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Game Theory and Its Applications in The Global Oil Industry

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D e c l a r a t i o n

I hereby declare that I am the sole author of the thesis entitled:

„*Game Theory and Its Applications in The Global Oil Industry*"

I duly marked out all quotations. The used literature and other sources are stated in the attached list of references.

In Prague on March 12, 2016

I would like to thank doc. Ing. Bronislava Hořejší, CSc. for her academic guidance, helpful advice and valuable comments while writing this thesis.

Title of the Master´s Thesis:

Game Theory and Its Applications in The Global Oil Industry

Abstract:

This thesis will enable the reader to see how applications of game theory can help understand the development in oil market. Firstly, the thesis will introduce to the reader the foundations of game theory, a branch of microeconomics studying strategic interaction. Special focus will be put on the theory of oligopoly, the most important collusive and non-collusive models of oligopoly and their similarities and differences. Secondly, the thesis will show the reader how these theoretic models can be applied to the past development within the global oil industry, most prominently on the Organization of the Petroleum Exporting Countries. Finally, the thesis will present possible applications of game theory and some of the models to the oil market after the price decrease which started in 2014. This would help the reader assess the potential outcomes of the current crisis and possible development in the future.

Key words:

Game Theory, Oligopoly, Oil, OPEC

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Abbreviations

BP .... formerly British Petroleum
D .... Demand
EIA .... U.S. Energy Information Administration
GDP .... Gross domestic product
IOC .... International oil company
MC .... Marginal cost
MR .... Marginal revenue
NOC .... National oil company
OPEC .... Organization of the Petroleum Exporting Countries
P .... Price
PdVSA .... Petróleos de Venezuela, S.A.
Q .... Quantity
TC .... Total cost
TR .... Total revenue
UAE .... The United Arab Emirates
US .... The United States of America
WTI .... West Texas Intermediate
WWII .... World War II
Π .... Profit

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Introduction

Since the oil price decrease has started in 2014, there has hardly been a day when oil prices and oil industry development would not be covered in the news headlines. Oil is an essential resource for individuals, firms and entire countries, and the development of its price is therefore closely watched and scrutinized. On the individual level, consumers generally welcome lower oil prices as they can consume other goods for the money they do not spend on oil, or save more money than they otherwise would. The companies who use petroleum as a resource welcome the oil price fall as well, for similar reasons as the individuals. However, the oil producers have to tighten their belts and operate at much lower profit, if not at a loss. The oil exporting countries are hit especially hard by the low oil prices as their budgets often rely heavily on oil exports. With oil being sold today for roughly a third of its price less than two years ago, the long-planned budgets can easily fall into deficit.

It was the foundation of the Organization of the Petroleum Exporting Countries in 1960 that has to a great extent enabled the unification of major oil exporting economies. This contributed significantly to the oil crisis in 1970s, which has shaken the world economy and has strengthened the position of the oil exporters. The current *oil crisis*, as the development is perceived by these countries, has the potential to be a watershed. The changes the crisis can bring may once again reshape the landscape of the global oil industry as we know it now.

For these reasons, the author of this thesis recognizes the potential and importance of the oil industry and of the current oil crisis. That is why the oil industry has been selected as the focal point of this thesis. To be able to understand why the players in the market behave the way they do, the thesis will use the theoretical models and concepts of game theory, a branch of economics which studies strategic interaction.

The first chapter of this thesis will be dedicated to the principles of game theory. The foundations of game theory will be presented and explained for the reader's convenience. In this section of the thesis the author will explain what the term *game* means in the terminology of game theory, and which types of games are recognized by this branch of science. Furthermore, key elements of the games will be described and emphasis will be put on strategies which the players can play in the games.

The second chapter of the thesis will be used for extending the theoretical basis of game theory laid out in the first chapter. The focus will, however, be much narrower. In this section, the most important oligopoly models will be described. In the second chapter, space will be provided for covering not only collusive and non-collusive oligopoly models, but also models in which decisions are made simultaneously and those where they are made sequentially. Since it is crucial to understand what makes one model more apt for describing the market than the other models, the differences between the particular models and their assumptions will be compared and emphasized. This will later on enable verification of the assumptions while applying the models in the practically oriented following chapters of the thesis.

The last two chapters will provide room for application of chosen game theoretic models to OPEC in different stages of its history in the third chapter, and their application to the global oil crisis 2014-2016 in the following fourth chapter. The third chapter will help the reader understand how the players in the global oil market interacted in the past and to what extent they were able to influence the oil prices. The objective of the third chapter is to verify which of the oligopoly models (if any) can be used to explain the behavior of OPEC countries. Connected with this objective is the objective of the following chapter, which will conclude this thesis. In the fourth chapter, we will aim to explain the current oil market crisis through the applications of game theory and the models included in the second chapter in order to see if the crisis could be solved using game theory. We will also aim to answer the question why the game theoretical models often fail to foresee future development in the market, and why they are unable to exactly predict the consequence of a player’s actions.

In general, this thesis should provide the reader with knowledge of what game theory is and how it can contribute to understanding the strategic interaction of the players in oligopoly markets. The theory presented to the reader in the first two parts of the thesis will be applied on the historic development of the global oil industry, and especially on particular stages in the history of OPEC. Finally, the thesis will be concluded with a chapter in which implications from game theory will be used for assessment of the current oil crisis.

1 Game Theory

Game theory is a branch of economic theory that studies strategic interaction. It finds application in a broad variety of real life situations ranging from interpersonal interaction (e.g. kids playing rock-paper-scissor), through interaction of multinational companies (e.g. wars for market share of Coca-Cola Company and PepsiCo) to interaction of blocs of states (such as the Western and Eastern bloc during the Cold War). Game theory has come to prominence during WWII, when it was used as a means for studying military strategy of belligerent parties, and has remained one of the focal points of economic theory since then. The modern foundations of game theory, however, were already laid in the 1920s by American physicist and mathematician John von Neumann who formalized some of the fundamental notions in this field. Together with Oskar Morgenstern, a German-born American mathematician, von Neumann developed further concepts and theories applicable to the interaction of the Allies and the Axis during WWII. Finally, some of the crucial developments of game theory were brought by the work of the late John Nash, who in his 1950 treatise on non-cooperative games introduced a concept of equilibrium which we now know as the Nash equilibrium (Dutta, 1999).

Before we get into detail to explain what the Nash equilibrium is and how it can be found and applied, it would be convenient to provide an explanation of what is understood under the term game in the sense of game theory, and how games can be divided according to their characteristics.

1.1 Games

As we have said already, game theory studies strategic interaction. Games are therefore situations involving strategic interaction, or, more precisely, simplified models of these situations, which can nevertheless be fairly complicated. Games are typically described as consisting of four basic components - players, payoffs, strategies, and information (Nicholson & Snyder, 2010). In a nutshell, players are the ones who make decisions in games, i.e. they can choose from different possible actions (e.g. PepsiCo deciding about its pricing strategy in the aforementioned example). These decisions are based on the possible payoffs that the players would obtain as the returns at the end of the game (e.g. PepsiCo winning over the whole Czech market for soft drinks, which would bring, say, €100 million annually). These payoffs are not necessarily monetary, but for simplification we will assume that they are only monetary. A mathematical function that describes the payoff a player would obtain from a given outcome of a game is called a payoff function. The set of choices or decisions that the player makes in a game, and which result in the player's actions, is called a strategy (e.g. PepsiCo withdrawing from the Czech market if Coca-Cola Company invests €100 million in advertising is an example of action which is a part of a broader strategy). The player's actions in a given game largely depend on the information that the player has about the game or, more specifically, what the player knows about the actions of the other player (e.g. a kid playing rock-paper-scissors would most probably deviate from playing each of the three options at random if she already knows what her opponent is going to play). Now that we have briefly outlined what games are and which elements they consist of, we may explain which types of games are recognized in game theory and where the differences lie between the particular types.

1.1.1 Simultaneous and Sequential Games

One of the most important qualities we need to learn about any game is the timing of the players' actions, i.e. whether the game is simultaneous or sequential. In a simultaneous (or also static) game the players play their actions simultaneously, that is at the same time. This means that at the time when the player needs to decide which action he or she is going to play, he or she does not know what the other player plays. No new information is disclosed in the game until the players play their actions. A typical example of a static game of two players is the well-known rock-paper-scissors game, where the players have to choose their action and reveal it simultaneously, i.e. without the ability to alter their action based on what the other player plays.

In a sequential (or also dynamic) game, on the other hand, the order of the players matters, because it determines which of the players will have the advantage of new information available for his or her decision making in comparison with information available for the first-moving player. The second player obtains new information regarding the first player's action, based on which he or she chooses his or her action in response, opting for the alternative which yields the best payoff for this particular situation.

1.1.2 Role of information in games

The role that information plays in games is no less important that the role of timing described in the previous paragraph. Firstly, the information available to the players may be complete or incomplete, referring to the knowledge of the other players' payoffs from the game, or to other game-relevant information. Thus, if the information is complete, the player knows what payoffs are associated with individual actions of the other player. Conversely, in a game of incomplete information, the player has more information about herself than the other player does - a vivid example is almost any card game, in which the player knows which cards are in her hands, but does not know which cards the other players hold.

The completeness and incompleteness of information should not be, however, mistaken for perfection and imperfection thereof. In a game of perfect information, the players can observe the other players' actions at any point in the game, i.e. the player knows the full history of the game at the point when he needs to make a move. In a game of imperfect information, opposite to this, the player who is making a move in the game does not have complete knowledge about the full history of the game (Gibbons, 1992).

1.1.3 Single-stage and Repeated Games

To characterize a game, and to be able to analyze and predict the players' action, it is vital to know if the game consists of one round only - such game is called single-stage game, or if the game has more rounds, then it is a repeated game. In a repeated game, the players who elaborate their strategies need to bear in mind, among other things, that they could be "punished" by their opponent if they chose their action undesirably or unfairly to the other players. In a specific case where the game is repeated for infinite number of times, or when it is repeated for a previously unknown number of times, the repetition itself provides an incentive for the players to play cooperatively, in contrast to choosing action based solely on their self-interest. This is the case, because the prospect of a long cooperation with stable payoffs is typically more valuable than higher immediate payoff with the prospect of lower payoffs for the rest of the rounds resulting from the lack of cooperation. We will follow up on this concept later on when discussing trigger strategies.

1.1.4 Cooperative and Uncooperative Games

As we can understand from the previous paragraph, one of the possible divisions of games is the one based on level of cooperation between the players. In cooperative games, the players are able to enforce a cooperative behavior, and the group thus reaches an outcome best for the group as a whole. In non-cooperative games, on the contrary, the players are driven only by their self-interest, not bearing in mind the group's well-being in itself.

1.2 Strategies

In point 1.1 we have already outlined that the set of choices or decisions that the player makes in a game, and which results in the player's actions, is called a strategy. In other words, strategy is an algorithm that tells the player which move to make at any point of the given game where the player is required to take an action (Dutta, 1999). A strategy according to which all moves are determined in advance, i.e. a strategy telling the player specifically which move to make in any specific situation that could arise in the game, is called a pure strategy. A mixed strategy, by contrast, does not determine specifically which move will be taken in any given situation, but it assigns probabilities to particular pure strategies for the game. Mixed strategy is thus indicating the probability at which the player will play a given strategy. It can be noted that a pure strategy is just a specific case of a mixed strategy, where the probability of the respective strategy is 1 and of other strategies is 0.

One of the axioms of microeconomics is that any rational individual wants to maximize his or her utility. Players of games obtain their utility from receiving payoffs, and therefore aim at maximizing the payoffs in order to maximize the utility. When the player wishes to maximize utility, he or she needs to take into account the moves the other player or players will make. Since the player can rarely be sure of the move the other players are going to make, he or she needs to think of his responses to all possible situations that might arise from the other players' actions. This idea leads us to a concept known in game theory as the best response.

1.2.1 Best response and equilibrium

The definition of the best response is very simple and intuitive – a player's strategy is the best response against another player's strategy if the player cannot earn higher payoff from any other strategy given what the other player is playing. The concept of the best response is prominently used in game theory to define equilibrium. Equilibrium, in microeconomics, marks a situation where the market demand and market supply meet and are equal. In this situation, no market player has an incentive to deviate from his or her current behavior. The equilibrium concept most widely used in game theory is the Nash equilibrium, named after John Nash, the prodigious mathematician mentioned in the introduction of this chapter. The Nash equilibrium is a set of strategies of the game's players, which are best response to each another. This effectively means that no player can be better off by altering his or her strategy unilaterally. This absence of incentives to deviate from this strategy effectively means that Nash equilibrium provides a stable solution to games. Despite the fact that there is not enough room in this thesis to prove this theoretical concept, it is worth noting that the Nash equilibrium can be found for any game (Nicholson & Snyder, 2010).

1.2.2 Dominant strategy

Dominance of a strategy is such quality of the strategy, which results in the strategy prevailing over other strategies. But how can a strategy dominate and prevail over others? As was explained earlier in this text, a rational player seeks to maximize his payoffs. A strategy that constantly yields higher payoffs than any other strategy, regardless of what the other players do, is said to be dominant, and the strategies which are not dominant are called dominated strategies.

1.2.3 Trigger strategy

When discussing single-stage and repeated games, we mentioned that if it is the case that the game is to be repeated for infinite number of times, or for a previously unknown number of times, the players might achieve better outcome playing cooperatively than if they choose higher short term payoffs instead. The underlying reason for this is that when a player of a repeated game chooses to deviate from an established cooperative outcome, he or she may trigger reaction from the other player of the game which aims at punishing this undesirable behavior. In game theory, such behavior would be a part of so called trigger strategy, where the players play cooperatively until one of them breaches this rule, and thus triggers a change in strategy of the other player.

Trigger strategies can be differentiated by the length of the period for which the punishment lasts. The hardest punishment is staying with the punishing strategy for the rest of the games, which potentially means for infinite number of following games. As this strategy is used for all the following games, and as it results in lower payoffs than playing cooperatively would provide, it opens up grim prospects for the player deviating from the cooperative strategy (and for the punishing player as well). Hence, it is called the grim trigger strategy.

The opposite of the grim trigger strategy within the trigger strategies is a so called tit-for-tat strategy. Under tit-for-tat strategy, the length of the punishment period depends on the punished player's behavior. If he or she reverts to the cooperative strategy, the punisher reverts to it as well, if he or she remains uncooperative, so does the punisher. In other words, the player playing the trigger strategy will adjust his or her strategy correspondingly to the strategy that the other player pursued in the round before (Osborne, 2004).

In this chapter, we have introduced the reader briefly into the complex world of game theory. Before we look into how these theoretical concepts are reflected in real world, we would like to draw the reader's attention to another concept of economic theory - the market structures and the outcomes they create.

2 Market structures and their outcomes

In this chapter, we would like to briefly summarize to the reader the main features of the economic concepts of different market structures, as understanding them is crucial for grasping the matter discussed in further chapters in this thesis. When market structures are discussed, we speak about fundamental characteristics of the market which influence, among other, how the market works, if or not the market players are able to exert any market power, and thus influence the price, or the fact if and how the market players are organized. There are four market structures for output markets which we will introduce here - perfect competition, monopoly, monopolistic competition, and oligopoly. The defining characteristics according to which we differentiate between them are the number of firms in the market, product homogeneity/differentiation, barriers to market entry, short and long run profits, ability to influence market price (i.e. if the firm is price maker or taker), and possibility of non-price competition.

2.1 Basic types of market structure

First, let us see a predominantly theoretical, nevertheless very important type of market structure - perfect competition. In perfect competition, there is a very large number of market players who produce a homogeneous product. Since there are no barriers to entry, new players enter the market whenever they can achieve short run economic profits there, which results in impossibility to achieve long run economic profits. Similarly, if there is negative short run profit in the market, firms will exit the market and enter other industries instead. This leads to lower supply which in turn pushes the price to a new equilibrium where economic profits are zero again. Since all firms supply homogeneous products, there is a large number of perfect substitutes for the firm's product, and the firm cannot influence the price of its production (if the firm set a price above the market price, it would not be able to sell its products).Therefore, the firm acts as a price taker. Also, non-price competition is impossible, since no product differentiation is possible, and money invested in advertising would only increase the costs without influencing the quantity sold of the products.

The opposite of perfect competition, if there was one, would be monopoly. If there is a monopoly in a given market, it means that only one firm supplies the whole market with its production, with no competitors present due to barriers to entry (e.g. legal barriers - patents, or factual, such as very high costs of market entry). Since there is only one firm supplying the product, we cannot speak about product differentiation. Moreover, the absence of competition results in absence of close substitutes to the firm's product. Contrary to perfect competition, the firm is able to generate positive economic profit not only in short run, but also in long run. This is caused by the fact that positive economic profits - which in perfect competition with no barriers to entry attract new entrants to the market - do not cause the change in monopoly with high barriers to entry. Furthermore, the monopolists do not accept the price formed in the market, since the firm acts as the price maker, meaning that it sets the price in the market (needless to say, the market price cannot be arbitrarily high, since the monopoly has to respect the market demand).

