GAME THEORY IN AVIATION AND PORT INDUSTRY

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UNIVERSITI SAINS MALAYSIA

2015

GAME THEORY IN AVIATION AND PORT INDUSTRY

BY

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THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF SCIENCE

FEBRUARY 2015

ACKNOWLEDGEMENT

The processes of preparing this dissertation from the very first draft until the finalization stage have been one of the most significant academic challenges I have ever had to face. This dissertation would not have been possible without the patience, guidance, and support from the people around me. It is to them I owe my deepest gratitude.

First, I would like to thank Dr. Joshua Ignatius who undertook the responsibility to act as my supervisor despite his many other academic and professional commitments. The good advice and support of him has been invaluable, for which I am extremely grateful.

I would like to take this opportunity to acknowledge the academic and technical supports of Universiti Sains Malaysia (USM), particularly to the staffs from the School of Mathematical Sciences and the Institute of Postgraduate Studies. I was offer a scholarship under the MyBrain15 program from the Ministry of Higher Education (MOHE) to fund my tuition fees, thus I would like to thank MOHE for giving such a financial aid opportunity.

I would also like to thank all my colleagues and friends from within or outside of Universiti Sains Malaysia (USM), for their support and encouragement throughout. Last but not the least, my family members were the ones who have given their unequivocal support, encouraged, and believed in me, in my entire endeavour. My mere expression of gratitude to them likewise does not suffice.

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LIST OF ABBREVIATIONS

AC	Air China Limited
CAAC	Civil Aviation Administration of China
CAB	Civil Aviation Bureau
CE	China Eastern Airlines
CMC	Central Military Commission
CNAC	China National Aviation Corporation
CS	Chine Southern Airlines
JV	Joint Venture
PKL	Port Klang, Malaysia
PRC	People's Republic of China
PSA	Port of Singapore Authority, Singapore
PTP	Port of Tanjung Pelepas, Malaysia
RMB	Renminbi, official currency of the People's Republic of China
TEU	Twenty-Foot Equivalent Unit
WTO	World Trade Organization

TEORI PERMAINAN DALAM INDUSTRI PENERBANGAN DAN PELABUHAN

ABSTRAK

Kajian ini memberi tumpuan kepada aplikasi-aplikasi model teori permainan dalam industri pengangkutan dan logistik yang melibatkan 3-pemain, dalam konteks bekerjasama dan persaingan. Khususnya, model teori permainan yang berkenaan telah digunakan dalam analisis senario bagi industry penerbangan di China dan industry pelabuhan di Malaysia dan Singapura. Industri penerbangan negara China telah menghadapi pelbagai cabaran sejak dari tahun 1979, akibat daripada aktiviti-aktiviti penyahkawalseliaan dan pembaharuan ekonomi, yang memulakan transformasi industri dari sistem perancangan pusat (kerajaan) kepada sistem kapitalis (swasta). Cabaran utama yang dihadapi oleh industri ini telah ditunjukkan dari segi pelonggaran syarat kemasukan syarikat baru ke dalam industri, lonjakan syarikat penerbangan yang baru dan syarikat penerbangan asing secara tiba-tiba, serta pesaingan harga yang sengit telah mengakibatkan kerugian serius bagi industri ini pada tahun 1998. Langkah pembaharuan industri telah diambil. Pada tahun 2002, usaha penggabungan industri telah mewujudkan tiga buah syarikat penerbangan dominan: *Air China Limited* (AC), *China Southern Airlines* (CS) dan *China Eastern Airlines* (CE). Selain daripada penggabungan mandate oleh *Civil Aviation Administration of China* (CAAC), bilangan kes pengambilalihan yang berjaya bagi CS dan CE adalah sama, manakala AC mempunyai 8 kes pengambilalihan yang berjaya dalam tempoh usaha penggabungan dan pengambilalihan. Dengan menggunakan model persaingan *Cournot* 3-pemain yang bermaklumat sempurna, keputusan CAAC dari segi kecekapan strategik telah dikaji berdasarkan perbelanjaan operasi, pendapatan penumpang dan keuntungan. Ketiga-tiga syarikat penerbangan menunjukkan prestasi yang lebih baik selepas pengambilalihan. Bahagian kedua tesis ini pula menunjukkan analisis terhadap permintaan trafik laut pelabuhan pindahkapal di Malaysia dan Singapura yang terletak di laluan Timur Jauh-Eropah: *Port of Singapore* (PSA), *Port Klang* (PKL) dan *Port of Tanjung Pelepas* (PTP). Thesis ini menyediakan analisis senario melalui model teori permainan 3-bentuk interaksi. Keputusan kajian menunjukkan bahawa pakatan strategik antara PSA dan PTP menjana keuntungan yang lebih lumayan kapada rangkaian *hub-and-spoke* semasa, sementara PKL tidak perlu terlibat dalam mana-mana strategi kerjasama sama ada dengan PSA atau dengan PTP.

