually became a well-established discipline and was constantly applied in various fields.

2.3. Basic Elements of Game Theory

The first is player. Player in the game refers to the number of people who participate in a competition or game. Two people are two players games, and multiple people are multipliers games.

The second is strategy. Each player in the same game has a complete execution plan, which is a feasible and globally planned action plan for each player from start to finish, known as a player's strategy. Similarly, the number of action plans determines whether it is a finite game or an infinite game.

The third is gains and losses. The outcome after the game is called gain or loss. The gains and losses of each player in the game are related to their own strategies and the strategies of everyone in the team. So the payoff function is a function that displays the relationship between each person's gains and losses and their strategies.

2.4. Nash Equilibrium

Nash equilibrium is one of the solutions in game theory, which represents a strategy combination that satisfies the following characteristics: when other players' strategies remain unchanged, any player who changes their strategy unilaterally in this strategy combination will not increase their own profits. Nash equilibrium is the result of non cooperative games, where neither party can achieve the best outcome due to lack of cooperation, and can only accept a helpless, neither good nor worst outcome that neither party wants [8].

3. Application of Game Theory in Economics

3.1. Market Competition Analysis

The application of game theory in market competition is particularly extensive. By constructing game models, economists can analyze different strategies and interactions between companies and predict market behavior. For example, price wars and advertising competition among enterprises in oligopolistic markets. The concepts of Nash equilibrium and Bayesian Nash equilibrium help us understand the optimal strategy choices of enterprises in a given market environment. The 'smart pig game' is a good example. Suppose there is a big pig and a small pig in the pigsty. There is a pig feeding trough on one end of the pigsty and a button on the other end. Press the button, and the machine will immediately pour 10 pounds of pig food into the trough. However, every time a pig presses a button, it has to pay the cost of consuming 2 pounds of food, and if a pig runs to press the button, turns around and goes to the trough, some of the pig's food will be eaten by another pig first. If the big pig presses the button, because the little pig will wait in the trough, it can only eat 6 pounds of food, and the little pig can have 4 pounds. If the little pig presses the button and turns back, the big pig will take 9 pounds of food, while the little pig will only take 1 pound. If two pigs can press at the same time and then turn around to have, the big and small pigs can each take 7 pounds and 3 pounds. From this table 1, the author can clearly see that the best strategy for a big pig is to press the button, while the best strategy for a small pig is to wait. Similarly, the author can apply the same principle to business competition: for large enterprises, the best strategy is to constantly research new products and technologies, while for small enterprises, the best method is actually imitation. If small businesses invest money in research and development, there is a high possibility that it will be absorbed by large enter rises. Assuming that the output of technological innovation for large enterprises is A1, the cost of technological innovation is a, and the output without technological innovation is A2, the output of that for small and medium-sized enterprises is B1, the cost of that is b, and the output without technological innovation is B2, the decision-making benefits of that for large enterprises and small and medium-sized enterprises are shown in Table 1 [9].

Table 1: Game of Enterprise Technological Innovation

Enterprise type		Large enterprises: Carry out technological innovation	Large enterprises: no Carry out technological innovation
small and medium-sized enterprises	Carry out technological innovation	(A1-a), (B1-b)	A2, (B1-b)
	no Carry out technological innovation	(A1-a), B2	0, 0

3.2. Resource Allocation Issues

In situations where resources are limited, game theory provides an effective analytical framework to study how to allocate resources fairly and effectively. For example, in the field of public goods provision, game theory can help governments design optimal pricing strategies to maximize social welfare. In addition, game theory can also be used to analyze information asymmetry issues, design effective incentive mechanisms, and promote effective government implementation.

3.3. Auction Theory

Game theory has important applications in auction theory. Auction is a mechanism in which buyers and sellers determine the price and ownership of goods through bidding or tendering. Game theory can help understand different types of auction mechanisms and study the strategies and optimal bidding rules of participants [10]. There are three examples of game theory in auctions.