The structure of a market with just few dominant firms in it is called oligopoly (a specific type of oligopoly which consists of only two firms is named duopoly). The products that the oligopolists supply to the market can be both differentiated and undifferentiated. Since there is more than one player in the market, there is a limited competition in it. However, entry of new firms is made very hard by high barriers to entry that prevail in the market. The firms in an oligopoly-characterized industry are able to generate both short term and long term profits. The size of these profits depends on the market price, which is determined by the oligopolists, who are the price makers. It is nevertheless important to note that the price-setting is a strategic decision, which includes strategic interaction with the other players in the market. As such, this strategic interaction is subject to the concepts of game theory as described earlier in this thesis, and as we will demonstrate in the following chapters. In addition to the aforementioned characteristics of oligopolies, non-price competition is an important tool employed by oligopolists in order to earn higher profits.

The fourth of the market structures is monopolistic competition. Under monopolistic competition, there are many firms competing in the market, as there are only low barriers to entry. The firms supply differentiated products and act as the price makers. Since there are many firms supplying substitutes to the firm's products, the price-making power of the firm is limited. Positive short run economic profits are achievable in the market in the short run. Not so in the long run, where only normal economic profits are generated, because positive short run profits tend to attract new entrants to the market. Similar to oligopoly, non-price competition is also possible in monopolistic competition, because the firms can use it as a means of driving up the sales of their differentiated products.

It is especially important for this thesis to study in greater detail the third of the market structures described here, the oligopoly, where few firms are present in a given industry, but more than one. As oligopolies were the subject of extensive studies over the last centuries, we will look at different models of oligopoly, their similarities and differences in the following sections. We will also use graphical representations to illustrate the topics described, to show how the models were developed, and how they can be understood and applied. Since there are numerous models of oligopoly to be described, it will be useful to divide them into groups according to the level of collusion between the oligopolists - into non-collusive models and collusive models.

2.2 Non-collusive models of Oligopoly

In a non-collusive (also non-cooperative) oligopoly, the firms in the market do not cooperate while choosing the quantity of products they supply, or while setting the price of the product. If the firms in the market do not cooperate, they have to be extremely cautious about the decisions they make, and about the reactions of their competitors to these decisions. Unwise decisions may ultimately lead to disastrous consequences, such as the firm being unable to sell any of its products, or the firm operating at loss. First of all, let us look at one of the oldest models of oligopoly, which bears the name of French economist and mathematician Augustin Cournot.

2.2.1 Cournot model

Cournot has published his ideas on oligopoly and many other topics regarding economics and usage of mathematical tools in economics in his 1838 opus *The Mathematical Principles of the Theory of Wealth.* In his concept, Cournot decided to illustrate the model of oligopoly and its prerequisites on a case of two natural spring water producers (hence, this case describes a duopoly) who choose the quantity of the output they supply to the market.

First feature of the market, as Cournot describes it, is that there are two players in it (or few of them). If this was not the case, the market structure described would either be a monopoly (with one player) or a competitive market (with greater quantity of players), which both have distinct features and function differently from the oligopoly (see section 2.1). The products that are supplied to the market are homogeneous, i.e. the consumer cannot and does not differentiate between them. The two firms do not cooperate in their efforts; instead they compete for the market and for the market share in order to maximize their profits. To maximize the profits, they exert the power they have over the price of the products they supply, which is achieved through the firm's output decision. The output decision sets the quantity of the goods supplied to the market and, together with the market demand which is linear and known by the producers, it determines the price. The output decision of the firms is made simultaneously by both players (we can imagine the strategic interaction as a simultaneous game). It is also crucial to note that the firms are rational, meaning that what they seek is to maximize the profits they generate from their activities. The profits depend on the firms' costs - which, for simplification, are assumed to be identical - and on the firms' revenues. To reiterate, the revenues firms make depend not only on the quantity they supply to the market themselves, but also on the quantity which is supplied to the market in total (i.e. on the quantity supplied by the others in addition to the firm's output). Last but not least, the model assumes that a change in the output decision of one player has no effect whatsoever on the output choice of the other player. This sort of assumption, in general, is called the conjectural variation[1]. Now that we have listed the assumptions of Cournot model, let us now move back to the illustrative example of the two producers of spring water mentioned in the previous paragraph (Cournot, 1897).

The two proprietors of the natural springs, proprietor 1 and proprietor 2, supply their product, spring water, to the market. The two springs are identical, and so are the qualities of the water they provide. For simplification, it is assumed that there are no costs associated with drilling and supplying of the water, meaning that the marginal costs (MC), i.e. the costs incurred when quantity produced increases by one unit, of both proprietors are identical and equal to zero ($MC_1=MC_2=0$). Since the water from both springs is a homogeneous good, the prices of products are identical and are determined by the market price ($P=p_1=p_2$). The whole market is supplied exclusively by the two proprietors we are looking at here, meaning that the quantity supplied to the

[1] Conjectural variation is the belief or assumption (a conjecture) that a firm makes about reaction of its competitor if the firm changes its output or price (the competitor's variation of output or price).

whole market is a sum of the quantities supplied by proprietors ($Q=q_1+q_2$). The income of the proprietor, as Cournot calls it or, in other words, the proprietor's revenue (and in a zero cost case also the profit) is equal to the quantity he or she supplies to the market multiplied by the price ($TR=P*Q=P*(q_1+q_2)$; $TR_1=P*q_1$; $TR_2=P*q_2$; $\Pi=TR-TC$).

Each of the proprietors seeks to maximize his or her profit and does so independently of the other proprietor. To calculate the profits for proprietor 1, we need to find the equilibrium in the market, the equilibrium price and quantity, from which we can establish q_1 and q_2. We have established that the price the proprietors charge for their good, the market price, depends on both their own output and on their competitors output - in other words, that the price is a function of both q_1 and q_2 [formally: $P(q_1+q_2)$]. We have also established that the producers know the market demand and that since there are only two suppliers in the market, the demand consists of the individual demands for particular producers' good ($D=d_1+d_2$). Let us now suppose that the market demand is given by the equation

$$Q=A-P$$

where Q is the quantity produced, P is the market price and A is the quantity demanded if price was equal to zero. From this equation, we can similarly express the equation for price and adjust it according to what was said previously about the Q being the sum of q_1 and q_2:

$$P=A-Q$$

$$P=A-q_1-q_2$$

As we have said earlier, we may view this duopoly interaction as a game. As stated earlier in the text, the Nash equilibrium is a set of strategies of the game's players, which are best response to each other. Hence, the strategy of proprietor 1 needs to be the best response to the strategy of proprietor 2 and vice versa. Again, the player's strategy is the best response against another player's strategy if the player cannot earn higher payoff from any other strategy given what the other player is playing. Because the firms in this model decide about the quantity they supply to the market, and because the firms' payoffs are represented by their profit, the best response strategy must provide highest profit possible for the output decision of the competing firm. Now, let us take it as proved that a firm's profits are maximized when its marginal costs are equal to its marginal revenues[2]. Since marginal costs in this case are zero, we need to find out when marginal revenues are also zero. To find marginal revenues, we will use the formula for counting total revenues ($TR=P*q_1$) and the formula for price as derived in the end of the previous paragraph

$$(P=A-q_1-q_2).$$

$$TR=P*q_1$$

$$TR=(A-q_1-q_2)*q_1$$

Using the rules about distributive property in algebra, we can rewrite the equation as:

$$TR=A*q_1-q_1^2-q_2*q_1$$

Using the first derivative of the total revenues function, we arrive at the marginal revenues function of the firm:

$$MR=TR'=A-2q_1-q_2$$

As mentioned earlier, the profit is maximized when marginal costs of a firm are equal to its marginal revenues. In a zero marginal cost case, the marginal revenues have to be zero as well.

$$\pi_{max}: MC=MR; MC=0 \rightarrow MR=0$$

$$MR=A-2q_1-q_2$$

$$0=A-2q_1-q_2$$

From this form of the equation, we will express q_1

$$2q_1=A-q_2$$

$$q_1=\frac{A-q2}{2}$$

We have now arrived at the best response function for proprietor 1, and we could proceed similarly for proprietor 2, whose best response function will in turn be

$$q_2=\frac{A-q1}{2}$$

[2] This is just a first order condition (MC=MR), second order condition -MC'>MR'

Now, we can find the equilibrium both by substituting the expression of q_2 from its best response function into the best response function of proprietor 1, or graphically by plotting the two functions into one common graph. Seeing that the results are the same in both cases, we will confirm the way we arrived at these conclusions. First, let us calculate the Nash equilibrium.

$$q_1 = \frac{A-q2}{2};\ q_2 = \frac{A-q1}{2}$$

$$q_1 = \frac{A-\frac{A-q1}{2}}{2}$$

$$2q_1 = A - \frac{A-q1}{2}$$

$$4q_1 = 2A\text{-}A\text{+}q_1$$

$$3q_1 = A$$

$$q_1 = \frac{A}{3}$$

Similarly, we could show that the equilibrium quantity for proprietor 2 is also one third of the quantity A. If plotted in a graph, the best response functions intersect in NE $[\frac{A}{3};\frac{A}{3}]$.

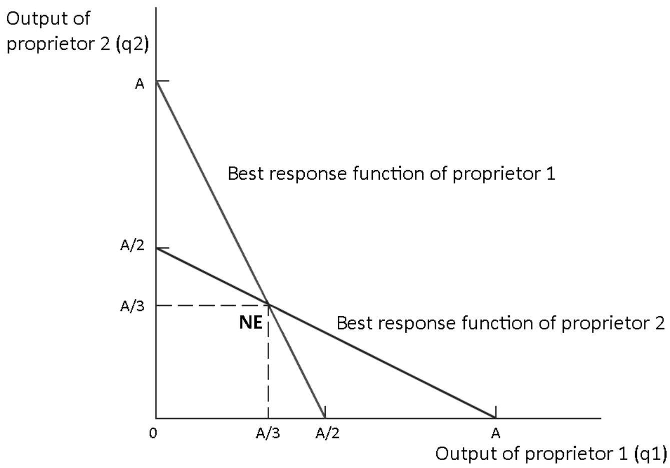

Figure 1 The Nash Equilibrium in Cournot duopoly (adapted from Nicholson & Snyder, 2010)

Before moving to other models of oligopoly, it would be useful to compare the situation in the market under Cournot duopoly with perfectly competitive market and with monopoly. In the case of the two spring water suppliers, the quantity supplied to the market by the two proprietors is two thirds of A ($q_1+q_2=\frac{2}{3}$ A), with the profits of $\frac{2}{9}A^2$(TC=0, TR=P*(q_1+q_2); P=A-Q=$\frac{A}{3}$; $q_1=\frac{A}{3}$; $q_2=\frac{A}{3}$; π=TR=$\frac{2}{9}$ A^2). In perfect competition, no long run profits are possible, and the price is set based on and equal to marginal costs which, in this case, are zero. Provided that the demand and cost functions are the same as in Cournot duopoly, the firms will together sell the whole A amount of output at a price of zero and at zero profits.

$$MC=P=0;\ Q=A-P$$
$$Q=A$$

In case of monopoly, the only firm in the market would maximize its profit by finding the quantity of output for which the difference between total revenues and total costs is greatest. In the zero cost case, the firm will supply as much natural spring water as to generate highest total revenues possible. Using the same demand curve, the formulas as shown before and first derivative to find marginal revenues, the optimal output for the firm can be computed using the following steps:

$$MC=0;\ q=A-P;\ P=A-q;\ TR=P*q;\ TR'=MR;\ \pi_{max}:MR=MC=0$$
$$TR= (A-q)*q$$
$$TR=Aq-q^2$$
$$TR'=MR=A-2q$$
$$0=A-2q$$
$$q=A/2$$

Thus, the firm will sell A/2 amount of output, where the profits will be maximized (the size of the profits will be the same as the volume of total revenues: $Aq-q^2$). If we compare the results here, it is clear to see that the duopoly as Cournot describes it provides outcomes somewhat between perfect competition and monopoly, with the volume of output being lower than in perfect competition but higher than in monopoly, and with the price being higher than in perfect competition yet lower than in monopoly.

Similar to most theories and theoretical concepts, even Cournot's model of duopoly, its formal prerequisites and its outcomes have faced criticism. One of the people who tried to challenge this model was another French economist and mathematician named Joseph Bertrand.

2.2.2 Bertrand model

In his 1883 joint review of Cournot's *The Mathematical Principles of the Theory of Wealth* and Walras'[3]*Elements of Pure Economics, or The Theory of Social Wealth,* Joseph Bertrand expresses his critique of the very foundation of Cournot model - the assumption that firms decide about the volume of output. Bertrand argues that the firms choose prices instead, which eventually leads to a very different conclusion about the situation in the market.

First of all, let us repeat that the other assumptions about the firms and the market are the same. There are two firms supplying homogeneous products (i.e. perfectly substitutable products) at constant marginal costs (a broader variant of the zero cost case in the previous model), and facing a linear downward-sloping demand curve. Importantly, in this case, there are no limits to the production capacity of either firm.

In Bertrand's view, the firms do not choose the output volume first, and then sell it whatever the price. Instead, they choose the price for which they are going to sell their products, and then produce the demanded quantity of output. It is for this reason that the adjusting variable in this model is the price. The conjectural variation in Bertrand model is that the competitors will not change their price if the firm changes its price, which is in principle very similar assumption to the one Cournot makes. It is crucial for the firm to realize that any rational consumer cares about the price only when deciding between perfectly substitutable products. If the prices of both firms are equal, then the market is divided evenly. However, if it is the case that one firm charges lower price than its competitor, it will supply the whole market alone (since there are no production constraints, this is achievable). On the other hand, once the competitor undercuts the firm's price, the firm will not be able to conclude any transactions and the competitor will face the entire market demand and thus realize profit. By this mechanism, there is always an incentive for a firm to undercut its competitor's price,

[3] Leon Walras (1834-1910), French mathematical economist, pioneer in the field of general equilibrium theory.

supply the whole market and exercise higher profits. The price will therefore steadily decline to the point where the firm no longer can increase its profit by decreasing the price, which happens when the marginal costs are equal to the price. If the firm chose to decrease the price below the MC, it would only achieve negative profit (loss), which is not desirable. If the firm chose to increase the price above the MC, when its competitor sells at P=MC, the firm would not be able to sell anything and achieve any profit, meaning that there is no incentive for this behavior either. This situation is therefore the only equilibrium in this game. It follows that the situation when both firms sell at P=MC is the Nash equilibrium, since the strategies of the two firms are the best response to each other (Bertrand, 1883; Nicholson & Snyder, 2010).

The best response functions and the Nash equilibrium in Bertrand duopoly case are depicted in Figure 2. For any price of proprietor 2 lower than the MC, proprietor 1 chooses the price p_1=MC. In this case, proprietor 2 is forced to increase the price, because he is operating at loss. For any price higher than MC yet lower than monopoly price (P_m) charged by proprietor 2, proprietor 1 has an incentive to lower the price to generate profit[4]. In case proprietor 2 charges price higher than monopoly price, proprietor 1 chooses to charge monopoly price and harvest the maximum achievable profits in the market. The only Nash equilibrium in the Bertrand game is therefore the intersection of the two proprietor's best response functions at the price $p_1=p_2=P=MC$ (marked by the blue spot in Figure 2).

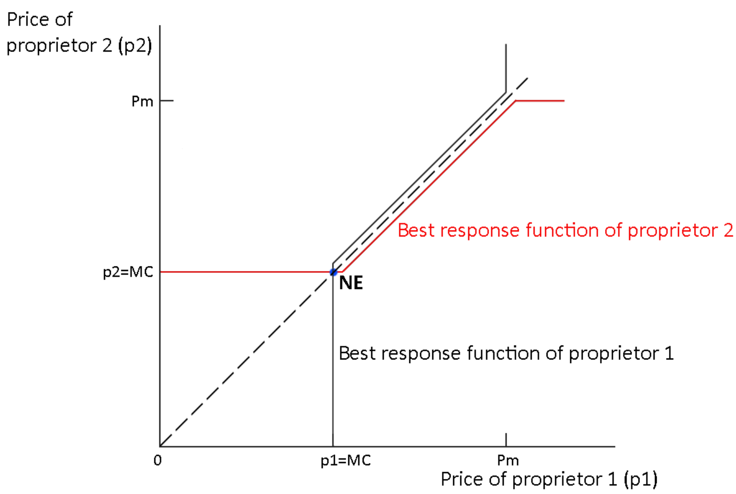

Figure 2 The Nash Equilibrium in Bertrand duopoly (adapted from Nicholson & Snyder, 2010)

[4] Monopoly price being the price a monopolist charges in order to achieve highest profits possible, i.e. the price at which the monopolist's MC=MR.

The conclusion that the outcome is P=MC might be surprising to some readers, since Bertrand duopoly is an example of an imperfectly competitive market structure, and since P=MC is also the outcome that would emerge from a perfectly competitive market. In economic literature, this contradiction is known as Bertrand's paradox. Similar to Cournot's, Bertrand's model was also subject to criticism. The condition that makes the model distant from reality is the assumption that the firms' production capacity is unlimited. This notion was criticized notably by Francis Ysidro Edgeworth, who corrected it and proposed an amendment to Bertrand's model.