GAME THEORY IN AVIATION AND PORT INDUSTRY

ABSTRACT

This research focuses on the applications of 3-player cooperative and non-cooperative game theoretic models in the transportation and logistics industry. In particular, respective game theory models have been applied in the scenario analyses of the China's aviation sector and the port industries of Malaysia and Singapore. China's civil aviation industry has witnessed many challenges since its deregulation and economic reforms in 1979, which saw the beginning of a transformation from a fully state-owned machinery to a rent-seeking private sector. The major challenges of the deregulation are a lax market entry, sudden surge in new and foreign carriers, and intense price wars that resulted in major losses for the industry in 1998. A reform was sought. In 2002, mergers and consolidation efforts led to three dominant carriers: Air China Limited (AC), China Southern Airlines (CS), and China Eastern Airlines (CE). CS and CE completed about the same number of acquisitions, while AC has 8 completed acquisitions within the consolidation period other than the mergers mandated by the Civil Aviation Administration of China (CAAC). Using a 3-player non-cooperative perfect information Cournot game, the strategic efficiency of the CAAC's decisions to consolidate the industry based on operating expense, passenger revenue, and profitability are investigated. All three airlines are better off with acquisition. The second section of this thesis analyses the ocean freight traffic demand for the Far East-Europe route among three main transshipment ports located in Malaysia and Singapore: Port of Singapore (PSA), Port Klang (PKL), and Port of

Tanjung Pelepas (PTP). This thesis provides a scenario analysis to the 3-way interaction through a game theoretic model. The results suggest that a strategic alliance between PSA and PTP generates greater profitability to the current hub-and-spoke network, while PKL should not commit to any cooperative strategy with either PSA or PTP.

CHAPTER 1

INTRODUCTION

1.1 Background

This research focuses on the application of 3-player cooperative and non-cooperative game theoretic models in the transportation and logistics industry. In particular, two different game theory models have been applied respectively in the scenario analyses of China's aviation sector and the port industries of Malaysia and Singapore. This section will begin with some background introduction of China's aviation industry, which is then followed by the port industries of Malaysia and Singapore ports.

1.1.1 Background of China's Aviation Industry

Previous research have analysed the Chinese aviation industry based on its major economic and political reforms between the period 1970 and 2002 (Dougan, 2002). The evidence shows that after four stages of reform (marketization, destatization, decentralization, and globalization), the aviation industry had turned from a strictly regulated industry into a partially deregulated one. The state's authority over the aviation industry had been reduced, owing to non-state factors, such as market sentiments, pressure from local government groups, and travel needs brought about by foreign enterprises.

China's airlines were once considered to be one of the world's most unsafe airlines (Dougan, 2002). Due to the economic reformation process, the aviation industry expanded rapidly, where new entrants formed a large number of airlines. The reformations prior to the 2002 consolidation have led the industry into a situation where many new airlines, which are not under the direct control of the Civil Aviation

Administration of China (CAAC), have entered the industry. As a regulator of the industry, the CAAC was not able to monitor the safe operations of all airlines and other operational standards. In addition, with the intense price war brought about by the increased competition from the new market entrants, China's aviation industry suffered a combined loss of more than RMB 3 billion in 1998 (Dougan, 2002). The loss was due to the discounted airfares sold at an unsustainable level, even when passenger loads were high. While passenger growth in civil aviation was steady before 2002, after 2002, the industry experienced an exponential growth (Figure 1.1).

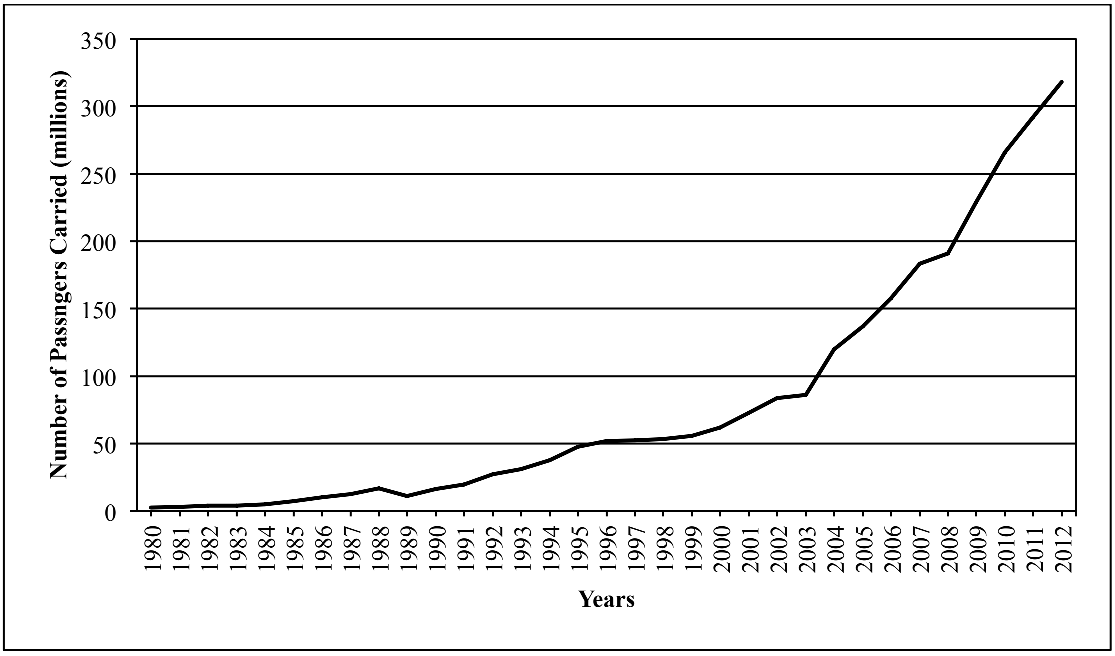

Figure 1.1 Passengers carried for China's aviation industry, 1980-2012 (Source: The World Bank, 2013)

