Franc Meunier • James Carre
Editors

# Game Theory

## *Economics, Theoretical Concepts and Finance Applications*

Mathematics Research Developments

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MATHEMATICS RESEARCH DEVELOPMENTS

# GAME THEORY

## ECONOMICS, THEORETICAL CONCEPTS AND FINANCE APPLICATIONS

FRANC MEUNIER
AND
JAMES CARRE
EDITORS



*New York*

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# GAME THEORY

# ECONOMICS, THEORETICAL CONCEPTS AND FINANCE APPLICATIONS

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# PREFACE

In this book, the authors present current research in the study of the economics, theoretical concepts and finance applications of game theory. Topics discussed include the comparison of the game theories of Stackelberg and Bertrand and which price model is practically applicable; two cooperative solution concepts compared from a game theoretic point of view; the concept of subgame perfection; applications of game theory and evolutionary game theory in auditing; smart regulation of city cross-roads on the basis of game theory application; and game theory as applied to rights arbitration and bankruptcy.

Chapter 1 – The objective of this study was to compare two strategies – the Bertrand game and the Stackelberg game – which can be applied to prices, set by four terminals in two ports of Pakistan. Numerical results were obtained by solving the multinomial logit model. The results show that in a Bertrand game, one container terminal (KICT), despite charging higher prices, captured a higher market share compared to its competitors. The results reflect the real data on the situation in the two ports in question. Because there are differences in market shares and costs among the container terminals, this study also analyzed a hypothetical leader-follower strategy using four sub cases. These results reveal that the leader can charge a monopolist price. However, it can capture a very high market share only when it has some natural advantages over its competitors. Moreover, there is a possibility that the leader will be wrong in assuming that the others will adopt its price. On this basis, it may be concluded that the Bertrand game in prices is probably the only one that consistently assumes rational and fully informed players.

Chapter 2 – Most scientific publications on the subject of cooperative solution concepts only analyze these concepts from a game theoretic point of view. Therefore, it is often disregarded whether the cooperative solution concepts can be put into economic practice. One example for a possible application of cooperative solution concepts in practice is the fair distribution of collectively earned profits in cooperations of legally independent corporations. This chapter intends to analyze whether cooperative solution concepts are able to solve this practical problem.

In the first part of this chapter two cooperative solution concepts are compared from a game theoretic point of view. The first cooperative solution concept is the widely known Shapley value that can be described as a rather "classic" cooperative solution concept. The second one is a younger, more innovative solution concept called $\chi$-value. These two cooperative solution concepts are compared with regard to the conditions and assumptions they are based on and the characteristics of their resulting solutions, e.g. the stability of a solution.

In the second part the two cooperative solution concepts are analyzed from an economic point of view. For this purpose, criteria for a successful use of game theoretic solution concepts applied on distribution problems in economic practice are introduced, e.g. information requirements. Special attention is put on the fairness aspect, as a solution concept can only be successfully used in practice if all business partners accept the solution as fair. Lastly, a practical example is used to illustrate the specific numerical application of the two solution concepts.

The findings of this chapter are of threefold kind. First, the variety of solution concepts and their results is illustrated by the comparison of the Shapley value and the $\chi$-value. Secondly, with the help of the calculation example it is revealed which information requirements and which other criteria have to be fulfilled in order to use the presented solution concepts in practice. Thirdly, it is analyzed whether at least one of the solution concepts is more likely to be put successfully into practice than the other.

Chapter 3 – In mainstream game theory, the prominent solution concept for dynamic games is the "subgame perfect Nash equilibrium". This concept combines the mathematical method of backward induction with the assumption of common knowledge of rationality. Whereas backward induction on its own is an indisputable mathematical method, there might be problems when it is paired with the common knowledge of rationality assumption. After presenting the concept of subgame perfection, this chapter explains why several acclaimed game theorists believe that using the concept of subgame perfection might be philosophically incoherent and likely to lead to paradoxical results. On a different level, it may be argued that subgame perfection is not necessarily the unique way to approach a dynamic game, as other concepts (such as a combination of forward induction with common knowledge of rationality) might be equally, if not more, plausible. This chapter illustrates this view with a comprehensive example. Finally, as another discontent against subgame perfection, it is shown that rational players might prefer to deviate from what subgame perfection instructs them to do, as long as one of the players holds (even very small) doubts about another player's rationality.