2.2.3 Edgeworth model

Francis Ysidro Edgeworth[5] challenged Bertrand's model in his 1897 article *La teoria pura del monopolio*[6]. In Edgeworth's view, it was unrealistic to assume that any real-world firm would be able to produce an unlimited quantity of product. Instead, as he suggested, the firm can increase the production, but still faces some production constraints. Without changing any other of Bertrand's assumptions, the presence of production constraints is responsible for a significantly different outcome in Edgeworth's duopoly case[7]. To describe the outcome of the model we will use the graphical representation provided in Figure 3.

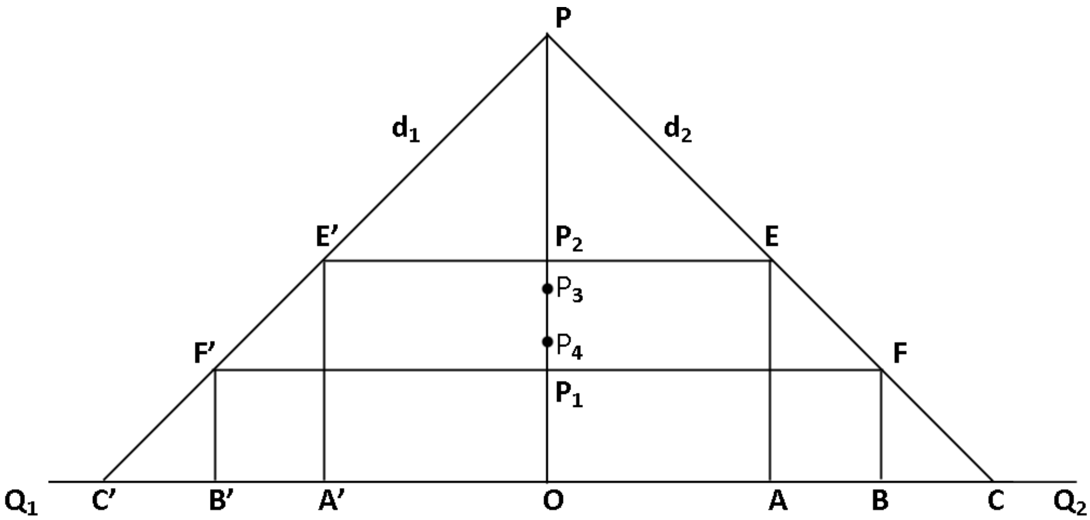

Figure 3 Edgeworth model of duopoly (adapted from Edgeworth, 1925)

[5] Francis Ysidro Edgeworth (1845 – 1926), Anglo-Irish political economist and philosopher.

[6] The English language original of the article was lost so the article had to be translated back into English, where it was published as *The Pure Theory of Monopoly*, which itself is a section of *Papers Relating to Political Economy*, published by Macmillan in 1925.

[7] Because Edgeworth developed and amended Bertrand model, the duopoly/oligopoly model is alternatively called Bertrand-Edgeworth model.

There are two firms (say, proprietors of natural spring water) in the market which face a downward-sloping demand function. The proprietor believes, as in the previous model, that the price of the rival proprietor will remain unchanged if he himself changes his price. As mentioned above, the production capacity of both firms is limited, meaning that the firm cannot supply the whole market itself. If the price charged by both firms is the same, the market is split equally between them.

The firms face individual demand curves d_1 and d_2 as shown in the graph above. Their maximum production capacity (i.e. maximal possible output) is OB' and OB respectively. The price at which the firms sell their maximal level of output is OP_1. Let us suppose that the firms choose to produce less than their maximal output. Instead, they produce OA' and OA amount of output and sell at the price of P_2. Assuming that there will be no change in price of the firm 2 in reaction to a change in price of the firm 1 makes, the firm 1 chooses to lower the price to P_3. The motive behind this action is that with lower price for a perfectly substitutable product, the firm will attract its rival's customers and will therefore be able to generate more profit through higher sales. When proprietor 2 finds out that his customers have left him for the cheaper products of proprietor 1, he makes a change in the price he charges. Assuming that the price of proprietor 1 will remain the same, proprietor 2 decreases his price below the new price established by proprietor 1, for example to the level of P_4. By doing so, he is able to sell his entire possible output to the market, since he has attracted customers of proprietor 1.

This action and reaction of both proprietors lasts until the price of P_1 is established, at the point where both proprietors sell their entire possible output again. At this point, the outcome is the same as in perfect competition, since the price in the market is equal to the MC. Edgeworth argues that when both firms produce the maximal possible output, they have incentives to reduce their production, because it would enable them to achieve higher profits. This is caused by the limited production capacity of the other producer, who can only satisfy a certain limited amount of customers. The other producer will therefore leave the some customers unsatisfied and willing to pay higher price which is more advantageous to the proprietor. He does not need to be afraid of competition, since the rival has already put his products to the market. The reaction of the competitor will be to follow suit and increase the price as well, meaning that less will be produced and sold at higher price. This trend will continue until the price of OP_2 is achieved, which is the price a monopolist would charge. At such price, any further increase would only diminish the firm's profit. In contrast, a decrease in price as described in the previous paragraph allows the producer to generate profits, and the whole cycle starts anew (Edgeworth, 1925).

As we have seen now, there is no stable equilibrium in Edgeworth's duopoly, because the prices shift constantly. The prices move between the price P_1, which is the price in a perfectly competitive market, and price P_2, which is the monopoly price.

There is a fundamental problem to be seen in the three previously presented models of oligopoly which makes the models unrealistic and therefore impractical. This issue has been pointed out and rectified by American economist Edward Chamberlin.

2.2.4 Chamberlin model

What Chamberlin[8] found unrealistic about Cournot, Bertrand and Edgeworth models was the assumption about conjectural variation and its self-falsification. The oligopolists in these models assume that their competitors will not change their price or quantity in reaction to the oligopolists' change in price or quantity. However, there is a reaction stemming from each and every such change, which itself falsifies the validity of the assumption. The oligopolist and the competitors, nevertheless, continue to assume that the conjectural variation is the same, i.e. zero. Chamberlin argues, on the contrary, that the oligopolist is rational and intelligent, and is therefore able to learn from the past, and to foresee both direct and indirect reactions to her actions. Let us observe the interaction between the duopolists as described by Chamberlin. A graphical representation of this interaction is presented in Figure 4.

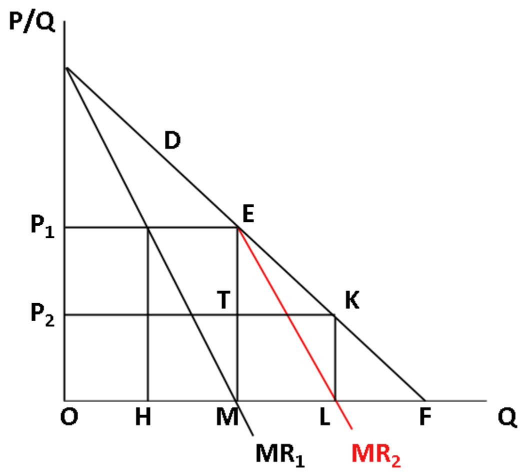

Figure 4 Chamberlin model of duopoly (adapted from Chamberlin, 1969)

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[8] Edward Hastings Chamberlin (1899-1967), American neoclassical economist.

There are two firms in the market which have zero MC and face a downward-sloping linear demand curve D. We assume that the firm that entered the market first is firm 1. This firm was for some time facing the entire demand curve itself and acted as a monopoly maximizing its profits while producing at MR_1=MC=0, selling OM quantity of output at the price OP_1. However, the firm does not enjoy the benefits of being a monopoly for long, since a new firm, firm 2, enters the market. The new entrant assumes that there will be no change in the former monopolist's output choice, and therefore sees the section EF as the section of the demand curve facing him, the red line in Figure 4 representing the corresponding MR_2. The new entrant then decides to produce at MR_2=MC=0, selling ML volume of output. The price in the market adjusts to the combined (aggregate) output of both producers, which is OL, shifting the price to P_2. The profit of the first producer decreases due to the decrease in market price (Chamberlin, 1969).

The crucial difference from the previously presented models is that now the first producer realizes that his actions are interdependent with the actions of the other firm, his action causing the competitor’s reaction. He therefore chooses to reduce the quantity he produces to secure stable profit. He does so by producing OH quantity of output, while firm 2 produces ML quantity of output, meaning that the aggregate output is equal to the monopoly output, and is equally split between the two firms. The price will increase to its former level of OP_1. Without any collusion the firms are able to maximize their joint profits and establish a stable equilibrium, understanding that their actions are interdependent with the actions of their rivals. The equilibrium level of output in Chamberlin model is equal to the monopoly level of output, since the firms realize that any change in their supply would, despite immediate profits, bring decrease in the long term profits (Chamberlin, 1969). Before we move to oligopoly models where the firms collude, let us look at the non-collusive oligopoly problem from a different perspective, as presented by Heinrich Stackelberg[9] and Paul Sweezy[10].

[9] Heinrich Freiherr von Stackelberg (1905-1946), German economist.
[10] Paul Marlor Sweezy (1910-2004), one of the creators of the Kinked demand model. The model was developed independently at the same time in the USA by Sweezy and in the UK by R.L. Hall and C.J.Hitch.

2.2.5 Stackelberg model

Contrary to Cournot, Bertrand, Edgeworth and Chamberlin, Stackelberg viewed the oligopoly as a sequential, not a simultaneous game. This means that the order in which the firms make the moves does matter, as it determines the outcome of the game. Before we dive into details, assumptions about this particular model that are different from the ones Cournot uses should be presented.

First of all, we assume that the game is sequential, not simultaneous. The second assumption is that the action the firm undertakes is at all times observable by the other firm. If this condition was not met and the competing firm could not observe the firm's effort, it would not be able to react rationally and the model would not function. Thirdly, Stackelberg assumes that the firm which makes the first move commits itself to it - the action the firm takes must be irreversible, and the rival needs to know this as well.

We will use the graphical representation of the Nash equilibrium in Stackelberg duopoly as laid out in Figure 5. Since both players know the conditions that prevail in the market and the conditions the other player is facing, they are able to make a qualified decision regarding their output. As Stackelberg's reasoning goes, the firm that makes its move first enjoys an advantage, because it knows how the other firm will react. It can therefore increase its own production to such level which suits it the most, i.e. level of output for which the profit is maximized. In effect, the first-mover can choose a point on the other firm's best response function to see the level of output the other firm will produce. In the case described in the graph, the firm chooses to produce $\frac{A}{2}$ level of output because at this quantity its MC equals its MR (and equal zero). The second firm, which does not enjoy the first-mover advantage, has to react to the first firm’s increase in output as reducing individual supply to the market reduces the aggregate supply, which helps to mitigate decrease in price and further decrease in the profits of firm 2. The new equilibrium, which emerges from this modified Cournot game (and which is marked as NEs in Figure 5), is called Stackelberg equilibrium. The original equilibrium of the Cournot game is marked NEc.

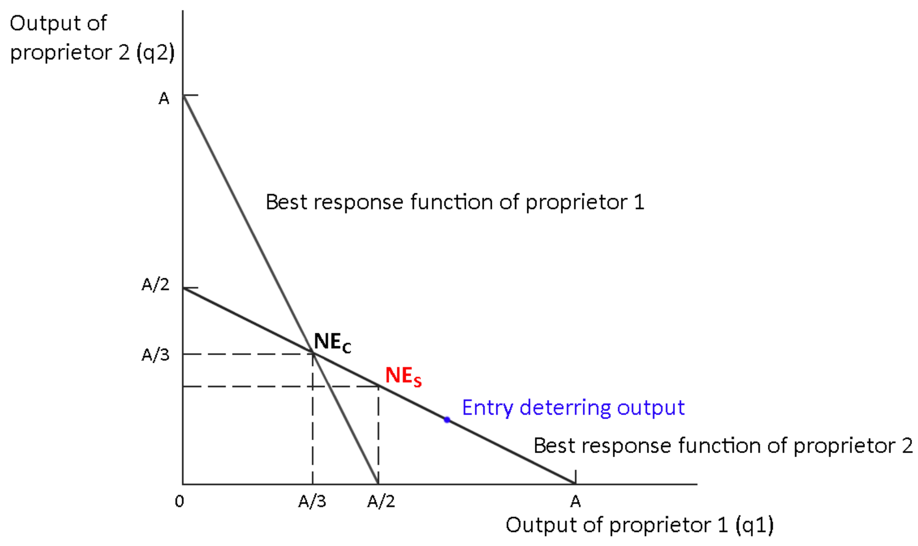

Figure 5 Nash Equilibrium in Stackelberg model of duopoly (adapted from Nicholson & Snyder, 2010)

The first-mover advantage in a Stackelberg game can sometimes be so big that it effectively deters other prospective market players from entering the market. Such situation is depicted by the blue point in Figure 5. In real life, this is rational as economies of scale are involved, making it cheaper for the firm to supply more output due to lower per-unit costs. The firm which considers entry, on the other hand, would be facing higher average costs, which deters it from market entry. The entry deterrence can be achieved by different means, such as limit pricing, where the incumbent market player sets the price below its profit maximizing optimum to deter new entrants. Similar to this technique is predatory pricing, which is aimed at driving current competitors out of the market by setting prices so low that the competitors prefer to exit the market than to stay in it.

2.2.6 Kinked demand model

Similar to Stackelberg, Sweezy also brings in a different perspective on the theory of oligopoly and tries to craft a model closer to real life. In the model of oligopoly presented by him, known as Sweezy model or as kinked demand curve model, he argues that the reaction of the competitors to the firm's change in price depends on the direction of the price change (Sweezy, 1939). If the firm decides to increase the price, its competitors will not follow suit and will maintain their prices to attract the firm's customers. If the firm chooses to lower the price, the competitors will fear losing customers and will therefore lower their prices in a similar manner. Let us observe the kinked demand model as represented in Figure 6.

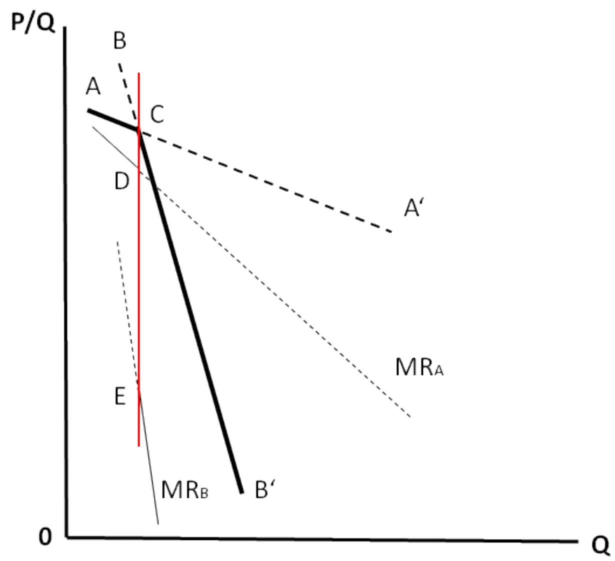

Figure 6 Kinked demand model of oligopoly (adapted from Hall & Hitch, 1939)

The firm whose situation is shown in the graph faces a demand represented by the curves AC and CB'. Its marginal revenues function is divided into two segments MR_A and MR_B. It is observable that the upper part of the demand curve, i.e. segment AC, is relatively less elastic than the lower part of the curve, segment CB'. This is caused by the fact that if the firm operating at point C level of output chooses to increase its price, the competition decides to keep its price intact. The firm which increased its price will not be able to sell its products, as its customers will buy cheaper products from the competition. Such price change will therefore have much more significant effect on the quantity the firm is able to sell, than a decrease in price. If the firm decreases its price, its competitors decrease their prices as well in order not to lose their customers to the competition. The firm which decreased its price will in this case not be able to sell much more of its output, since the competition adjusted their prices. As Hall and Hitch empirically tested, the model provides an explanation for why oligopolies maintain their pricing strategy. The reason for maintaining price is that an increase in price would lead to a loss of market share, while a decrease in price would ultimately cause only lower profits without any significant effect on the firm's market share.

In section 2.2 and its subsections we have covered the most important models of non-collusive oligopoly. In the following section, we will take a closer look on the models that assume that the firms, in some way or another, collude. The element of collusion substitutes a crucial difference to the aforementioned models, since it helps eliminate some of the uncertainty the firms have to face while making their decisions.

2.3 Collusive models of Oligopoly

In general language, collusion means secret or illegal cooperation between two or more parties, which is aimed at cheating or deceiving others. In economic parlance, the word is used to address an element of very often illegal cooperation and coordination of actions of players in the market, which is aimed at distorting the market conditions to the players' benefit. In our case, we will talk about collusive oligopoly. This is an oligopoly where the oligopolists' behavior is guided by an agreement, to which they are a party, which aims at obtaining benefits (for simplification we will assume that firms only aim at maximizing profit) which they would not be able to achieve if perfect competition prevailed in the market. It is interesting to note that the collusion is not illegal per se, but some ways of arriving at the collusion are illegal - typically the ones that require explicit agreement (Harrington, 2012).