Although the CAAC no longer retains full control, it could still enforce policy changes on the industry. The CAAC is more than a regulator and safety authority; it decides on the routes that local and foreign airlines can fly and on the development of the industry. Since 2002, the CAAC had mandated that nine airlines be reduced into three major state-owned airline companies, under a major Chinese aviation consolidation exercise (Figure 1.2) (Dougan, 2002; Shaw *et al.*, 2009). The consolidation provides CAAC with a means to regain control over the industry, as well as improve the industry's overall profitability. The three major groups were reformed under the Civil Aviation System Reform Program, and were given a chance to buy or lease more aircraft. The Big Three comprising Air China (AC), China Southern (CS), and China Eastern (CE) is a consolidation effort to manage pricing and to better plan the concentration of routed in the network (Zhang & Round, 2011). Even though their operating costs may be relatively lower than the other regional airlines, they are all saddled with inefficiencies from the consolidation process, primarily AC with China Southwest Airlines; CS with China Northern Airlines; CE with Yunnan Airlines.

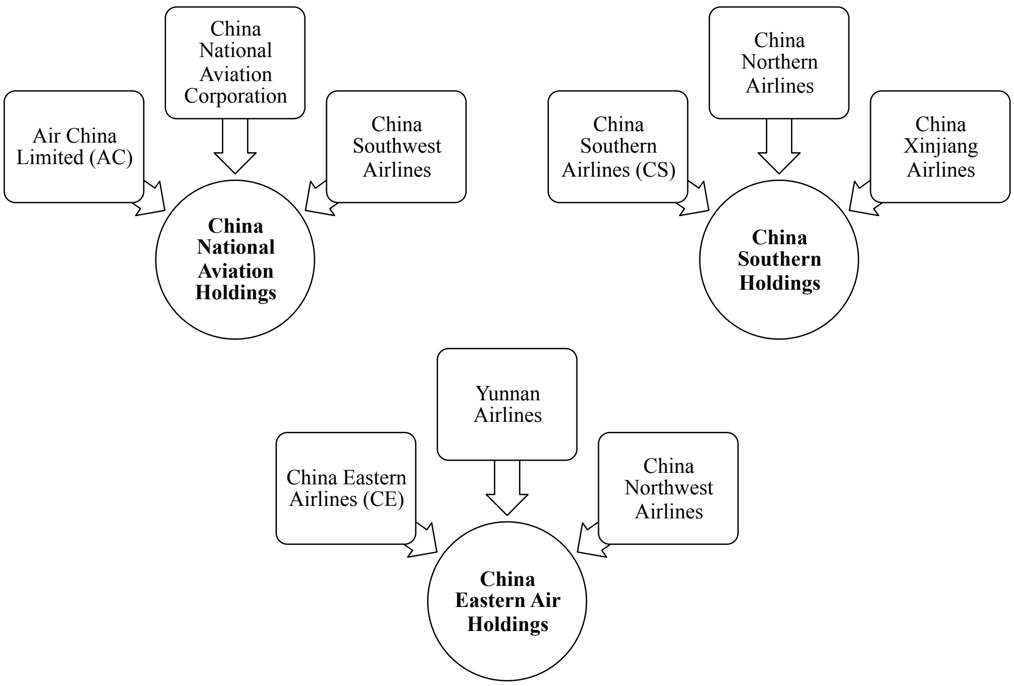

Figure 1.2 Nine smaller regional carriers forming the Big Three – China National Aviation Holdings, China Southern Holdings, and China Eastern Air Holdings

Since joining the World Trade Organization (WTO) in 2002 (Agarwal & Wu, 2004), the industry has been facing more intense competition. The mergers that took place are expected to increase industry competitiveness in a sustainable fashion, and not through further price wars. This also suggests a market correction effort by the Chinese government to ease the outcome observed from its earlier liberalization, which saw major losses in the industry due to an initial intense direct competition. Competition outside of these three major carriers is considered to be negligible, as AC, CS, and CE hold 28.9 percent, 26.6 percent, and 23.6 percent market share, respectively in terms of revenue-passenger kilometres (Chiu, 2013). This situation provides an ideal representation of an oligopolistic market.

Price deregulation took place after the three merged groups became more established, which allowed airlines to freely decide on airfares and this ended the government-controlled fare system. Therefore, the airline sector in China is an oligopolistic market structure. Through deregulation, CAAC allowed new entrants to the industry, including Hainan Airlines, which later became the fourth largest airline in China. We exclude the study of Hainan Airlines as follows. First, Hainan Airline is predominantly point-to-point flight operation while the other airlines use a hub-and-spoke flight operation. Second, Hainan Airlines is an independent airline, not owned and controlled by the state (Peng, 2010).

1.1.2 Background of Malaysia and Singapore Ports' Industry

The introduction of containerization method in the mid-1950s resulted in an efficient method of transferring goods. Containerization intensified the competitive port industry, where larger ports try to maintain their status as the industry leaders. Market expansion due to liberalization over the years and the opening of manufacturing locations in labour competitive countries has moved logistics operations globally. This paved the way for an increase in cross border networks and led to the growth of global container traffic. Table 1.1 shows the world's top 20 major container ports and their respective container traffic from 2002 to 2012. The development of container terminals in the Asia Pacific region has been more dynamic compared to the other regions elsewhere, as eight of the top 10 major world ports are located in this region. The ports of Shanghai and Singapore are the two leading container ports globally, handling 32,529 million TEUs and 31,649 million TEUs in 2012 respectively.