Chapter 4 – An audit in accordance with International Standards of Auditing (ISA) should be designed to provide reasonable assurance that the financial statements as a whole are free from material misstatements. Misstatements in the financial statements can arise either by fraudulent reporting or inadvertent error. The former appear when, the government or the auditee firm manipulate on purpose financial reports in order to gain an illegal advantage, while the latter appear due to unintentional mistakes or misinterpretations in gathering or processing of data. Even though, actions should be taken for both cases to be avoided the most critical one, however, that should be detected and confronted is fraudulent financial reporting. In this chapter, initially, the fraud detection problem is formulated as a two-player game between the auditor and the auditee where the auditor aims at eliminating misstatements, reducing at the same time his audit efforts, while the auditee aims at benefiting from fraudulent financial reporting and defalcation. Then, this analysis is extended to cover the case of audit of group of financial statements. Since classic game theory formulations fail to specify: 1) how the players arrive at equilibrium, 2) whether this equilibrium is stable or not and, 3) what is the long term behavior of the auditor's tenure on the quality of auditing, an alternative formulation based on evolutionary game theory will be also presented.

Chapter 5 – Introduction of new technologies, optimizing the process of driving, is actual problem for city motion in Europe. One of the most perspective ways for improving of city logistics is application of Intelligent Transport Systems (ITS). For city transport, tactical traffic management involves monitoring the actual traffic situation in real-time (including volumes, speeds, incidents, etc.) and then controlling or influencing the transport flows using that information in order to reduce congestion, deal with incidents and improve network efficiency, safety and environmental performance, or achieve other goals. Special attention to development of ITS is connected with increasing of intensity of city transport motion. It easy to predict the situation, when city transport motion intensity will increase to such level, that any barrier on a way (cross-roads, little damage, repair works, etc.) may be a reason of traffic jams. All this leads to time and funds losses, in most degree lowers the effectiveness of transport work and makes worse the ecological situation. Recent fact is especially important for big towns, therefore in places of traffic jams appearing the concentration of exhaust gases increases in few times more.

Thus the problem of development "smart" regulation for city transport motion is actual. It is evident that complexity of properties of city transport motion makes to regard the development of ITS as many-stage problem. This paper is devoted to "smart" regulation of city cross-roads (the most common dangerous places) on a base of Game Theory.

Chapter 6 – The ancient rights arbitration and bankruptcy problems involve controversial claims and surprising judge's decisions given without any justification back then. They have generated many studies and debates. Recently, Guiasu (*Synthese*, vol.181, Supplement 1, pp.65-79, 2011) showed that the old solutions given to these problems may be completely justified using the Shapley value from the *n*-person game theory, measuring the power of each player in a game. The objective of this chapter is to give a compact and simplified version of the methodology used by Guiasu in 2011.

# CONTENTS

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***Chapter 1***

# STACKELBERG OR BERTRAND: WHICH PRICE MODEL IS PRACTICALLY APPLICABLE?

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## ABSTRACT

The objective of this study was to compare two strategies – the Bertrand game and the Stackelberg game – which can be applied to prices, set by four terminals in two ports of Pakistan. Numerical results were obtained by solving the multinomial logit model. The results show that in a Bertrand game, one container terminal (KICT), despite charging higher prices, captured a higher market share compared to its competitors. The results reflect the real data on the situation in the two ports in question. Because there are differences in market shares and costs among the container terminals, this study also analyzed a hypothetical leader-follower strategy using four sub cases. These results reveal that the leader can charge a monopolist price. However, it can capture a very high market share only when it has some natural advantages over its competitors. Moreover, there is a possibility that the leader will be wrong

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in assuming that the others will adopt its price. On this basis, it may be concluded that the Bertrand game in prices is probably the only one that consistently assumes rational and fully informed players.

**Keywords**: Bertrand game, Stackelberg game, container terminals, game theory, competition

## 1. INTRODUCTION

In an oligopoly market with homogeneous products, the Cournot model is most often chosen to describe market interaction. The Cournot model derived Nash equilibrium when firms compete in output. In a competitive situation with few players and an inhomogeneous product, however, the outcome in terms of market shares and prices can often be treated as the result of a game in which each player maximizes profit, but with due consideration of the expected reactions of its competitors. When the competitor's actions are confined to setting the prices of their own product (service), the outcome can be modeled as Bertrand equilibrium (Pindyck and Rubinfeld, 2001). Each of these static, simultaneous-decision models of oligopoly has a sequential-decision counterpart. These sequential-decision models are the result of von Stackelberg's strategic analysis of quantity setting. Stackelberg models rely on leadership by one of the rivals. Von Stackelberg originally extended the Cournot model to include leadership behavior (von Stackelberg, 1952). This means that the Stackelberg leader's output choice influences the output choices of its rivals, and the Stackelberg leader chooses output in full recognition of its followers' reactions. Von Stackelberg's insight can readily be adapted to the Bertrand pricing model. In this case, the leader would choose a price to which its followers would respond. Higgins (1996) called this the Stackelberg price-setting model (a variant of Bertrand competition) in contrast to the original Stackelberg quantity-setting model (a variant of Cournot competition).