It is possible to differentiate between horizontal and vertical collusion. Horizontal collusion is an agreement between horizontal competitors, i.e. firms on the same level of supply chain (such as Coca-Cola and PepsiCo), whereas vertical agreements are the ones made by firms on different levels on the supply chain (a retail store chain colluding with dairy products supplier). We also differentiate between overt and tacit collusion. An overt collusion is a formal collusion agreement, while tacit collusion is a collusion established tacitly, i.e. without explicit agreement between the parties. Rather than being a separate model of oligopoly, tacit collusion is one of the modes of collusion between the firms. As such, it is a crucial element in price-leadership models. An example of overtly collusive oligopoly, on the other hand, is a cartel.

2.3.1 Price fixing cartel

Cartel is a widely used term which is sometimes misunderstood or not fully understood. To prevent this misunderstanding, we would like to define and describe cartel in the following paragraphs. According to the European Commission, “a cartel is a group of similar, independent companies which join together to fix prices, to limit production or to share markets or customers between them." (European Commission, 2013). Even though legal definitions sometimes vary from the ones used in economics, this one is very accurate. It includes different kinds of cartel, the most prominent of which is the price fixing cartel.

In a price fixing cartel, the members of the cartel (such as firms or states) agree on maintaining a stipulated price in the market, which enables them to increase the profits in comparison to competitive market outcome. In a perfect cartel outcome, the firms agree to produce a level of output where their joint profits are maximized, i.e. the level of aggregate output where the MR are equal to the sum of the firms' MC. This perfect cartel outcome is the same as the outcome of a multi-plant monopoly, with the cartel members jointly exercising highest profit achievable under given market conditions. This situation is illustrated in Figure 7.

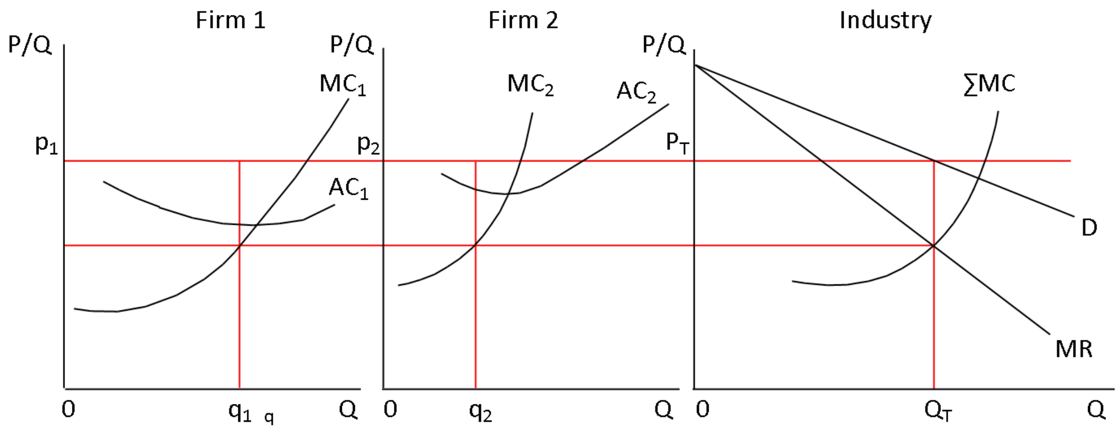

Figure 7 Perfect cartel outcome and the situation of two representative firms (adapted from Dwivedi, 2006)

The assumptions about this model are as follows. The cartel consists of two representative firms in an oligopolistic industry, firm 1 and firm 2. The firms produce homogeneous or easily substitutable product but operate at different marginal and average costs MC_1 and AC_1, and MC_2 and AC_2 respectively. These cost curves are known to the cartel members. If the two marginal cost curves are summed up, we arrive at the $\sum MC$ curve. Both the market demand D and the corresponding MR curves - which are shown in the graph on the right hand side - are known to the firms. The profit maximizing output choice for the cartel (Q_T) lies where the $\sum MC$ intersects the MR curve. This way, the marginal costs at which the output will be produced are determined. To see which quantity of output will be supplied by particular firms, we plot this level of MC into the firms' graphs and see their volume of output q_1 and q_2. Furthermore, we know that the cartel members sell at the same price, which is the market price P_T. To determine the profit exercised by each cartel member, we look at the difference between the member's AC and the market price P_T, and multiply this difference (profit per unit) by the quantity supplied. It is also possible that the cartel member operates at loss, but such situation creates an incentive for the cartel member to cheat, since they can achieve better outcome by deviating from the cartel agreement.

The enforceability of the cartel agreements is one of the most crucial weak points of cartels in general. Since cartels are very often illegal in the markets where they operate, the members cannot use legal action to enforce the agreements. Thus, cheating may not easily be punished, and the lack of effective threat creates incentive for the members to cheat and produce more output than stipulated in pursuit of individual increase of the profit. The members should be aware that such behavior, even though it is tempting in the short run, may cause decrease of the profits in the long run. This is the case because cartels could be viewed as a real-life example of the classical game prisoner's dilemma[11]. Another problem regarding the enforceability of a cartel agreement is that it is usually very complicated to verify if the cartel members actually adhere to the agreement or not. As we will see in the practical part of this thesis, this constitutes a major challenge for the members. In practice, it is also very challenging to estimate properly the market demand curve (and the MR curve consecutively), and to ensure that the firms' MC curves are computed and submitted properly to the cartel authority. It is also very important to take into account the transaction costs associated with negotiation of cartel agreements when considering their feasibility.

2.3.2 Market-sharing cartel

Apart from the price fixing cartel, there is also a market-sharing cartel. There is a looser element of collusion in the market-sharing cartel but it distorts the market nevertheless. The market-sharing cartel can for example consist in allocating the customers to a particular firm based on geographic area or on other criterion relating to the customers. Such behavior reduces competition and is thus illicit in most states.

[11] For further information refer to Nicholson & Snyder, 2010.

We can illustrate how this cartel model functions with the help of graphical representation presented in Figure 8.

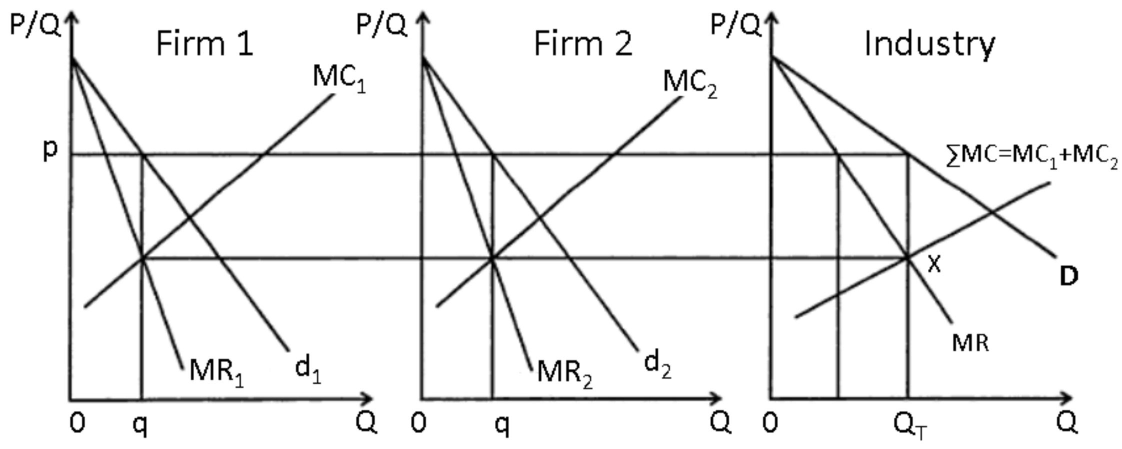

Figure 8 Market situation in an industry with market-sharing cartel (adapted from Dwivedi, 2006)

Again, there are two firms in the market which sell a homogeneous product and have identical cost curves. The market demand curve D is known to the firms which face their identical partial demand curves d_1 and d_2 and respective MR curves. The market share of each firm is, for simplification, the same. The horizontal sum of the MC curves labeled ∑MC intersects the MR curve at point labeled X which determines the joint profit-maximizing choice. The aggregate level of output is Q_T, price at which the demanders are willing to buy this output is labeled p, as it is the price at which each of the firms sells. As we know that total output is shared equally between the two market players, each of them supplies q amount of output and generates the same amount of profit equal to the difference of price and average costs multiplied by the output (p-AC)*q. The two models of collusive oligopoly presented so far have not taken into account the threat posed by a possible entry of a new player to the market. This is, however, reflected in Price leadership model.

2.3.3 Price leadership model

Price leadership model can be present in three different forms - we speak about dominant firm price leadership, collusive price leadership, and barometric price leadership. In dominant price leadership, an industry consists of a dominant firm which has an established position of the price-leader and other smaller firms who behave as followers. Collusive price leadership, on the other hand, is a situation when there are dominant firms in the market which set the prices that the minor firms follow. As a result the prices are close to monopolistic prices. In the last type, barometric price leadership, there is one firm (the barometric leader) which is able to reliably consider the changes in market conditions and then adjust the price, acting as a "barometer" of the market. The prices which reflect the barometric leader's price are set around the competitive level (Ono, 1982). In this thesis we will only present the dominant price leadership model which is, in our view, the most important of the models. We will present the model as shown in Figure 9.

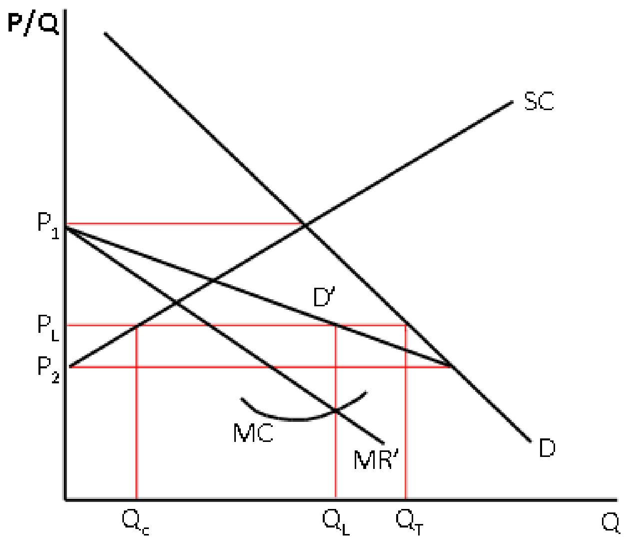

Figure 9 Dominant model of price leadership (adapted from Nicholson & Snyder, 2010)

The market consists of a dominant firm - the price leader - who sets the price and of a competitive fringe. The competitive fringe consists of all the other firms in the market which act as price followers. The market demand is labeled D, the demand for the price leader is marked D'. The supply of the competitive fringe (derived as the sum of the firms' MC curves) is SC while the dominant firm's marginal cost curve is MC. The leader's marginal revenue curve is labeled MR'.

The demand for the dominant firm D' is constructed as follows. From the market demand curve we subtract what the competitive fringe is able to supply. We see that the competitive fringe is able to supply at price of P_2 and greater, with P_1 being the price which would prevail in the market if no dominant firm was present (at P_1 the SC curve intersects the D). Now, if we proceed with the subtraction as described, we will arrive at curve D', that is the dominant firm's demand, from which we can construct the MR' curve as well. At the intersection of MC with MR' is the profit maximizing optimum of the price making leader. By plotting the quantity on the D' curve we get the price the price leader sets – P_L. At this price, the dominant firm supplies Q_L amount of output while the competitive fringe supplies Q_C.

There are some limitations inherently connected to the practical functioning of dominant firm price leadership. For example, the competitive fringe often tries to compete on a non-price basis with the price leader, challenging the leading firm without openly cutting the price. This practice is sometimes also called secret price-cutting. Another practical problem is derivation and assessment of the SC curve. To derive the SC curve, the dominant firm would need to consider the MC curves of all the firms in a competitive fringe, which is in practice almost impossible as this information would be highly guarded for its sensitivity and moreover hard to obtain for the firms themselves.

In this chapter we have presented the most significant models of oligopoly. We have started by showing the development of six non-collusive models of oligopoly, their similarities and contrasts. We have then moved onto describing three collusive models. In the next chapters, we will aim at applying these models and the game theoretic principles shown in the first chapter to the global oil industry in general and to OPEC in particular.

3 Applications of game theory on OPEC in the global oil industry

Before presenting some of the games identifiable within the global oil industry, this thesis would like to firstly offer basic overview of the industry and its specifics. Secondly, major trends in the industry will be described, including the trend of development of volume of supplied and demanded oil worldwide, volume of the reserves available, and perhaps most importantly, of the market price of oil. The price of oil is influenced by numerous factors, and the most important ones will be outlined in this chapter to provide background for the game theory applications described later on in this chapter.

3.1 Oil industry overview

Petroleum, or oil, is a scarce resource which has served as an indispensable source of energy for a great part of modern history. Today, about one third of all energy consumed worldwide comes from petroleum and most vehicles use fuel based on oil. With the ever increasing population, economic growth and consumption, it is clear that oil will remain in focus in the upcoming years as well, and it is thus vital to understand the oil industry in greater detail.

3.1.1 Determinants of oil price

Since oil is a natural resource, its quality may differ based on the source from which it has been obtained, which explains why there are price differences among various types of oil. There are lighter and heavier oils, depending on their density; there are also sweet and sour oils, depending on their sulfur content. In general, lighter and sweeter oils are more desirable since they are easier to refine. Another important determinant is the geographical source of the oil which predetermines the costs and effort associated with transport of the oil to the refinery. Crude oils can be differentiated by these criteria and traded on commodity markets under specific names such as Arab light, WTI, or Brent.

As was previously mentioned, petroleum is a natural resource. As such, it can be found in reservoirs under the Earth surface in varying depths and in various types of bedrock. Depending on the characteristic of the bedrock and on the depth in which the oil is located, there are multiple methods how it can be extracted, which are divided into conventional and unconventional. The conventional method of extracting oil is the oil well method, where an oil well is tapped by vertically drilling a hole into the Earth surface. Unconventional methods, on the other hand, include a variety of different ways of extracting oil other than the conventional oil well method. These include for example horizontal drilling, surface mining, in situ processing, and hydraulic fracturing (fracking)[12]. Unconventional methods, in general, require higher investment and/or are more costly to maintain than conventional oil wells, and are therefore, as will be discussed later in this thesis, only viable if the oil price is at a sustainably high level. Based on available historical data, it can be said that oil prices are rather volatile. This fact is illustrated in Figure 10, which shows the development of oil prices during the last one and a half centuries.

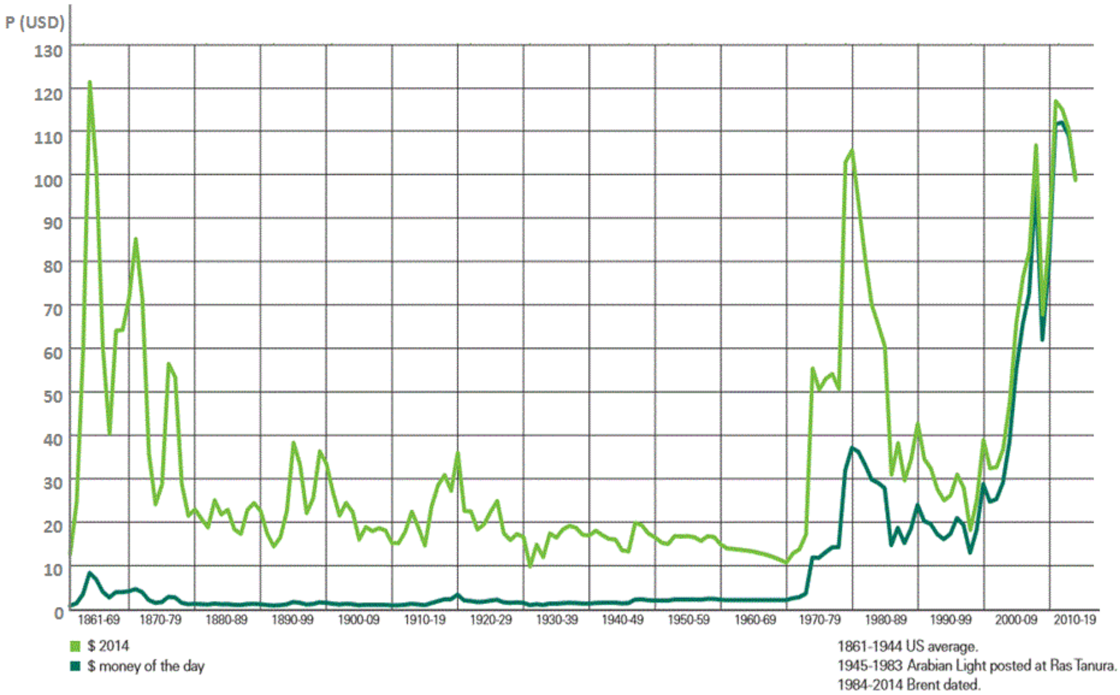

Figure 10 Development of oil prices in 2014 USD and in USD of the day
(BP Statistical Review of World Energy, 2015)

From the supply disruptions during oil shocks in the 1970s to the most recent rapid changes happening in 2010s[13] due to Arab spring, the prices have been influenced by a number of reasons which facilitated and enabled them. From the economic point

[12] The terms fracking and in situ processing are sometimes wrongly used as interchangeable. The key difference is that fracking is a method which consists of injecting liquid under high pressure into the rock to fracture it and allow petroleum and gas, which would otherwise be trapped there, to flow freely. In situ processing, on the other hand, is a common term for processes which are aimed at extracting non-liquid kerogen or bitumen from rock; this is done by heating the rock *in situ***,** meaning in the ground without mining. The mined substances than pour out of the rock and are separated and collected.
[13] The rapid fall in prices which started in 2015 is not reflected in the graph.

of view, these changes are connected to both movements along and shifts in demand and supply curves.