The globalization process fuelled by increasing international trade has led to the rapid development of the maritime transport industry. Shipping lines deploy ever-larger vessels to achieve better scale economies by reducing the unit cost per TEU. Table 1.2 shows different generations of container vessels introduced, with their respective maximum capacity. Maersk Line, the world's largest shipping company, has placed orders with Korea's Daewoo Shipbuilding & Marine Engineering Co. Ltd. to construct 20 units of Triple-E vessels (Editorial, 2013). The Triple-E vessel is the world's largest and most efficient container vessel. The new vessel got its name from the three E's, which stand for "Economies of scale", "Energy efficiency", and "Environmentally improved". Ten vessels will be delivered to Maersk Line from 2013 to 2014, with the rest scheduled for delivery in 2014 and 2015. The introduction of the E-class vessel by Maersk is expected to meet the increasing demand as well as to maintain its position as the world's largest shipping line.

Table 1.1 Top 20 major container ports globally

Rank (2012)	Rank (2002)	Port, Country	Container throughput, ('000 TEUs)		Growth rate, (%)
			2012	**2002**	**2012/2002**
1	4	Shanghai, China	32,529	8,620	277.37
2	2	Singapore, Singapore	31,649	16,941	86.82
3	1	Hong Kong, China	23,097	19,144	20.65
4	6	Shenzhen, China	22,941	7,614	201.30
5	3	Busan, South Korea	17,030	9,436	80.48
6	33	Ningbo-Zhoushan, China	16,830	1,860	804.84
7	28	Guangzhou Harbour, China	14,743	2,180	576.28
8	16	Qingdao, China	14,500	3,410	325.22
9	13	Dubai, United Arab Emirates	13,280	4,194	216.64
10	25	Tianjin, China	12,300	2,410	410.37
11	7	Rotterdam, Netherlands	11,866	6,515	82.13
12	11	Port Klang, Malaysia	10,000	4,533	120.60
13	5	Kaohsiung, Taiwan, China	9,781	8,493	15.17
14	9	Hamburg, Germany	8,864	5,374	64.94
15	10	Antwerp, Belgium	8,635	4,777	80.76
16	8	Los Angeles, U.S.	8,078	6,106	32.30
17	26	Dalian, China	8,064	1,367	489.90
18	22	Tanjung Pelepas, Malaysia	7,700	2,660	189.47
19	36	Xiamen, China	7,202	1,750	311.54
20	21	Tanjung Priok, Indonesia	6,200	2,800	121.43

Source: American Association of Port Authorities

Table 1.2 Various container vessel generations and their respective capacity

Vessel generation	Year	Vessel type	Max. length (meters)	Max. draft (meters)	Max. capacity (TEUs)
First	1956	Early Containerships	200	9.0	500-800
Second	1970	Fully Cellular	215	10.0	1,000-2,500
Third	1980	Panamax	250	12.5	3,000-3,400
Fourth	1985	Panamax Max	290	12.5	3,400-4,500
Fifth	1988	Post Panamax	285	13.0	4,000-5,000
Sixth	2000	Post Panamax Plus	300	14.5	6,000-8,000
Seventh	2004	New Panamax	366	15.2	12,500
Eighth	2006	Post New Panamax	397	15.5	15,000
Ninth	2013	Triple-E	400	15.5	18,000

Source: The Geography of Transport Systems, 3rd Edition (Rodrigue, 2013)

However, there still exist drawbacks in deploying the larger container vessels. Given the draft limits of container ports, fewer ports are able to serve the vessels directly without infrastructure improvement (Lee *et al.*, 2008) . The subject of optimal ship size has been investigated by, among others, Cullinane and Khanna (2000), with sensitivity analysis showed that shipping lines actually enjoyed economies of scale at the optimal vessel size of about 8,000 TEUs. Although medium-sized vessels are the most cost effective, larger vessels enable carriers to cope with market demand fluctuations (Gelareh *et al.*, 2013). Container ports have to project future demand into building better port equipment and infrastructure such as larger cranes and larger warehouse space in order to serve even larger vessels in the future.

1.2 Research Scope and Objectives

In the context of China's aviation industry, though the merger was initiated by the CAAC, inter-airline competition still exists, which affects the profitability among the airlines. This thesis considers a 3-player Cournot game to assess the competition among China's three airlines – Air China Limited (AC), China Southern (CS), and China Eastern (CE). Specifically, we investigate the differences in the pre-and-post merger initiative of 2002, particularly on the effects of M&As on airline profitability and to justify if the decision made by the CAAC has positive or negative externalities on the industry and the three airlines.

Moreover, the second part of this thesis's analysis focuses on the interaction of three ports from Malaysia and Singapore that are homogeneous in terms of location and their role in serving the Far East-Europe trading route. The main objective of the ports' study is to explore both cooperative and non-cooperative (competitive) opportunities that lie among the three major transshipment container ports located in the proximate region. The three ports are the Port of Singapore (PSA), Port Klang (PKL), and Port of Tanjung Pelepas (PTP). Cooperation motivation among PSA, PKL, and PTP remains unexplored in the literature. The main contribution of this research is to bring out this issue among the players specified. Anecdotal evidence suggests that competing head on among the ports may not be a sustainable strategy, especially when, ceteris paribus, cost is the main motivator for carriers to switch ports. Therefore, we investigate the possible port alliances, and whether this would generate economies of scope for the overall industry as well as contribute to the economies of scale for the individual ports.