According to Higgins (1996), price-and quantity-setting Stackelberg models result in different outcomes – market performance, industry profit, and profit allocation – from their non-leadership counterparts. In Stackelberg models, the decisions of followers and the choice of output or price by the leader are made sequentially in two stages (Shapiro, 1989; Stackelberg, 1952, pp. 190–214). In stage 2, the followers individually and independently maximize their profit functions as if the decisions of all others, as well as the leader, were given. The associated Nash equilibrium conditions effectively define the dependence of each follower's decision variable on the choice of decision variable by the leader. In stage 1, the leader chooses to maximize profit, anticipating how his choice affects those of his rivals through these same marginal conditions. Thus, the leader's decision is strategic in the sense that his choice affects his profit not only directly, as in the simultaneous decision model, but also indirectly through the influence that his choice has on his rivals' optimal decisions, which directly influence his profit (Ordover and Saloner, 1989). Thus, the Stackelberg leader's choice differs from his Nash equilibrium choice in simultaneous-decision models (Higgins, 1996).

In a Stackelberg quantity-setting model, the leader determines the quantity to produce and sell, and the followers set their own quantities to produce and sell. What if prices are the instrument of competition? In that case, there is no symmetry between prices and quantities as instruments of competitive action. With a homogeneous product, a leader can set the price. If he knows what the total market demand and the aggregate supply of the remaining producers are, it can set the price that will maximize its profit. This is actually equivalent to a monopolist, except that the leader does not face the total demand function of the market, but has to deduct the supply of the remaining producers.

What if service providers offer inhomogeneous services? One may ask, what makes the services inhomogeneous from the customers' point of view? The answer must have something to do with quality, especially the following two aspects:

- Quality aspects that the service provider can control, which usually affect the cost of providing the service
- Quality aspects that are outside the control of the service provider

In a market for service provision, quality of service may be an instrument of competition along with price. In addition, service providers may have an advantage over others, due to such natural circumstances as location. The objective of this paper is to compare two strategies that might be adopted by four container terminals at two ports in Pakistan. In the container terminal industry, competitors offer similar but, from the perspective of individual customers, not quite homogeneous services. Thus, the Bertrand (simultaneous-move) game is a natural strategy in the present setup with its differentiated services. But, due to differences in cost and market share among container terminals, is it logical to consider the applicability of a Stackelberg game? This question will be answered with the help of numerical solutions obtained by solving the model with an embedded logit model for market shares. The rest of this paper is organized as follows. Section 2 presents a literature review, section 3 describes the case studies, and section 4 discusses the model and derives the reaction functions for Bertrand and Stackelberg cases. Section 5 presents the solution of the game for the Bertrand model and for the four Stackelberg-model cases, followed by conclusions in section 6.

## 2. LITERATURE REVIEW

According to our literature review, there have been a few attempts to apply game theory to the port sector. Yap and Lam (2006) used Cournot's simultaneous quantity-setting model to derive the overall costs of using the terminal. The model was applied to analyze competition between container terminal operators in Southeast Asia: Singapore, Port Klang, and Tanjung Pelepas. As the selected ports handled a substantial share of transhipment containers in the region, Cournot's quantity-setting model was modified to account for the transhipment trade. Yap and Lam assumed linear demand functions for the terminal operators in the model. The results explained that the increasingly cost-competitive operators in Port Klang and Tanjung Pelepas were able to close the gap with PSA Corporation in Singapore in terms of the overall costs of using their terminal facilities between 1998 and 2002, although PSAC continued to enjoy a dominant share of the container-handling market in the region. Yap and Lam's paper also highlighted the tremendous amount of opportunities available to these terminal operators to advance and capitalize on their competitive advantages beyond aggressive price competition. Anderson et al. (2008) developed a game-theoretic best response framework for understanding how competing ports will respond to development at a focus port and whether the focus port will be able to capture or defend market share by building additional capacity. They applied this model to the investment and competition currently occurring between the ports of Busan and Shanghai. Unlike the analyses upon which port expansion plans are typically based, Anderson et al. explicitly accounted for the incentives and opportunities for fellow competitors to respond to investments (or the threat thereof) or to defend appropriate market share through a game-theoretic response framework. However, they did not apply a two-stage Bertrand competition model. Instead, in order to develop a game-based analysis of Busan and Shanghai port development policies, they abstracted from the pricing game, focusing instead on strategy in the development game given the observed or projected prices.