First of all, it is necessary to understand that the global oil markets are far from being perfectly competitive. The relatively low numbers of oil producers, together with high barriers to entry create space for market power of oil producers. Since there are players in the market who control a significant share of the whole oil production, their influence on the market price is significant. This way, long run economic profits can be achieved even with a relatively undifferentiated product such as oil (notwithstanding the differences in sweetness and lightness of oil it is still treated and traded as a commodity).

Secondly, what also needs to be taken into consideration is the relative short term price inelasticity of both demand and supply. Since there are few close substitutes to oil for consumers in the short run (e.g. no other fuel can be used for engines), the quantity demanded will decrease by less than the price increase. On the other hand, if prices were to increase, suppliers' quantity supplied will not change significantly either, since increase of production capacity is only possible with long-term investments. It is in the long run when the long-term investment, technological changes and advances will allow for the supply to accommodate the increase in demand. Considering that a great portion of the projects that can potentially be involved in such case is unconventional, and bearing in mind that unconventional sources require longer time between investment decision and actual production, the trend is that the supply is becoming less elastic when unconventional sources of oil are used.

Factor that influences prices in petroleum markets both at regional and at global level is the availability of infrastructure, which includes both the transportation infrastructure (pipelines, existence of appropriate tanker ship routes and ports) and the refineries. Another important factor influencing the supply of oil and therefore the price as well are supply disruptions. These can be caused by natural disasters (such as hurricanes in the US[14]), by political instability in a region (such as instability caused by Iraq invasion during Arab spring, as shown in Figure 10 in respective years), or by a political decision (e.g. OPEC output decisions). As far as trends in the market for oil are concerned, the most significant include, but are not limited to, economic growth

[14] For further fading on impact of one of the most impactful hurricanes in the US history, hurricane Katrina, on the US oil industry please see http://www.eia.gov/oog/special/eia1_katrina_083105.html.

which brings about increase in oil consumption[15], an increase in usage of non-conventional technologies[16], and the depletion of current oil reserves of petroleum while discovering new ones. The latter also includes reconsidering previously dismissed projects due to improvements in technology, which make some projects viable - when there is a higher level of prices in oil markets, projects with high MC can also be realized, which would otherwise not be possible as they would incur economic losses. To complete this simplified overview of oil markets and their characteristics, attention should be paid to the most important market players, some of which will be viewed as players in the games that will be identified. The players involved can be either national oil companies – NOCs (such as Saudi Aramco, Pemex, or PdVSA), which are dependent on decisions of respective national government (which are influenced by membership in organizations such as OPEC), or international oil companies – IOCs (such as ExxonMobil, BP, or Royal Dutch Shell).

3.1.2 Global oil market players

In countries whose economy largely relies on petroleum production and export, oil industry plays a crucial strategic role. In these countries, it is a common practice that the oil industry is dominated by one company, which is partially or wholly state-owned and state-controlled. This way, the government can exercise its power over the national oil company and retain its profit, restricting or expanding production in line with its budget needs and long-term strategy. As the NOCs are state owned, they may or may not suffer from the common illnesses of state-owned enterprises, including corruption, inefficient HR management and agency conflict. The role of NOCs in the global oil industry is strengthened due to the existence of the so-called global oil cartel, OPEC (Organization of the Petroleum Exporting Countries). This international intergovernmental organization founded in 1960 and headquartered in Vienna consists of thirteen states that produce and export oil. Together, the OPEC member countries[17]account for about 40% of current world oil production (as shown in Figure 11), with by far the biggest producer being Saudi Arabia. For comparison, the Russian

[15] Positive correlation between changes in petroleum prices and economic growth explained in greater detail on the website of U.S. Energy Information Administration. For further information, please see https://www.eia.gov/finance/markets/demand-nonoecd.cfm.
[16] The topic of unconventional methods and their viability under current market conditions will be addressed in the thesis.
[17] As of February 2016 OPEC member countries include Algeria, Angola, Ecuador, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela.

oil production for the same period as displayed in the figure below accounts for about 11 per cent of the world production, while the US production exceeds 14 per cent of the total.

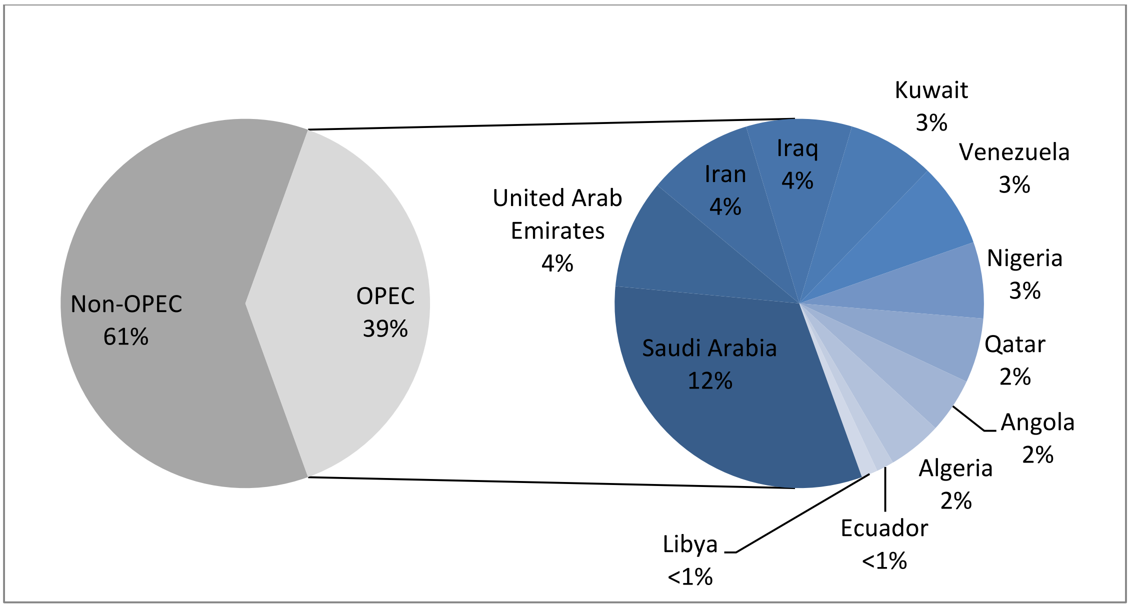

Figure 11 Breakdown of total oil production in 2014 (data retrieved from EIA, 2016a)

Moreover, the OPEC member states claim to control up to 80% of world oil reserves (OPEC, 2014), even though other sources indicate that this number might be slightly overstated (EIA, 2016a). The breakdown of oil reserves in non-OPEC and OPEC countries is shown in Figure 12. These two figures can help us understand how important role OPEC plays in the global oil market and why its output decisions can have as significant impact on market price as they do.

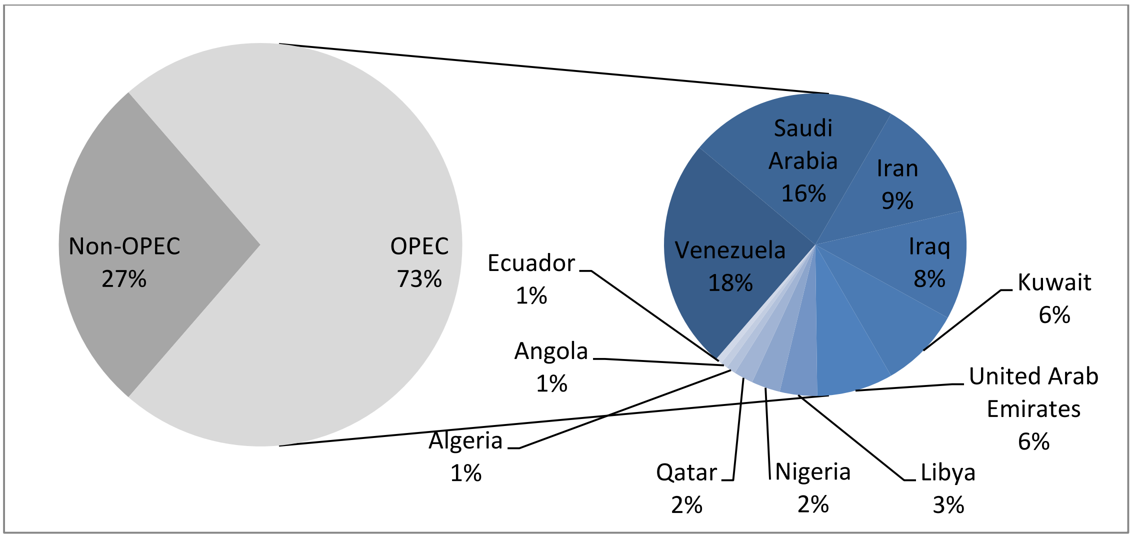

Figure 12 Breakdown of total oil reserves in 2014 (data retrieved from EIA, 2016a)

The other group of market players consists of international oil companies – IOCs. These companies are owned by private investors and their aim is therefore maximizing the shareholder value of the company. In line with this objective, their decisions should be based on rational economic factors in order to satisfy the interests of the shareholders. Agency problems, even though they are present in these firms as well, are more often eliminated by more efficient management. The most important IOCs are also known as *Big Oil* and *Supermajors*. Representatives of Big Oil are most prominently the American giant ExxonMobil, the British-Dutch company Royal Dutch Shell, BP (formerly British Petroleum), and Sinopec which is incorporated in China. For comparison with OPEC members – the oil reserves of Exxon Mobil, the biggest of the Supermajors, are approximately 0.2 per cent of total world reserves while its production amounts to less than 3 per cent of the total (ExxonMobil, 2015).

3.2 Modeling OPEC behavior

Now that the players in oil markets have been presented, the focus will be moved towards game theory applications in the global oil industry. The space provided in the following sections will be used for discussion of applications of game theory on oil industry, with the aim of applying the models defined in the theoretical part to the economic reality. Firstly, it will be discussed if the development in the oil market can or cannot be described by non-oligopoly models. Secondly, we will look at global oil market in the light of the theory of oligopolies, including both collusive and non-collusive models.

3.2.1 Property rights model

Despite the common notion that OPEC is a cartel (or a different oligopoly) and that players in the global oil market are exercising market power, there are also suggestions, models and arguments supporting the idea that the oil market is rather influenced by factors which do not easily fall within an economic model. These models explain the rapid changes in oil prices which occurred in the second half of the 20th century by two sets of causes – the first model by political decisions and the second one by changes in property rights. The advocates of this model propose that the oil producing states are guided rather by political and security motives than by wealth maximization. This approach, however, seems to be somewhat oversimplifying. As Griffin and Steele (1986) suggest, wealth maximization serves as a proxy for fulfillment of other objectives and functions of the state. To show why these models fail to describe the reality of global oil markets, they will shortly be introduced in this subsection. The discussion will be started by looking at the so-called property rights model, which explains the changes in price of oil not by market power of the producers, but by the changes in ownership of the resource.

This school of thought argues that what made the rapid changes in the competitive market possible were the changes in property rights to oil which shifted them from IOCs to NOCs, placing the ownership under the control of states. According to Mead (1979) the countries had lower discount rates than the international oil companies, and therefore they assigned higher value to future production in comparison to IOCs, and thus kept higher reserves. Discount rates were higher for the international oil companies because of the uncertainty they were facing as the risk of expropriation of the oil rights was imminent. The ever increasing taxes imposed on oil production in the host countries were a second reason which contributed to the rapid increases in the firms' discount rates. Once the property rights were transferred from IOCs to NOCs, the production growth slowed down as a consequence, leading to a sharp decrease in production. To understand how fast and big the changes due to expropriation were, let us observe a table showing the relative share of oil production under state control for selected countries (see Table 1).

Table 1 Percentage of government owned oil production in OPEC countries (Griffin & Steele, 1986)

	1970	1972	1974	1976	1978	1980
Saudi Arabia	0.9	0.7	58.5	58.7	58.7	97.7
Iran	4.5	5.0	96.2	96.2	94.6	100.0
Kuwait	1.2	1.2	55.1	90.6	94.1	90.6
Iraq	0.0	53.8	77.2	100.0	100.0	100.0
Libya	0.0	3.6	60.7	64.2	65.7	67.5
U.A.E.	0.0	0.0	49.5	62.1	64.4	64.4
Venezuela	1.2	1.9	2.5	100.0	100.0	100.0
Qatar	0.0	0.0	60.0	78.5	99.4	100.0
Nigeria	0.0	0.0	54.9	55.1	54.9	71.1
Indonesia	11.7	16.2	30.5	36.6	44.6	45.7
Algeria	14.6	76.9	88.2	90.5	89.1	93.7
Ecuador	-	1.3	25.4	25.5	62.9	62.7
Gabon	0.0	0.0	0.0	0.0	0.0	0.0

When the data from Table 1 is compared to the development of oil prices (see Figure 10), a link between the property rights changes and the price shocks can be seen. Throughout 1950s and 1960s, the nominal oil prices did not increase, because the growth in oil demand was balanced by the increase in production. By 1974, however, the property rights were to a great extent in the hands of the biggest oil exporting countries, and the increase in production slowed down, accompanied by a sharp increase in world oil prices.

The shortcomings of this model, on the other hand, are the uncertainty about who was the party who desired fast production increases in the years prior to the oil shock – if the companies desiring to produce as much as possible before the oil is expropriated, or the countries which were seeking tax revenue. Furthermore, this model fails to explain the sharp increase in prices in 1978-9, when the oil production was already state-owned and the discount rates could not be further decreased due to ownership change (Griffin & Steele, 1986).

3.2.2 Political model

Other authors argue that the changes in price can be attributed to political factors, which cause the supply shocks and are thus able to influence the price. Verleger (1982) and Epstein (1983), the representatives of this view, claim that OPEC was always rather an example of political organization than anything else. In his view, the increase in oil prices in 1973 was caused not by OPEC decision, but by the political instability caused by Yom Kippur War and consequently by unilateral decision of Saudi Arabia to cut its own production[18] followed by some OPEC states, while other members kept and some even increased their production at the time. In the period of economic recession in the middle of the 1970s, the countries again proved that the agreements they made within OPEC were not set in stone when they repeatedly broke them, supplying more oil at a lower price (which lead to a minor global decrease in price). However, towards the end of the decade in 1979 and the year afterwards, it was political factors again – regulatory action in the US, the Iranian revolution, Iraqi Invasion to Iran and announcements made by Saudi Arabia that it will decrease its production - that made the oil price skyrocket. In Figure 13, let us observe the development of oil prices with links to the political situation in the periods of rapid changes.

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[18] The decision Saudi Arabia made was, according to Epstein, pragmatic. The Saudis needed to cut the production of one of their major oil fields in order to perform maintenance works, and the fact that their decision to restrict production was followed by other countries provided them with credibility.