Note that it is not our intension to develops a new theory in the transportation industry, or solving network problems in the aviation and port industries. The objective of this research is to apply cooperative and non-cooperative game theoretic models in analysing both cooperative and competitive strategies among aviation (China's Big Three) and port (Singapore and Malaysia) industries. To our knowledge, no study has been conducted with respect to the application of game theoretic model in these industries, particularly in their geographical areas. Therefore, our intention is to cover the research gap as stated above. 3-player game theory models have been applied to the study of two different transportation industries: aviation (China) and port (Malaysia and Singapore) industry. Under the scenario analysis of the Chinese aviation industry, we try to analyse whether the major consolidation effort that took place in the year of 2002 serve its purpose well in improving the profitability of the industry. Besides that, it is also our intention to find out whether there exist any cooperative opportunity that lies among the three respective ports (PSA, PKL and PTP) analysed in this study.

1.3 Organization of Thesis

This thesis is organized as follows: Chapter 2 provides an overview on the historical timeline of game theory development. This chapter also includes discussion of various game theoretic models.

Chapter 3 provides the relevant literature on several subjects, which are related to our studies. The literature begins with the discussion of mergers and acquisitions (M&As) cases in the aviation industry, follows by the general applications of game theoretic models in analysing industry cases that involve M&As and strategic alliances. Cooperative and non-cooperative approaches that have been applied in the previous studies, which are related to the port industry has been summarized in the end of this chapter.

Chapter 4 provides the industry review on China's aviation industry transformation and development. It is then followed by the methodology and introduction of the necessary Cournot game model. The methodological section provides detailed notation definitions and various scenarios correspond to the Cournot game theoretic model that has been applied in China's aviation industry. This chapter ends with the presentation of the results based on the eight different scenarios developed under the Cournot game models.

The second part of this research, which focuses on the port industry in Malaysia and Singapore, has been presented in Chapter 5. This chapter provides some industry context of the three ports involved in the analysis, which follows by the methodology and the presentation of the mathematical formalization of the game theory model with its relevant assumptions. The findings have been discussed to make complete to this chapter.

Chapter 6 concludes the study with a discussion on managerial implications and suggestions for future research.

CHAPTER 2

AN OVERVIEW ON GAME THEORY

2.1 Introduction to Game Theory

Game Theory is a study of applied mathematics, a branch under the field of Operations Research, which is concerned with how rational individuals make decisions when they are mutually independent. Game theory models involve mathematical modelling of strategic behaviour with the combination of ideas and theorems to provide a rational basis for resolving conflicts, both with and without cooperation. The fact that individuals are bound to be in conflict with important decisions illustrates the importance of game theory. It provides a framework for analysing situations in a more rational perspective and to formulate alternative choices depending on various circumstances.

2.2 Brief History of Game Theory

Dimand and Dimand (1996) provides a detailed literature on the development of game theory. Their discussion covers the work before the analytical work, 'Theory of Games and Economic Behavior' written by Von Neumann and Morgenstern (1944). In this chapter, we will be giving only a brief discussion on the several important milestones in game theory.

The initial concept of game theory is derived from probability theory. Game theory began with the idea written in the letter by James Waldegrave to Pierre Rémond de Montmort in November 13, 1713. Waldegrave provided the first known mixed strategy solution of a matrix game for a card game, *le Her*. The principle of minimax strategy has been introduced to solve the game. Therefore, the mixed strategy game, which is based on the concept of probability, is considered as one of the important initiative of game theory. However, the minimax theorem had not been further applied to other areas (Dimand & Dimand, 1996).

Game theory deals with mathematical modelling of conflict and cooperation. Formal mathematical analysis of conflict emerged from World War I in the writings of 'Aircraft in Warfare' by Lanchester (1916) and 'Mathematical Psychology of War' by Richardson (1935). Lanchester's work examined how to win battles by choice of appropriate strategy such as concentration of forces, while Richardson attempted to understand the dynamics of arms races and the statistics of outbreak of wars as aids to prevent war. He analysed conflict in order to produce peace.

In the year 1928, John Von Neumann managed to provide the general proof of the existence of minimax solution concept (Von Neumann, 1928). The concept of minimax was then used to solve strategic form games. Von Neumann also provided a comprehensive and formal concept on game theory. Game theory started to gain prominence when the 'Theory of Games and Economic Behavior' written by Von Neumann and Morgenstern (1944) was published. This publication is usually credited as the origin of the formal study of game theory. Most of the earlier works were working on specific problem rather than on constructing a mode of thought, which had little influence until the published work of 'Theory of Games and Economic Behavior'.

However, the concept of equilibrium used in game theory is attributed to Cournot (1838) to duopoly models. In 1950, John Forbes Nash Jr. introduced and proved the concept of (Nash) equilibrium in his PhD. thesis named 'Non-Cooperative Games' (Nash Jr., 1950). Nash introduced the concept of (Nash) bargaining solution for coalitional games in 1951. The Nash equilibrium concept introduced is generalized for both non-cooperative and cooperative games. Each player's strategy is optimal in the Nash equilibrium. Regardless of what other players' choice of strategy, no players will have the incentive to deviate from the optimal strategy in the Nash equilibrium.