Zhang (2008) considered both the quantity and price of competition between ports and examined the interaction between hinterland access conditions and port competition. Competition between ports is treated as competition between alternate intermodal transportation chains, while the hinterland access conditions are represented by both the corridor facilities and the inland roads. When a port that is competing in quantities increases its corridor capacity, this will increase the port's own output, reduce the rival port's output, and increase the port's own profit. On the other hand, an increase in inland road capacity may or may not increase the port's own output and profit, due to various offsetting effects. Finally, inland road pricing may or may not increase the port's own output and profit. De Borger et al. (2008) analysed the interaction between the pricing behavior of the ports and optimal investment policies in port and hinterland capacity. They used the framework of a two-stage game in capacities and prices. Their main focus was on a governance structure in which capacity decisions are public, but pricing decisions are private. The game is analysed by backwards induction. De Borger et al. obtained the following results. Firstly, profit-maximizing ports internalize hinterland congestion in so far as it affects their customers. Secondly, investment in port capacity reduces prices and congestion at both ports, but increases hinterland congestion in the region where the port investment is made. Investment in a port's hinterland is likely to lead to more port congestion and higher prices for port use, as well as to less congestion and a lower price at the competing port. Thirdly, the induced increase in hinterland congestion greatly reduces the direct benefits of extra port activities. Finally, imposing congestion tolls on the hinterland road network raises both port and hinterland capacity investments.

Saeed and Larsen (2010a) applied a two-stage game that involved three container terminals located in the Port of Karachi in Pakistan. In the first stage, the three terminals must decide whether to act as singletons or to enter into a coalition with one or both of the other terminals. The decision at this stage should presumably be based on the predicted outcome for the second stage. The second stage was modeled as a Bertrand game with one outside competitor and the coalition and the terminal in the Port of Karachi (if any) that had not joined the coalition as the participants. Furthermore, three partial coalitions and one grand coalition among the three terminals at the Port of Karachi were investigated. The concepts of "characteristic function" and "core" were used to analyze the stability of these coalitions. Analysis revealed that one combination does not satisfy the superadditivity property of characteristic function, which means it can be ruled out. The resulting payoffs (profits) of these coalitions were analysed on the basis of "core". The best payoff for all players was in the case of a grand coalition. However, the real winner was the outsider (the terminal at the second port), which earned a better payoff without joining the coalition, and hence played the role of the "orthogonal free-rider."

Saeed and Larsen (2010b) used a game theory to analyze the effect that the type of concession contracts has on ports users' surpluses and on the profits of terminal operators (or port authorities). To perform this analysis, Saeed and Larsen selected Pakistan's three ports, which function as landlords and have therefore signed concession contracts with the private operators of their container terminals. However, the features of the contracts are currently different for each terminal. The results revealed that, in the long run, it is profitable for the Port of Karachi to establish a same fixed fee contract with its private terminals. However, users are better off in a situation if a percentage fee concession contract would be adopted in the long run. The game's theoretic framework was then extended to the analysis of the strategic decision that port authorities faced in terms of the trade-off between unit fees and annual rent in the last case. An optimal concession contract was obtained, which is feasible for both parties in the sense that it contains high unit fees (variable cost) and low annual rent (fixed cost). Yip et al. (2010) proposed a non-cooperative game theory model in which two terminal operators apply for terminal concessions in two adjacent ports. The modeling results suggested that a terminal operator's profit increases with its market power. Consequently, it always prefers to control more terminals in the region. However, when all terminal operators expand their operations to every competing port in the region, they will be worse off due to an increase of inter- and intra-port competition; this situation is similar to the prisoners' dilemma. When a port authority has enough market power to charge a high price from, or share a large proportion of the terminal operators' revenue, the port authority would prefer to introduce inter- and intra-port competition rather than allow one terminal operator to monopolize all terminals in the region.

Kaselimi et al. (2011) applied a game theory model to examine how terminal scale, in combination with market size, affects terminal competition. The starting point is the landlord port management system with long-term concessions agreements that shape the formal relationships between the port authority (who owns the land) and the private terminal operators (who use the land for terminal activities). A two-stage game theoretic model was developed