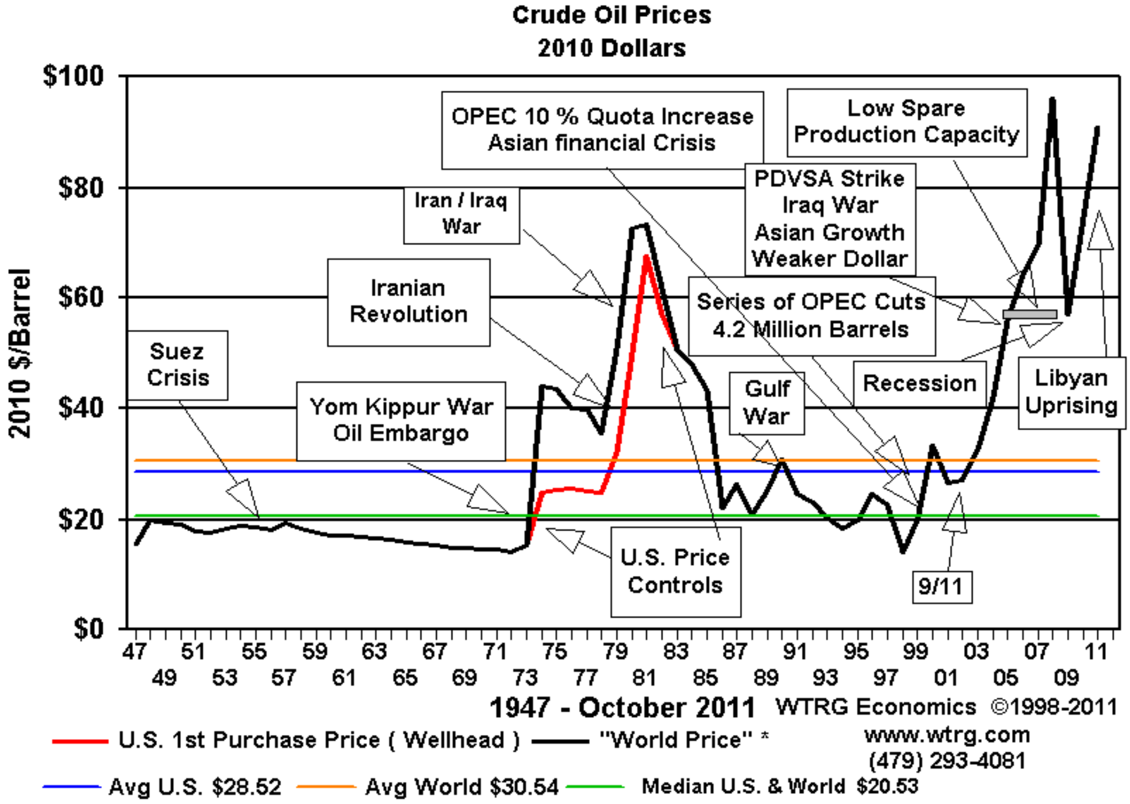

Figure 13 Development of oil prices in 2010 USD and their link to political events (Williams, 2012a)

The political model, according to this figure, might seem more than plausible, as all the major spikes in the graph are linked to a major political event[19]. There are nevertheless good reasons why this model is not the only one needed for describing the complexities of the global oil industry. First of all, strictly speaking it is not an economic model. Secondly, it is rather descriptive than prescriptive, and it does not enable any predictions for future development. Finally, this model only manages to capture the root causes of the development in a market, not the mechanisms and principles upon which these changes happen. For these reasons it is deemed necessary to continue with applying other models to the oil market and OPEC in particular.

[19] For a detailed analysis of the development of oil prices and its linkages to political situation at the time please refer to: http://www.wtrg.com/prices.htm

3.2.3 Target revenue model

The price shocks in the 1970s have been subject to many theories which aimed at the most appropriate explanation of this extraordinary oil price changes. One of the models not related to oligopoly theory is the target revenue model, which uses the backward-bending supply curve, as illustrated in Figure 14[20], to explain the course oil prices took in the early 1970s (Alhajji and Huettner, 2000). What is important to notice in the graph below is that multiple competitive equilibria can exist for the oil market – in this case a stable high price (P_3) and low price (P_1) equilibrium and an instable medium price (P_2) equilibrium. The curved marked as DD' is the demand curve while the bending SS' curve is the backward bending supply curve.

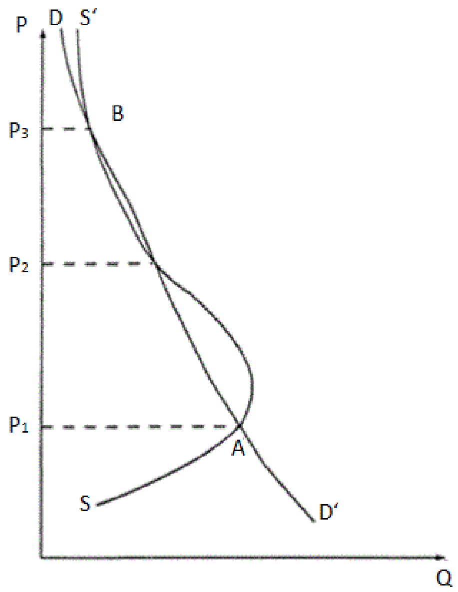

Figure 14 Backward bending supply curve of the oil producers (Crémer & Salehi-Isfahani, 2013)

According to the model, the price increase itself was triggered by political instability in 1973-1974. The reaction of the oil producers to this increase was, however, not an increase in production, but just the opposite – a cut in the output. This decision is based on the assumption that the oil revenues were tied to national budgets of the oil producing countries. The in-country investment options of these countries were limited and the investment abroad was not considered an option due to political

[20] The backward-bending supply curve is commonly used to graphically represent the individual supply of labour. If a wage is exceed a certain level, the individual reacts to further wage increases not by working more (supplying more labour), but by substituting the labour with leisure time – because the free time brings more utility to the individual than the additional income.

risk and low return. Given these constraints, the countries have a target level of revenue which they wish to achieve. Since there is no reasonable investment available for any potential excess revenues because the absorptive capacity of the countries is limited, the countries are deriving higher benefit from keeping the oil in form of reserves. This way, the increase in prices caused by the political events in the decade could possibly lead to a decrease in production of the oil exporting countries, which would push the prices even higher. On the other hand, a decrease in price should lead to an increase in oil production by the exporters, and to further decrease in the price of the commodity.

However, as Griffin and Steele (1986) point out, the price drop in 1983 (see Figure 10) did not lead to the outcome predicted by the model – i.e. to an increase in production. On the contrary, the production actually decreased, which could imply that this model has significant shortcomings. Furthermore, as Crémer and Salehi-Isfahani (2013) bring up, this model fails to explain why in 1979-80, some countries (such as Kuwait) decreased their production, while others (such as Saudi Arabia) started pumping more oil into the market. Also, this model does not acknowledge the existence of the market power of large producers such as Saudi Arabia.

As we have seen, the behavior of OPEC has been subject to theoretical research. We have also seen that there are non-oligopoly models that try to describe OPEC’s functioning. These models, as has been presented above, prove imperfect in explaining some patterns in the organization’s behavior while correctly capturing and explaining others. In the following section, we will aim at describing OPEC and the oil market through both collusive and non-collusive oligopoly models, analyzing the positions of the organization and of its members within the industry. This way, the thesis wants to prove the applicability of the oligopoly models to the oil market and wants to show that these models could prove useful when considering possible future development of oil prices.

3.2.4 Price fixing cartel

In this section, it will be considered whether or not the broadly used term oil cartel can be used in line with economic theory when describing OPEC, if the organization acts cooperatively or non-cooperatively, and which roles its members have within the organization. After the WWII, the global oil market was dominated by a group of IOCs known as Seven Sisters, which controlled vast majority of the market and which were able to exert a significant power over the market. It is worth mentioning that the market with seven major players was not only very concentrated, but the players were strongly connected as well. As Griffin and Steele (1986) point out, the companies typically jointly owned and operated their production activities and facilities in the host countries. In Saudi Arabia, for example, the concession was co-owned by Exxon, Texaco, and Chevron – each owning a 30 percent stake and Mobil owning the rest. This way, the decision interdependency in the industry was fairly strong. Despite the barriers to entry, the profits achievable in the industry attracted new entrants and the prices were getting more and more similar to competitive ones. As the oil exporting countries relied heavily on the oil revenues due to fiscal reasons, they needed to act and restore the prices to a higher, more desirable level. To strengthen their position against oil importers, OPEC was founded. According to the OPEC statute, the aims and objectives are coordinating and unifying the policies regarding petroleum, and stabilizing oil prices to avoid undesirable fluctuations (OPEC, 1961). In other words, the member countries join the organization and commit themselves to act in accordance with the organization's decisions in order to be able to enjoy higher payoffs (represented by revenues from oil production). Let us now look at OPEC and see if its qualities meet the conditions and characteristics of a price fixing cartel.

First of all, we would like to reiterate that the oil market consists of relatively few relevant big players and the barriers to entry are immense. Thus, basic conditions of an oligopolistic market can be viewed as met. Furthermore, the product can also be considered as homogeneous. The reason why OPEC is viewed as a cartel is inherently connected with the principle of its functioning, which is quite simple. Oil ministers of OPEC member states meet biannually and, based on current market state and projections for future development, decide together on the price they will charge for the product, aggregated output of the countries and the portion of the volume which each of the states is allowed to supply to the world market. The allotment of oil supplies that the organization as a whole and each country respectively is allowed to supply to the market is known as the production quota. These quotas, even though they were introduced as a voluntary measure, are a very powerful tool which, if the countries do not adhere to it, can cause painful reactions of other member states as will be shown below. Based on the reasons in this paragraph, it can be judged that OPEC not only has a strong market power, but also that it did not hesitate to use it in the past.

If OPEC worked as a perfect price fixing cartel (see section 2.3.1 for more detailed characteristics of this model), it would limit or expand the quantity supplied to the market. This way, it would influence the price so that the marginal revenues are equal with the sum of marginal costs of the countries, and the payoffs of the countries are thus jointly maximized. This way, the cartel would act as a multi-plant monopoly and monopoly profits would be earned. In theory, the members of a perfect cartel have a predetermined share on the cartel profit, and therefore leave the price and output decision to the central authority. Knowing that the share of the profit is given, the producer will not have an incentive to increase its production in the first place as the output increase would result in a non profit-maximizing outcome. In real life, however, things tend to be more complicated. The countries act as sovereign producers despite their membership in OPEC, since it is the states that make the output decision in the end. As the countries receive their actual revenues as a payoff, not a predetermined share of the OPEC total revenues, cheating is commonplace. If the countries chose to deviate from the agreement and supply more in order to maximize revenues in the short run, they cause the prices to decrease due to the basic demand-supply relationship. In a perfectly functioning cartel, there would be an effective mechanism in place that would prevent the potentially deviating country from oversupplying - simply because the threat of being punished and losing revenues in the long run would be too big. This would motivate the countries to compliance with the cartel agreement.

The situation described above would be an ideal result which, in reality, is almost impossible to enact for multiple reasons – mainly because OPEC as an organization does not have any effective sanction mechanisms which could serve to punish a state deviating from the agreed oil production policy. With little incentive not to cheat (at least a bit) and with tempting payoff associated with cheating, the countries tend to diverge from the policies agreed upon and the perfect cartel solution is not achieved. The possibility of monopoly profit in the cartel is for these reasons very low, and even if it occurred, the perfect cartel outcome would be jeopardized by instability. To illustrate how frequent the overproduction within OPEC is, let us observe Figure 15, which shows the relation between total OPEC output and the total production quota.

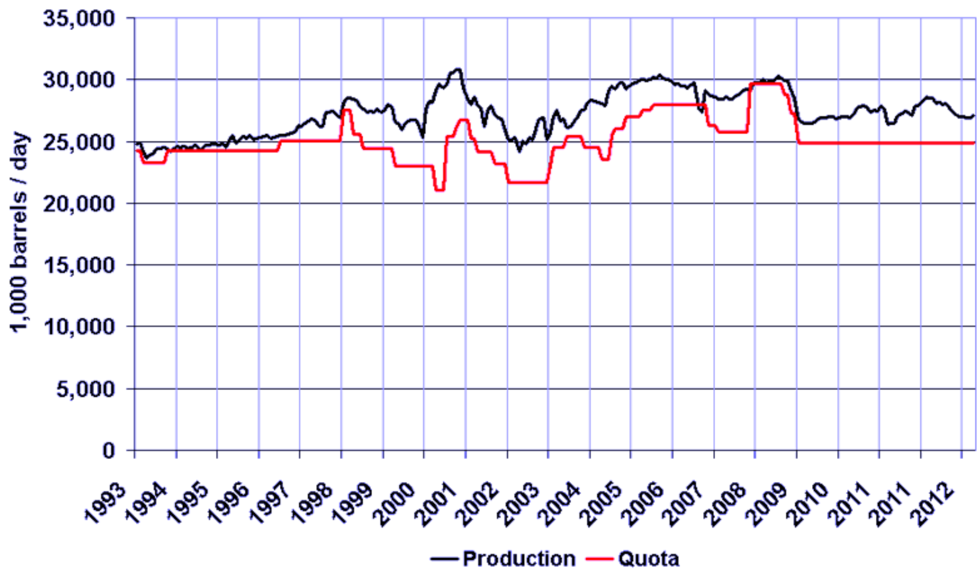

Figure 15 Actual OPEC production vs. quota 1993-2012 (Williams, 2012)

Empirically, the countries jointly produced more than the agreed output 96% of the time – and therefore decided to abandon usage of individual production quota system in 2012, keeping only the joint production ceiling (Colgan, 2015). As noted above, there is little incentive for the countries not to produce slightly more than agreed, but there is an incentive not to exceed the limits significantly. This incentive not to deviate a lot is put in place by the so-called tit-for-tat strategy (see in section 1.2.3) practiced by Saudi Arabia, which will be described in more detail in a separate section below. Another, rather practical factor preventing the perfect cartel outcome from happening is lack of timely and precise information about the state and development of the market demand and of the changes in non-OPEC oil supply. Finally, there is the fact that market share for OPEC has not been large enough to provide it with enough market dominance (Alhajji and Huettner, 2000).

3.2.5 OPEC as a market sharing cartel

Similar to the findings presented in the previous section, numerous studies suggest that rather than being a price fixing cartel, OPEC has in the past behaved as a market sharing cartel[21]. In contrast to price fixing cartel, the members of a market sharing cartel jointly decide on how they will share the market rather than on the price they will charge for the output. Since we aim to describe the application of the model

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[21] For further reference see Griffin (1985), Jones (1990), Gülen (1995), or Almoguera et al. (2011)

on the real world, the implications are not as clear cut as described in section 2.3.2 of this thesis. First of all, in the theoretical model we described a duopoly in which the firms were equally big. In reality, the number of OPEC members fluctuates over time, while the typical size is around 11 countries. Secondly, the marginal costs curves were the same in the theoretical duopoly model, whereas they will certainly differ in reality (the costs of drilling actually vary greatly depending on the location of the well). For these reasons the market will not be shared equally between the cartelists. The shares of the total production allotted to particular countries are described as quotas and depend not only on the MC curve, but also on their production capacity and bargaining power. But let us return to the basics of the market sharing cartel model.

In this model, the total market demand is faced by the producers to whom it is also known. Given that we know the market shares of the producers, we divide the market demand into partial demands for each producer. Where the MR and MC curves intersect lays the profit maximizing output and respective price – which is the same for all the players. In this scenario, the outcome for the producers would be the same as under multi-plant monopoly.

The shortcomings of this model relate to the conditions themselves. For the market sharing cartel to function, the members would have to operate with similar marginal cost curves. This condition might hold true for some of the gulf producers, but cannot be extended to all OPEC members, which are rather diverse and operate under various cost conditions. Secondly, and maybe even more importantly, the players in the market would have to agree with the share that they have, meaning that they should not be trying to increase their share on someone else’s account, i.e. trying to cheat. The development of shares of OPEC producers in the world oil market can be seen in Table 2. From this table the reader can best verify the validity of the model assumption regarding the stability and acceptance of market share. Generally speaking, cheating is tempting for the producers as it might bring additional profit in the short run, and therefore also common (see Figure 15 for comparison of quota and real production).

Table 2 Share of OPEC member states on the oil market 1973-1983 in per cent of the market (Griffin & Steele, 1986)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Saudi Arabia	23.9	26.8	25.1	27.1	28.4	26.9	29.8	36.8	43.6	35.0	28.9
Kuwait	9.5	8.1	7.4	6.8	6.1	6.9	7.8	6.2	5.0	4.5	6.1
United Arab Emirates	4.8	5.3	5.9	6.1	6.2	5.9	5.8	6.4	6.7	6.6	6.5
Iran	18.4	19.1	19.0	18.5	17.5	17.0	9.5	6.2	5.8	10.6	13.8
Iraq	6.4	6.2	8.0	6.8	6.1	8.3	10.8	9.3	4.0	5.0	5.7
Libya	6.9	4.8	5.2	6.1	6.4	6.4	6.5	6.6	5.0	6.6	6.1
Nigeria	6.4	7.2	6.3	6.5	6.5	6.1	7.2	7.6	6.4	7.0	7.1
Venezuela	10.6	9.4	8.3	7.2	6.9	7.0	7.4	8.1	9.3	10.3	10.2
Indonesia	4.2	4.4	4.6	4.7	5.2	5.0	5.0	5.9	7.1	7.3	7.9
Other	8.9	8.7	10.2	10.2	10.7	10.5	10.2	6.9	7.1	7.5	7.7

To test the hypothesis that OPEC is indeed a market sharing cartel, Griffin (1985) came up with a single equation model including the world demand for oil and non-OPEC supply of oil, from which he derived the demand for the organization's oil. Once the test was done, the evidence was supportive of the hypothesis that eleven OPEC member countries operate as partial market sharing cartel which is able to partially effectively coordinate its output. Jones (1990) adds that in partial market sharing model the cartelists are also able to respond less than proportionately to any changes in production by other cartel members, with no limits being set to reactions to changes in price. According to the latter study, partial market sharing behavior could be also used for description of majority of OPEC countries in the period between 1983 and 1988 (subsequent to Griffin's study).