Lloyd Shapley, who was Nash's peer at Princeton University, introduced the concepts of Shapley value and the core, which are solution concepts for cooperative games, conceived by Edgeworth (1881). The concept of Shapley value was introduced to determine the power of the members of the United Nations Security Council. The paper published by Shapley and Shubik (1954) represents one of the earliest explicit applications of game theory to political sciences.

Game theory became accessible to a wider audience with the publication of the 'Games and Decisions' by Luce and Raiffa (1957). Throughout the years, game theory has been applied to a wide range of behavioural analysis studies, mainly in warfare, economics, political science, psychology, evolutionary biology, real world business decision, transportation industry, and many more. In order for researchers who lack the mathematical background to further understand and apply the concept of game theory, there exist some references such as 'Game Theory and Political Theory: An Introduction' (Ordeshook, 1986), 'Decision Making using Game Theory: An Introduction for Managers' (Kelly, 2003) and many other references that focus more on the basic ideas and formulation of game theory, without putting too much emphasis on the theorems such as the ones in 'Theory of Games and Economic Behavior'.

2.3 Elements of A Game

Game theory models are high-level abstraction of real-life situations. These models consist of three basic elements; they are the players, strategies, and payoffs. By player, we refer to any two (or more) interdependent variables, including individuals, companies, countries, or even animals, which makes rational decisions (at least conceivable to us humans) in the game. The strategies refer to the available options or choices for each individual in the game. Finally, the payoffs denote the outcomes (rewards or penalty) received by each individual in the end of the game depending upon what other individuals' choices. Note that each player's payoffs may correspond to monetary reward, such as profits, revenue, etc., or the utility (satisfaction) of each player in the end of the game.

Any situation that involves decision makers with a certain set of decision choice can be illustrated as a game, and analysed by using game theory. Players' strategies, objectives, and their potential payoffs will be analysed systematically in a game. Therefore, game theory replicates models of rational decision-making situations in reality. However, real world scenarios are often more complex. The application of game theory resembles an extreme simplification model of real world situations (economics, business, biology, crime, war, etc.) with some defined assumptions. Such simplification is to make the resulting models more tractable. From the definition itself, we know that game theory is a study of how rational players make their decisions when they are mutually independent. Therefore, the two assumptions that are to be made in order to apply game theory are rationality and mutual independence.

Individuals are said to be rational when they seek to maximize their welfare, vice versa. Individuals who make their decision with respect to their own self-interest are assumed to be rational. Due to the complexity that lies among the decision-makers, this assumption may seem to be unrealistic, since in reality, individuals are not always rational while making decisions. However, the assumption of rationality is necessary to narrow down the range of possibilities, while obtaining the long-run equilibrium of the game, which works best for the players.

In the context of the assumption of mutual independence, the welfare of any player is assumed to be at least partially determined by the actions of other players in the game. Each player's decision will directly affect their own payoffs, while affecting others' payoffs. In the context of non-cooperative games, none of the player can be better off without making someone else worse off. However, in games involving incentives among the players to cooperate, all players could be better off at the same time.

2.4 Game Theoretic Models

This section will provide the general taxonomy of game theory concepts. The division of game theoretic models are based on several dimensions, which we will discuss them in the following subsections.

2.4.1 Non-Cooperative vs. Cooperative Games

The available strategies of the players are the ones that determine whether the game is a non-cooperative game, or a cooperative game. A game is cooperative when there exist possible joint actions among the players. On the other hand, it is impossible for the players to form binding commitments in a non-cooperative game. A non-cooperative game has also been denoted as a competitive game.

2.4.2 Strategic Form vs. Extensive Games

A strategic form game (also known as normal form, static or simultaneous games) is a game model in which all players made their decisions simultaneously, without knowing the strategies of other players. By contrast, an extensive form game (also known as dynamic form or sequential games) model illustrates the situation where players made their decisions in a specific order of the game. The representations of these two types of games are different as well. The normal form games are often represented in payoff matrices, while the extensive form games are represented in decision trees to show the sequential decision moves of the players. In extensive form games, players take turns to make decisions at different node in the decision tree.

2.4.3 Games with Perfect vs. Imperfect Information

In the games with perfect information, the players are fully informed about each other's strategies. However, only sequential games will be the games of perfect information, since the players of a simultaneous game do not know the strategies played by the other players. In the games with imperfect information, they may be imperfectly informed, or totally not informed at all about others' choices.

2.4.4 Taxonomy of Game Theory

In general, game theory can be divided into two broad areas, named the non-cooperative games (or competitive games) and the cooperative games (or coalitional games). Within the literature, a distinction can also be made between strategic form games (or static form games) and extensive form games (or dynamic form games), as well as by the type of informational structures, whether the games have complete or incomplete information and also perfect or imperfect information.