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3.3.1. First Price Closed Auction

The first price closed auction is widely used in economics with many cases. For example, in the classic stamp auction model, although the price cannot appear again, in the auction bidding, both the buyer and the seller will reach a Nash equilibrium to protect their own interests.

3.3.2. Second Price Closed Auction

The second price closed auction combines price competition with the free market and is widely used in Internet advertising bidding, online market and other markets. For example, in online advertising bidding, the advertising position obtained is the second highest price relative to the bidding position.

3.3.3. Alliance Game

Alliance game auctions usually occur when auctioneers and participants attack each other and their strategies dominate each other. In the case of non cooperative games, the merger or alliance pattern can be manifested as the formation of an alliance among the participants, or as a judgment of counterattack.

3.4. Game Strategy and Cooperative Behavior

Game theory is not only applicable to competitive environments, but also to analyzing various appropriate behaviors. Economic actors do not act independently, they not only have competitive relationships but also cooperative relationships with each other. For example, the application of the prisoner's dilemma. The prisoner's dilemma refers to the situation where two suspects, unaware of each other's choices, often give up cooperation for themselves and end up with a worse outcome. There are also many uses in real life. For example, A and B went to fetch water. If both people choose to fetch water, then they can both drink water with only half of their effort. If A goes to B but B doesn't, then A has put in effort but B can still drink water, and A suffers a loss, and vice versa. But if neither of them goes to fetch water, neither of them can drink. In an ideal situation, everyone would feel that choosing to fetch water is a win-win outcome. But it turned out that neither of them would actually go fetch water. Because both of them choose the most advantageous ideas for themselves from their own perspectives. If B draws water, A needs to exert effort to draw water, but they can still drink without drawing water. Not fetching water is a better choice. If B doesn't fetch water, A will suffer losses, and if A doesn't fetch water, they won't suffer losses. So for A, not fetching water is the best method, and for B, it's the same, so in the end, everyone will have no water to drink. This behavior of sacrificing collective interests in order to achieve personal interests will lead to the emergence of Nash equilibrium. Of course, the game in reality is infinite, and there may be participants in each round who will "punish" the betrayer in the new round due to the betrayal of the previous participant. But for the ultimate benefit, multiple participants will gradually tend to cooperate as the number of games increases.

4. Limitations of Game Theory

4.1. Limitations of Model Assumptions

The game theory model is based on a series of assumptions, such as complete rationality, complete information, etc., which deviate from the real economic situation. The general game model is a situation where both parties are equal. But in reality, there is often a game between large enterprises and small and medium-sized enterprises. The initiative is mostly in the hands of large enterprises.

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4.2. Asymmetric Information Issues

Asymmetric information is widely present in reality, which affects the accuracy and applicability of game theory models. For example, the game between buyers and sellers. For example, if the seller knows the average market price, but most buyers do not pay attention to the price, then the seller can inflate the price.

4.3. Participant Limit

Game theory models are typically applicable to a small number of participants and are difficult to handle numerous participants in complex economic relationships. In the economic market, participants are diverse.

4.4. Hidden Factors and Unpredictable Events

There are numerous hidden factors and unpredictable events in the real economy that affect the predictive ability of game theory models. For example, the subprime crisis in 2008, the global health crisis in 2020 (COVID-19), etc. These can have a significant impact on the economic market, and their occurrence is sudden.

5. Conclusion

This article discusses the application of game theory in economics and provides examples for analysis. Although most of the examples were conducted under ideal conditions and some overlooked special circumstances, they provide valuable insights for the development of real-life situations. In this article, different outcomes can be obtained through different ways of game theory in different situations such as the economic market, in order to maximize the interests of both buyers and sellers. Game theory provides people with a powerful analytical tool to understand and predict behavior in the market. Of course, in addition to this, it is also necessary to consider the environmental impacts and irrational factors in real life to ensure the effectiveness of the analysis. With the development of behavioral economics and computational social sciences, the application of game theory will become more comprehensive and extensive, promoting further development of economics.

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