One of the problems identified with market sharing cartel are the divergent aims of its members' groups, which can potentially threaten the stability of the cartel in the long run. The group of producers who are able to produce at lower marginal costs could increase their profits by setting their output level higher than their quotas allow, which, as we have shown for other cases in this thesis, would lead to decrease of the joint cartel profit. Moreover, if this behavior leads to the loss of trust of the other cartel members and the cartel falls apart, the profits of the former cartel members would only decrease as they would not be able to exercise as much market power as before.

Despite the cartel models proposed in this section, OPEC in reality has limited power over its member states' actions and rarely acts as a single body influencing the global oil price as agreed. However, there is one country, which has been able to unilaterally significantly influence the price by modifying its oil production – Saudi Arabia.

3.2.6 Price leadership with a dominant player

In a price leadership model with a dominant firm, as described in section 2.3.3 of this thesis, we describe an industry which consists of a price leader with established dominant position, and of competitive fringe players who act as price followers. Let us assume that price leadership model with a dominant player[22] was applicable during some periods of time to the behavior of OPEC.

If the model is to be applied on OPEC, it is necessary to identify who shall play the role of the dominant player and which countries shall be regarded as the competitive fringe. This task may not be as easy as it seems, since the model has been applied to the organization in three main variants. First and foremost, it has been used to capture the prominent position Saudi Arabia plays within OPEC and which is unquestionable given its reserves, production capacity, costs and spare capacity. In this version of the model, the role of competitive fringe is played by all the other member states. Secondly, the role of the dominant producer can be ascribed to OPEC core group[23] with the other member states being the competitive fringe. Finally, OPEC as a whole is by some viewed as the dominant firm, while the role of competitive fringe is played by all other world oil producers. Given the character of this thesis and room it provides, only one model will be described here. As Alhajji and Huettner (2000) tested the validity of the models in their study and confirmed that according to their analysis the model only holds true for Saudi Arabia as the dominant player, we will favor this variant and will also view Saudi Arabia as the dominant player and the rest of OPEC as competitive fringe.

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[22] As this section of the thesis aims at describing the behavior of OPEC and its member countries, the word *firm* in the Price leadership model with dominant *firm* will despite general conventions be substituted by the word *player*.

[23] The countries listed among OPEC core are typically Saudi Arabia, Kuwait, Qatar, United Arab Emirates and Libya.

Let us therefore assume that the model as described above is valid. If we make this assumption, the demand for Saudi oil would be determined by the total demand for OPEC oil and the supply of competitive fringe, i.e. the other members of OPEC. The demand for OPEC will be calculated simply by subtracting demand for non-OPEC oil from total demand for oil. The difference between total quantity demanded and quantity supplied by the fringe is supplied by Saudi Arabia. Saudi Arabia acts as a price leader, setting the price for all market players. It chooses a price which indicates a level of output of Saudi Arabia where its marginal costs equal the marginal revenues. The competitive fringe players accept the price as given and make their output decision by computing where their marginal cost curve is equal to the price set by the price leader. The Saudi Kingdom acts as the residual seller, because it supplies the volume of oil to the market that is equal to what is left from the market demand after subtracting the supply of the fringe.

What makes this model better than the previous cartel models according to Griffin and Steele (1986) is the absence of problems presented by price determination in market sharing model and the absence of rivalry between the organization's members – simply because the only country who makes the decision about price is Saudi Arabia. According to their line of reasoning, all the other OPEC members who take part in ministerial conferences in Vienna behave the same way – as fringe players. This model, similarly to the previously introduced ones, presents major shortcomings because it fails to explain some past behavior and developments. Firstly, as was demonstrated in previous section (see Table 2), the shares of the producers are relatively stable over time despite the developments in the market – suggesting that the producers might be involved in collusion in order to enable output restriction. Similar conclusion can be made based on the decrease of production in 1983, which was borne by all OPEC players, who had to decrease their output level. Secondly, it is the suggestion that all countries apart from Saudi Arabia behave as competitive fringe and have no market power that makes this model imperfect.

Let us now move from modeling the behavior of OPEC and the oil market as a whole to understanding the behavior of its particular players. We will start this by looking at Saudi Arabia.

3.2.7 Saudi Arabia as a swing producer

The demand for oil is changing over time and so is the volume of production countries are able to produce, irrelevant if OPEC members or not. To keep the market price relatively stable and thus enable sustainable long term profit, it is necessary to balance increase of the volume of oil supplied by one or more producers in the market by decreasing petroleum production somewhere else in the market, given that other conditions remained the same. Under the same assumption, when other suppliers decrease their production for any reason, stabilization can be achieved by increasing the production by another market player. The player whose role is to balance the production in this sense is known as a swing producer. To act as a swing producer in the oil market, the country (or company) needs to have considerable excess production capacity it does not use which can be involved when other players' supply is disrupted. The decision to employ this excess capacity or the opposite action of a decrease in currently used production capacity should be possible with low costs. Moreover, these reactions need to be quick so that the actor can effectively balance the market changes without any major price fluctuations. Finally, from the practical point of view it is important that the swing producer has enough financial reserves that enable its smooth functioning even with temporarily decreased revenues from oil production (Berman, 2016).

The player who fulfilled the aforementioned criteria in the past is Saudi Arabia, who played the role of the swing producer repeatedly in the history of OPEC[24].When Saudi Arabia acts as a swing producer, it has to balance the fluctuations in the supply of competitive fringe by restricting or expanding its own production. When the quantity supplied by other OPEC members decreases, and the demand for OPEC oil remains constant, the quantity demanded that Saudi Arabia covers with its supplies increases. As we said in the beginning of this section, the quantity demanded for OPEC oil changes over time as the total world oil consumption changes, and the suppliers' ability to react to these changes differs greatly. Saudi Arabia, which possesses considerable spare production capacity, can react quickly to balance these fluctuations, whereas other countries with lower or none spare production capacity cannot. This way, Saudi Arabia can manage to contribute to the desirable higher price

[24] The Saudi Arabia's role of swing producer was not only a conscious one, but it was also openly admitted during long reign of Sheikh Yamani over the Saudi oil ministry. See: United Press International (1985) and Daniels (1986)

stability. The Saudi Kingdom, as a rational player, does so if and only if that strategy is profitable for the country. This last criterion is very important in understanding when and why the country decides to stop acting as the swing producer. When the production of the Saudis decreases below the level achievable under the non-cooperative Cournot game of individual profit maximization, the country would decide to change its strategy and increases its production. This way, the outcome of the game is jointly worse for the producers, but the effects are not borne solely by the Saudis, but by all the producers. Such strategy will be described in the next section of this thesis.

Based on the available historical data, it has been verified that the Saudis acted as the swing producer within OPEC (Al Yousef, 1998). This has also been confirmed by Griffin and Nielson (1994) who observed that Saudi Arabia was deliberately playing the swing producer role provided that the other countries did not produce too much in excess of their allotted quota. The development of oil production of Saudi Arabia and other OPEC countries is shown in Figure 16. In the graph, the Saudi reactions to other members' changes in supply can clearly be identified when the dotted line mirrors the upward spikes in the solid line with its drops and vice versa.

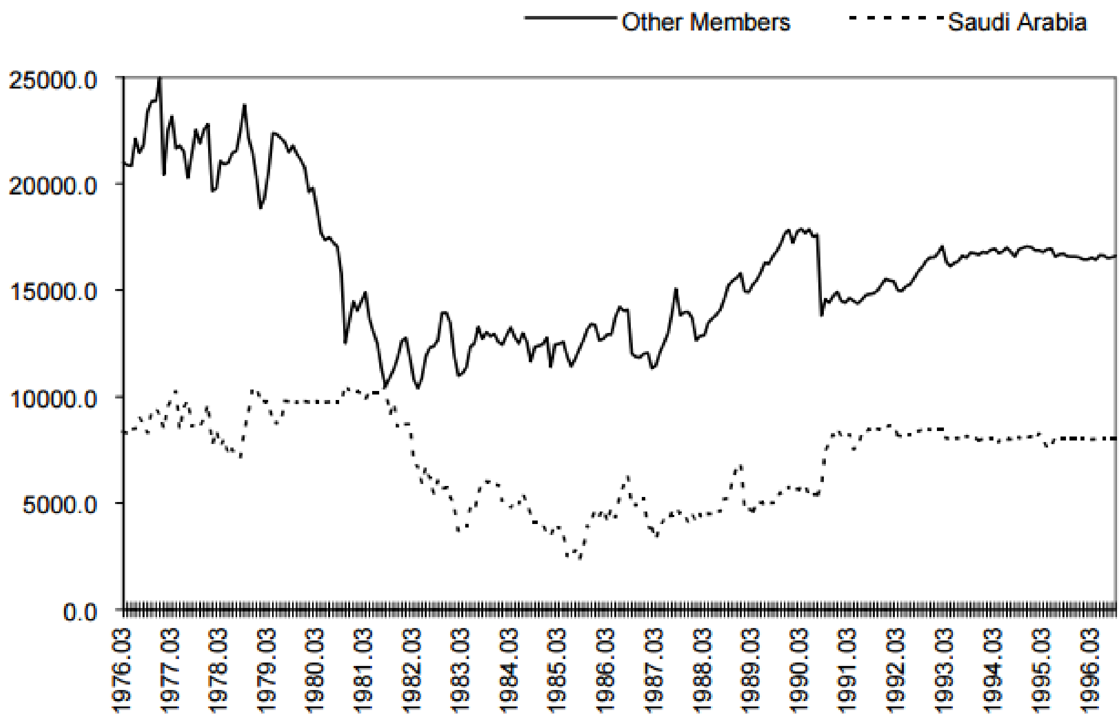

Figure 16 Oil production of Saudi Arabia and other OPEC member states in thousands barrels per day (Al-Yousef, 1998)

Some media also believe that the rapid fall in oil prices which happened in 2015 was caused by Saudi Arabia's decision to abandon its role of swing producer. The role has been assumed by the country before the crisis, which enabled the oil prices of more than $100 per barrel (oilprice.com, 2015). When Saudis decided to increase their production, they wanted to increase their revenues. Little did the Saudis know that they will trigger one of the biggest falls in oil prices in history. The current situation in oil market will be discussed in more detail in one of the following sections, but for the sake of completeness it was deemed appropriate to mention the major root cause of the current state of events in this section of the thesis as well.

From the facts that have been presented so far it is to be understood that the role Saudi Arabia plays within OPEC has been developing and changing over the decades because of the changes that the oil industry and world political-economic reality has undergone. It is important to reiterate that the swing producer role, while being beneficial for OPEC members as it stabilized the oil prices over time, was only viable for Saudi Arabia if the other members played principally according to the rules. If this was not the case, and the profit the Saudis obtained was to fall below the Cournot outcome (as in August 1985), they would abandon the swing producer strategy and start playing tit-for-tat (Griffin & Nielson, 1994).

3.2.8 Saudi Arabia playing tit-for-tat strategy

The tit-for-tat strategy, in general, is a strategy under which one player punishes another player for not playing cooperatively, resorting to uncooperative behavior himself. As opposed to grim trigger strategy, once the punished player reverts to playing cooperatively, the punishing player follows suit and returns to playing cooperatively as well. When applied on the behavior of OPEC member states, we can say that a state may either play cooperatively, adhering to the joint profit maximization pattern and producing such amount of output that matches its quota, or a state can play uncooperatively. If a country decides to play uncooperatively and produces significantly more than the allocated quota in order to increase its short run profit, the behavior will be matched by Saudi Arabia. Such reaction therefore presents effective punishment, because the increase in production would push the prices in the market down. When the punished state realizes that in order to earn long term profit it needs to play cooperatively and does so, the production of the agreed volume by the punished state is rewarded by Saudis who revert to producing the agreed level again, or to being the swing producer, which brings the countries higher profits.

According to the analyses conducted by Geroski, Ulph, and Ulph. (1987) and Alkhathlan, Gately, and Javid (2012) this strategy has been repeatedly applied by Saudi Arabia throughout OPEC’s history. The research done by Griffin and Nielson (1994) supports the idea as well, backing it with empirical evidence. What the study says is that Saudi Arabia, will tolerate cheating by other members of the organization provided that the profit it earns itself is above the Cournot-game level. Once the profits decrease below the Cournot-game level, Saudis abandon their swing producer role to play tit-for-tat, increasing their production until all the players get to Cournot-level profit. The impact of this strategy can be seen in Figure 17.

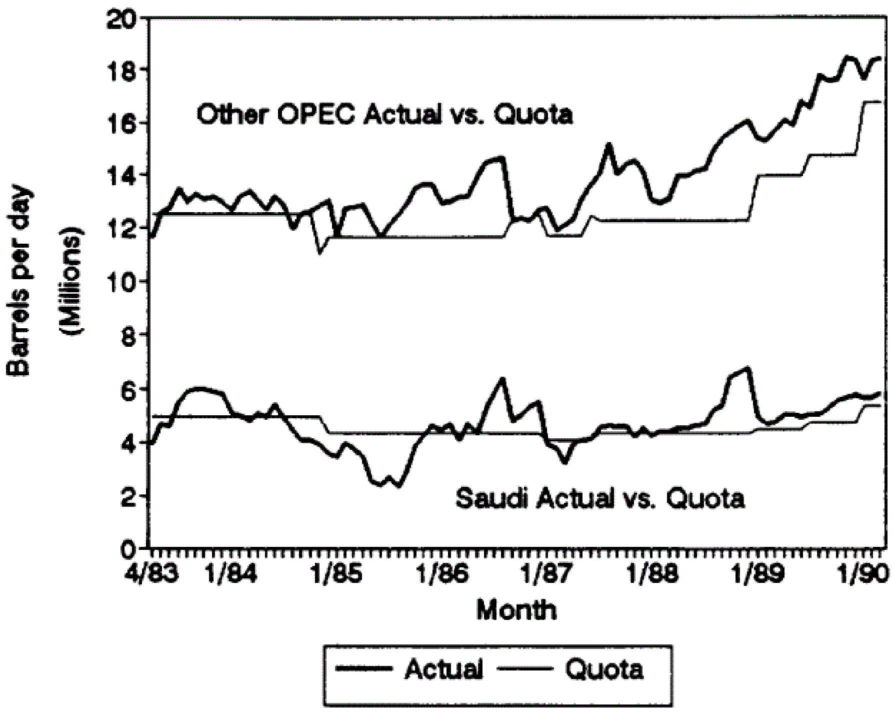

Figure 17 Breakdown of actual OPEC production vs. quota 1983-1990 (Griffin & Neilson, 1994)

Other members of OPEC have been producing above the quota, while the share of Saudi Arabia, who behaved as the swing producer, was constantly decreasing from early 1984, until mid 1985. Then the Saudis decided to boost their production to punish the states that played non-cooperatively and produced in excess of the agreed volume. We can see that the volume produced by the Saudi Kingdom increased from about 2 million bpd in mid 1985 to more than 6 million bpd about one year later. We can also see that this level of production served its purpose and helped to discipline the other OPEC members, who decreased their volume of output to the quota level, allowing Saudi Arabia to recover its market share and position (Griffin & Neilson, 1994). A similar series of events was triggered by the flagrant cheating of OPEC states in 1988, when they exceeded the quota level by more than 3 million bpd. Saudi Arabia reacted to this by adopting the tit-for-tat approach and increased its production from about 4 million bpd to more than 6 million bpd within a year.

In section 3.2, we have seen that OPEC has undergone quite a few changes during its development from the early 1960s, throughout the oil shocks and crises in 1970s and 1980s until today. The complexity of the oil market and of the behavior within OPEC can hardly be captured in one, standard theoretical model. Particular phases in the organization's history, side to some of the models while other periods in the development indicate a similarity to a different one. In line with this, the evidence has been exhibited to support the application of target revenue model explaining the stabilization of increased oil prices in the mid 1970s. We have seen that rather than being a price fixing cartel, the *oil cartel* could have been characterized as a market sharing cartel in a great part of the 1970s and 1980s. Moreover, it was shown that the role of Saudi Arabia within the organization could be notably viewed as the dominant player role in the non-collusive price leadership model. Finally, evidence has been presented that the strategy that the Saudi Kingdom has played in the past has been that of swing producer within OPEC, provided that the country is able to earn above Cournot-game profits. If this is not the case, the country resorts to tit-for-tat strategy to punish the other players who played non-cooperatively and only had their short-run profits in mind. In the next section, we will aim at applying the theory to explain the situation in oil markets nowadays[25], and what led to falls in prices which have begun in 2014 and are still happening as of early 2016.

[25] This section of the thesis is being written February 2016 and therefore reflects only the developments to date.

4 Applications of game theory on the current oil market situation

In the last fifteen years, the oil prices have constantly been developing, without showing a period in which they would be more or less stable. In the early 2000s, the crude oil prices were around \$30 per barrel. From then onwards, as the global economy was rising, so were the oil prices - hitting a historic ceiling of more than \$140 per barrel in mid 2008. In the beginning of the financial crisis, the prices have dropped to approximately \$40 per barrel to recover soon, and moved in the range of \$80 to \$110 per barrel for the next five years. In the summer of 2014, however, the prices started to drop significantly – from the price of \$110 per barrel to their current level of not much more than 30 per cent of their former price, as shown in Figure 18. In this section, we would like to explore how applications of game theory can help us understand the price development in the last years. This way, the underlying motives of the players will be put into context and their positions will be easier to assess and grasp for the reader.