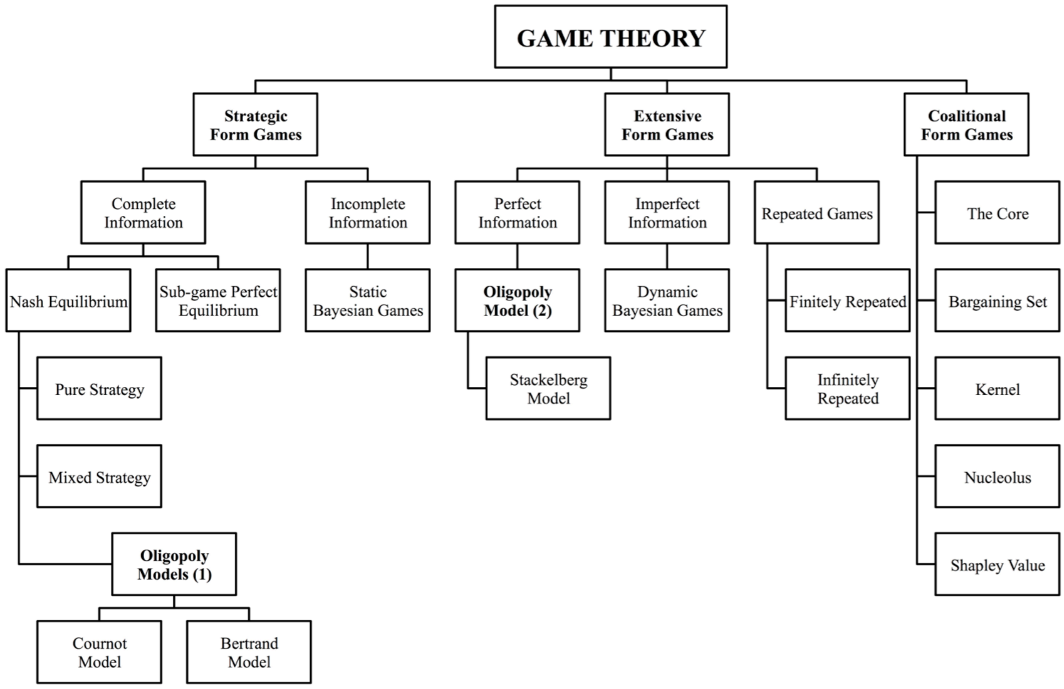

Figure 2.1 Taxonomy of game theoretic models (based on compilation by author from various source of references)

Games with perfect information is often confused with games with complete information. Both are distinctive in concept and application. In games with complete information, the available strategies and payoffs of all players are commonly known. However, the players may not have any information on how other players will choose their strategy from the available choices. On the other hand, in games with perfect information, the other players may not know the available strategies and payoffs of other player, but every single move from each of the player will be perfectly observed by others.

Generally, strategic form games consist of a set of n players, where each player has their own set of strategies, S_i. Each player's payoffs are dependent on their respective choice of strategies, and also with respect to all the other n players' choice of strategies. Therefore, players would have to construct their best response function, considering all other possible configuration of strategies of other players.

There are two types of strategies played in strategic form games; they are the 'pure strategies' and 'mixed strategies'. In games with pure strategy solution, players will always play a specific strategy that lies in the Nash equilibrium; while in games with mixed strategy solution, players will play their strategies randomly according to a specified probability. Nash Jr. (1951) proved that every non-cooperative game has at least one equilibrium point, in both pure and mixed strategies. The strategies that lie in any Nash equilibrium is the point where each player are better off regardless of what other players will choose for their strategies. Therefore, no rational players have the incentives to deviate from the strategies in Nash equilibrium of the game. Nash equilibrium remains the most widely used game theoretic concept in this day.

Another type of equilibrium other than Nash equilibrium is the sub-game perfect equilibrium, which was developed by Selten (1965). Sub-game perfect equilibrium is the equilibrium that was determined by solving the game using the method of backward induction, in which the optimal strategies of players are determined from the end of the tree. Application of sub-game perfect equilibrium in strategic form games yields the concept of forward induction. Note that sub-game perfect equilibrium solves dynamic games and is always applied to pure strategies and not mixed strategies. When sub-game perfect equilibrium exists in mixed strategies, it is called the sequential equilibrium concept.

In duopoly market structure, there exists two competing firms that produce homogeneous products and services in the market. Competition among firms can be separated into price competition and quantity competition. In general, there are three different models in the studies of game theory that are commonly used to analyse the competition of duopoly (2-player competition) and also oligopoly (n -player competition) market structures, namely the Cournot, Bertrand, and Stackelberg models. Note that both Cournot and Bertrand models are categorized as strategic games, while Stackelberg model is under the category of dynamic games.

Cournot (1838) anticipated the definition of equilibrium and applied it in the context of duopoly model. The concept of equilibrium has been formally proved and extended by Nash Jr. (1950). Cournot model is used to analyse the competition where firms are competing against each other in terms of quantity. In Cournot model, firms choose their quantities simultaneously; having each player's decision will affect other players' payoffs.

Bertrand (1883) suggested a different model than Cournot model, in terms of strategies available, payoff functions, and behaviour of the players in the game. In Bertrand model, firms are actually competing in terms of prices simultaneously, rather than quantities as in Cournot model.

Von Stackelberg (1934) proposed a dynamic Stackelberg model of market competition in which a dominant (leader) firm makes his first move followed by subordinates (followers). Firms are assumed to compete against each other by choosing their strategies in terms of quantities in Stackelberg model, as in the Cournot model, but sequentially. However, Stackelberg model can be further extended to analyse price competition model, as in the Bertrand model.

In the book published by Luce and Raiffa (1957), the authors drew particular attention to the fact that the assumption of complete information is rather unrealistic in practice. Therefore, the concept of Bayesian Nash equilibrium was developed by Harsanyi (1967-68) in order to solve strategic games with incomplete information, where each player's payoffs are no longer a common knowledge to other players in the game, in which the payoffs function of a player is uncertain and not known by others. Strategic games with incomplete information are also known as static Bayesian games. The concept was extended by Fudenberg and Tirole (1991) and named Bayesian perfect equilibrium, which is applicable to dynamic games with imperfect information.

Repeated games are essentially strategic form games that are played twice or more times instead of once. A finitely repeated game has the number of times the game being played to be a fixed with a finite number. The concept of Nash equilibrium and sub-game perfect equilibrium are applied to solve finitely repeated games.

Infinitely repeated games are games where players played against each other over an infinite number of times. Since the infinitely repeated games has no end, methods of backward induction and obtaining a sub-game perfect equilibrium is impossible. Therefore, Nash Folk Theorem is necessary to solve the infinitely repeated game, where the game will stop if only any of the players deviates from the agreed sequence of actions. All the players will choose to stop the game as a punishment to the deviant of the game (Osborne & Rubinstein, 1994). On the other hand, Fudenberg and Maskin (1986) developed the Perfect Folk Theorem to solve infinitely repeated games, where the threats of punishment must be credible. In the Perfect Folk Theorem, if the punisher does not punish the deviant, then the punisher is punished.

Coalitional or cooperative games show that there exists possible actions for at least some or all players to cooperate among each other. Nash initiated an important research agenda named the 'Nash Program' in 1953. The initiation of the 'Nash

Program' is to bridge the gap between the two counterparts of game theory (non-cooperative and cooperative games). 'Nash Program' claims that all coalitional games can be reduced to a non-cooperative formulation. Contrary to this notion is what may be termed the 'Aumann Program', which claimed that; at least two or more players may have a common interest in ganging up against the other players in the game when there exists more than two players in a game.

In coalitional games, there are several types of equilibrium concept, depending on the structure of the games. Generally, they were divided into several models and alternate solution concepts for coalitional games: the core, the stable set, the Nash bargaining sets, Shapley value, and the nucleolus. In a simple objection coalitional game, an equilibrium is broken if any one of the players deviates from the equilibrium's allocation. The coalitional game is divided into two types; they are the games with transferable utility and games with non-transferable utility.

In coalitional games with transferable utility, the value function gives the total payoff to the coalition, which is to be allocated among the players within the coalition in a pre-defined way. However, the non-transferable utility coalitional games show nothing about the allocation of the total payoff of the coalition, where the players are not sure of their respective payoff when joining the coalition. A game with non-transferable utility is a more general game comparing to a game with transferable utility.

A cohesive coalition ensures that the payoff gained by any player in the coalition to be greater than the payoff that the player gains from involving in any other coalition (including sub-coalitions) or remain alone. The core is an equilibrium and solution concepts for coalitional games that require no set of players are able to break away and take a joint action that makes all of them better off. The core is also a subset of the stable set, where the outcome of the core solution is said to be a stable solution if no coalition can deviate and obtain a better payoff for all its members (deviants). It is assumed that any deviation occurs in the game will end the game, ignoring the fact that any deviation by a player may trigger other players to react against it that will lead to a different final outcome.

Contrary to the core, other solution concepts allow players in the coalitional game to deviate from the solution, where each possible deviation may lead to a stable outcome or be balanced by a counter-deviation. There are two approaches in this area. The first approach involved the solution concept of the stable sets. In this approach, any objection or deviation made by the players in the coalitional game will lead to an alternative outcome. This alternative outcome is constrained to be the stable set outcome, where no coalition will lead the players to achieve better payoffs, with alternative stable outcome. A coalitional game may have multiple stable sets. However, when the core itself represents a stable set, then there will be only one stable set, which is the core itself.

However, the second approach illustrates the solution concepts of the Nash bargaining sets, the Kernel, and the Nucleolus, which show that any deviation (or objection) in a game will be cut short after two stages (Maschler, 1992). The game will regain its stability with a balancing counter-objection. The counter-objection is unlike the situation in the stable set, in which the objection moves to the point where the player deviates. Rather, the counter-objection in this approach suggests a different point, which allows players to perform better than the point where the deviant deviates. Different notions of objection and counter-objection give rise to a number of different solution concepts. Before proceeding to the next section, we first define Player 1 as the player who objects, while Player 2 as the player who counter-objects in order to obtain a better description of the solution concepts.

Both the objection and counter-objection in the case of the bargaining set is between Player 1 and Player 2, in which when Player 1 is dissatisfied with the current coalitional allocation against Player 2, Player 1 will form his own coalition that exclude Player 2. Meanwhile, Player 2 will counter-object by forming another coalition of his own (by excluding Player 1). Since each objection and counter-objection must exclude the player who are to be objected to, then the core is defined as the set of allocation where no objections or counter-objections by the other players.

The Kernel case is defined when the objection and counter-objection is between Player 1 and a coalition formed by Player 2 that excludes Player 1. Note that when Player 2 forms a counter-objection coalition against Player 1, the total payoff gained by the coalition members when Player 1 objects is less than the total payoff gained when Player 2 counter-objects by forming coalition against Player 1. The difference between the bargaining set and the Kernel is that the objection and counter-objection in the Kernel case requires the consideration of the total payoffs of all the members in the coalition and the total gain (or loss) of a coalition's move.

The objection and counter-objection in the Nucleolus case is between coalition and coalition (Schmeidler, 1969). An objection by a coalition formed is assumed to yield better payoff than the original ones, while the counter-objection coalition formed against the objection coalition suffers a loss. This case is rather different from the previous two cases (the bargaining set and the Kernel); it is essential to minimize the loss of the counter-objection's coalition formed in the Nucleolus case.