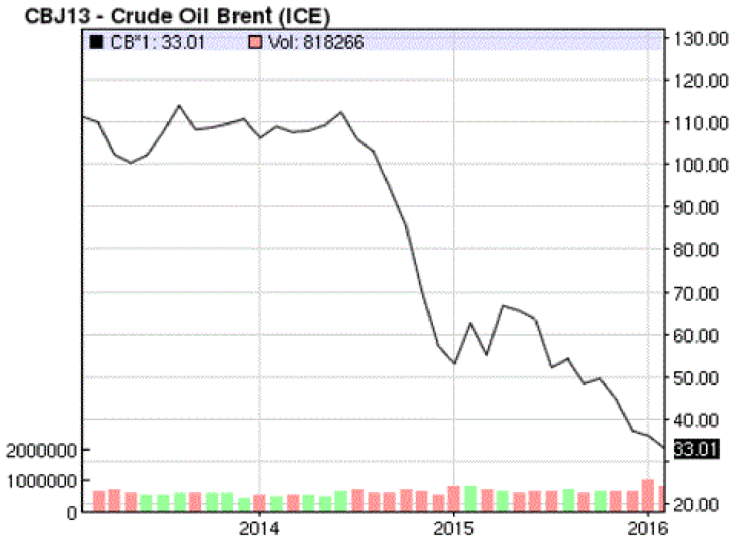

Figure 18 Three years' development of Brent oil prices (NASDAQ, 2016)

4.1 The rise (and fall) of shale producers

As in other markets, the prices in oil markets are derived from the demand and supply. What makes the current situation in the oil market different from the oil price slumps it has experienced in the past is that this time it is the predominantly the supply side of the market that has caused the change, and not the demand side[26]. The oil glut in 1980s, for example, was caused by the decrease in demand after the oil crisis in the late 1970s (Hershey, 1981). The current falling prices, however, have been caused by the producers oversupplying the market.

The increase in supply has been quite rapid and can be attributed predominantly to the phenomenon of shale oil production in the US. It was the relatively high prices of oil throughout the 2000s that made this rather expensive method of oil production possible. Thanks to these higher prices the investment in shale oil projects was economically viable and the US production has increased from about 5 million barrels per day five years ago to about a double nowadays (EIA, 2016b). With the oil demand relatively stable, such output increase was bound to cause a major change in the oil market, unless there was a player in the market willing to decrease its production and act as a swing producer. Some might have expected that this role will again be taken up by Saudi Arabia that, as we have shown in the previous sections, played it many a time.

Before we come to assessing such possibility, let us state facts that are crucial for understanding the position of the shale producers. First of all, as we have mentioned above, the production of shale gas is relatively expensive in comparison with other production methods, despite the trend of decreasing production costs as the technology becomes more advanced. We can see the comparison of shale production costs to the costs of other oil production methods in Figure 19.

[26] The development on the demand side, nevertheless, has contributed to the market development as well. Notably, the demand of the People's Republic of China which was fueled by the rapid economic growth in the past is strongly affected by the Chinese economic growth slowing down.

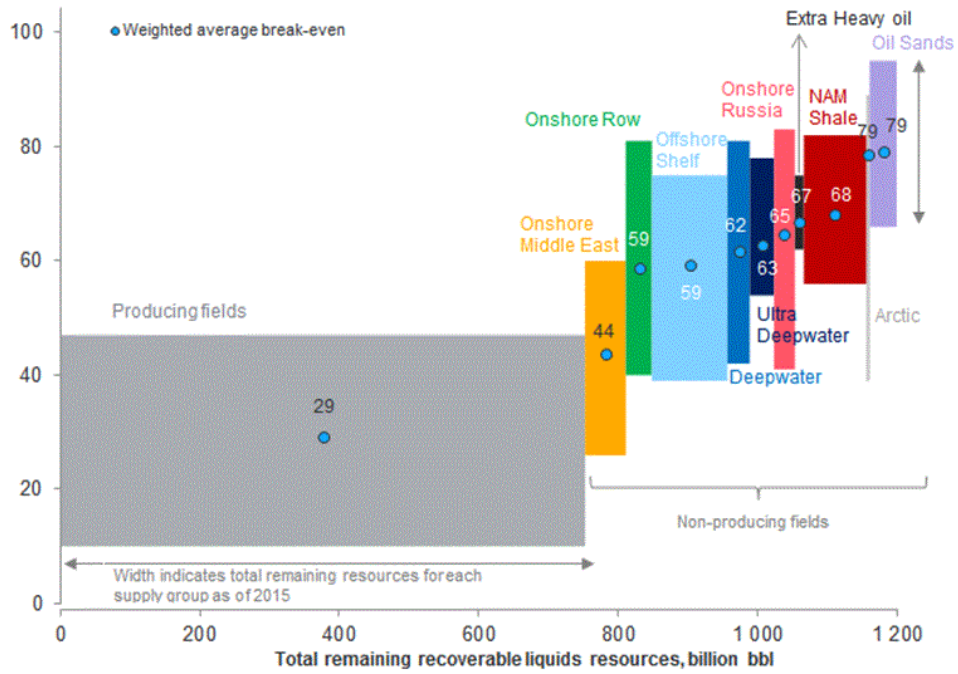

Figure 19 Comparison of oil production methods by average breakeven price and recoverable reserves (rystadenergy.com, 2015)

This figure shows a combination of two important indicators for each production method. Firstly, the vertical axis shows us the breakeven price interval and the average breakeven price. These prices are calculated using the NPV method with the discount rate of 7.5 per cent. The horizontal axis shows us the remaining recoverable reserves for each of the methods in billions of barrels. If we take shale oil producers, we can see that their average breakeven price is 68 US per barrel. The field producers, such as Saudi Arabia, have the average breakeven at $29 per barrel, which is less than half of the former. The total recoverable reserves of the North American shale producers are less than 100 billion barrels, whereas the oil fields still hold up to 800 billion barrels of recoverable oil (rystadenergy.com, 2015).

Secondly, it is worth taking into consideration that shale oil industry is not concentrated. There are therefore a large number of small firms who take part in the shale oil operations, which limits the possibilities of a unified output decision.

The final point is connected with both previous points. As the shale oil industry has very high requirements on capital expenditures, vast majority of the small players that had decided to enter the market had to include a lot of debt in their capital structure, so their leverage is very high. This increases their cost of capital and thus makes their breakeven price even higher.

During the shale oil boom and the resulting situation in the oil markets the topic has been raised[27] whether the shale producers are becoming the swing producer of the oil market. The reason for this is not only the increasing share of shale oil on the total oil production, but also the fact that there is still a lot of drilled but untapped shale oil wells, which could potentially be put into production if necessary. The disadvantages of the swing producer role are listed in the previous paragraphs and are very strong. The response by the shale producers would not be timely enough and would be far more expensive than that of the conventional producers. Secondly, the swing producer role would require the US shale producers to act as a unified body which, again, is very improbable. The country which can effectively act as the swing producer, the same way it did since the 1970s, is Saudi Arabia.

4.2 The position of Saudi Arabia

As we have seen in section 3.2.7, the Saudi Kingdom has repeatedly taken upon itself the role of the swing producer. This time, however, the game is different for the Saudis. The fact that the oil glut was caused by the supply and not by the demand plays a major role here. The production capacity in the Northern America is booming due to massive exploration effort and due to the exploitation of shale gas fields, and so is the part of this capacity which can be employed in production in relatively short time. The short run and long run elasticity of the shale producers' supply is crucial here, as it indicates how fast they can react to the change in market price. If the Saudis accepted the swing producer role for the future, the consequence could be potentially life threatening for the country – with increasing shale production it would be losing its market share and would generate less than Cournot-game profit.

As a result, what the country did was the exact opposite of the swing production. In November 2014 OPEC meeting Saudi Arabia openly stated that it decided not only against cutting its production as might have been expected, but to actually increase it slightly (Zervos, 2016). The expectable reaction of the market has followed and the oil prices started to fall. So what made the Saudis act this way and not the opposite?

[27] See for example http://www.worldoil.com/news/2015/8/19/us-shale-operators-may-be-the-new-swing-producers or http://www.economist.com/news/business/21651267-american-shale-firms-are-now-oil-markets-swing-producers-after-opec

There are multiple reasons for this behavior. First and foremost, by increasing its output it has clearly stated its mission of keeping a significant market share in the oil market and its understandable unwillingness to give it away. Also, the prices that have been common in the markets before the current glut were high enough to attract new entrants to the market – notably the shale producers. Vast amounts of money have been invested into research and development of shale oil production technologies. Logically, the more is invested into the technology, the more efficient it can potentially become. The more efficient is the technology, the lower are oil production costs and the better the competitiveness of shale oil production. It is therefore very probable that Saudi Arabia allowed the prices to decrease in order to stop the flow of money into shale oil research and development and into prospecting of new shale oil beds which would add even more production capacity. Evidence suggests that this has proven successful for the Saudis. According to the energy consultancy Wood MacKenzie (2016), the combined value of oil and natural gas projects that have been put on hold due to the oil price decreases is estimated at $380 billion, deferring production of additional 2.9 million barrels per day. Large share of those projects arguably are shale oil projects.

Secondly, high prices of oil in general are not only attractive for new entrants to the market with the same product, but also for the entrance to the market of oil substitutes. The more expensive oil becomes, the more effort and money would be invested into finding alternative sources of energy, and into development of more efficient machines which would require less fuel. This would weaken the Saudi position which is relatively solid given the vast Saudi oil reserves. If oil becomes substitutable, these reserves would be worth less and the country would lose a lot of money and power.

The third reason for the behavior of the Saudis might be seen in its relationship with Iran, which can be characterized as that of rivals rather than friends. Since the sanctions on Iran have been lifted recently, the country has been able to start exporting oil without restrictions, adding some 1 million barrels per day to the market. If the Saudis withdrew and let the prices be higher, they would not only lose share (relative to Iran), but they would also let Iran earn considerably more money through the oil export revenues. These revenues could potentially be used to buy imports (such as modern oil extraction equipment) which have not been available in the country when the embargo was in place.

The final reason is one of the most prominent ones as well. It would be simply more expensive for Saudi Arabia to lower its production than to pump more at lower prices. The country is able to produce oil at very low costs, possibly the lowest in the world, and it has very large oil reserves available for production. Despite decades long efforts to decrease the reliance of Saudi Arabia on oil through diversification the country is still strongly dependent on the oil sector, which is the single biggest contributor to the nation's GDP (Aissaoui, 2013). In fact, the problems that the Saudi budget faces due to the low oil prices are not unique within OPEC, as illustrated in Table 3.

Table 3 Fiscal breakeven price and deficit for OPEC countries (cnbc.com, 2015)

		Fiscal Break-even price	Fiscal deficit (% GDP)
Algeria	$	96.10	-13.90%
Angola	$	110.00	-3.50%
Ecuador	$	-	-5.10%
Iran	$	87.20	-2.90%
Iraq	$	81.00	-23.10%
Kuwait	$	49.10	1.20%
Libya	$	269.00	-79.10%
Nigeria	$	122.70	-2.80%
Qatar	$	55.50	4.50%
Saudi Arabia	$	105.60	-21.60%
United Arab Emirates	$	72.60	-5.50%
Venezuela	$	117.50	-24.40%

In the table, it can be seen that under the current market price of about $33 almost all the countries will have deficit budgets, as these were forecast for much higher oil prices. In spite of the vast financial reserves possessed by the Gulf countries – UAE, Qatar, Kuwait and Saudi Arabia, even these countries cannot tolerate the low prices for a long time. For these fiscal reasons of increased oil production it can be assumed that the Saudi supply curve is backward bending. If this is true, the country is seeking target revenue – and it most probably is doing so given that oil revenues are an essential source of the country's budget. With the oil prices down, the country simply has to pump more oil to arrive at the same level, or to at least try to come closer to it.

4.3 What should the Saudis do?

In the previous paragraphs, we have outlined the situation Saudi Arabia and other countries find themselves in nowadays. With all the factors that need to be taken into consideration, the decision making process of the Saudi oil minister is undoubtedly incredibly hard. In this subsection, we will try to describe this process by writing it down in form of a game, as a simplification of the approach proposed by Fattouh, Poudineh, and Sen (2015). To be able to do that, we will assume that Saudi Arabia is only seeking economic goals in the game and not political ones. The aims that the country achieves through modification of its output are securing target revenues and target market share. There are four basic situations in the market, some of which can trigger a reaction from Saudi Arabia. These are the cases when either the price or the market share is below the target level, or both of them are below the level, or neither of them is.

If the market conditions are such that neither the price nor the market share is below the target level, no change in output decision needs to be made, since it would not be desirable. If the revenues are lower than the target due to lower price yet the market share is in line with the target, the country should consider if the benefits of affecting the price by an output decrease are higher than the costs associated with such move. If this is true and the benefits exceed the costs of the price increase, the output should be decreased, otherwise no action is required. In the situation in the market where the price meets the target level yet the market share does not, we should again consider if the benefit of output increase outweighs the costs associated with it. If yes, the output should be increased, if not, no change shall occur. Finally, if both the price and the market share are below the target level, the country would need to ask itself which of the two aims has a priority – and proceed accordingly along the respective scenario out of the aforementioned two.

The situation best describing the one Saudi Arabia is facing nowadays is the second one, meaning that the market share of Saudi Arabia is relatively fine but the price it gets for the production is not, since it by far does not allow it to fill the national budget. Let us now see under what circumstances the country should cut its output as was suggested above. For this, we will look at a game in which Saudi Arabia and other OPEC members act as two quantity choosing players. The payoff can be either A, B, or

C (or the negative value thereof), or 0. The relation of the three payoffs can be characterized as follows:

$$A>B>C>0$$

The countries do not have information about the ability of shale oil producers to come into the picture quickly by increasing their production, if the players – the Saudis and the rest of OPEC – decide to cut their output. Since they do not know the elasticity of the shale oil supply, we will look separately at a game in which the supply is elastic and in which it is inelastic. The payoff matrices for these games are shown in Figure 20. In both games, the players will have two options – either to cut the output or to leave it at the current level. In the game we will observe first, US shale supply is elastic, which means that the shale producers are able to adjust quickly to the price changes. In this case, the dominant strategy for both players is clear – not to cut the output.

Game 1: Elastic US supply

		Other OPEC members	
		Output cut	No change in output
Saudi Arabia	Output cut	-C, -C	-A, 0
	No change in output	0, -A	0, 0

Game 2: Inelastic US supply

		Other OPEC members	
		Output cut	No change in output
Saudi Arabia	Output cut	A, A	C, B
	No change in output	B, C	0, 0

Figure 20 Payoff matrices for games in the falling market (Fattouh, Poudineh, & Sen 2015)

In case that the supply of shale producers is inelastic, the payoffs of the game look quite different. If both players (Saudi Arabia and Other OPEC members) decide to cut their output, the prices will increase more significantly than if only one player decides to make the cut. This is reflected by the highest possible payoff (A, A) in the upper left field in the matrix. If only one of the players decides to cut the output while the other maintains the current output level, the output-cutting player would receive lower payoff then its counterpart, but both payoffs would be positive. If no action is taken, neither player can enjoy any benefit and the payoffs are thus zero.

The biggest practical problem with determining a proper reaction for the Saudis in this game, and to a great extent in the real world as well is that there is not enough available data about the elasticity of supply of the US producers. If this crucial information is missing, the players cannot determine in which of the games they find themselves, and therefore their choice will be made under uncertainty. To make a decision under these conditions, the player would calculate the expected payoff of both strategies (in this case 0 for output cutting and B/4 for no change in output) and based on this information the player will be able to determine which one to play (in our case no change in output). Thus, the recommended strategy for Saudi Arabia, provided that the assumptions are true and that the country does not have information regarding supply elasticity of the shale producers, would be not to change output, because this strategy has higher expected payoffs.

As the most recent development has shown, the Saudis might now finally be switching to this strategy[28]. In order to at least partially decrease their level of uncertainty, the Saudis try to leverage the position they find themselves in by negotiating with other oil producers on a common action. Even though they are not finalized yet, the talks between the Saudi Kingdom, Russia, Iran and other OPEC oil producers held in Qatar which aimed to freeze the output on the current level, have already helped the prices increased slightly (Sheppard, Raval, & Farchy, 2016). This agreement, being the first output agreement within OPEC since 2014, has potential to be a watershed in the current oil prices. Whether the strategy Saudi Arabia chose was right and this agreement will indeed turn out to be a turning point, will be only known in the future.

It remains true, however, that the small victory of Saudi Arabia might prove pyrrhic. With the prices of oil being very low, the shale producers will exit the industry for the time being. Saudi Arabia and other oil exporters whose budgets are reliant on oil revenues will suffer deficits and would have to consider austerity measures. Once the

[28] See for example: http://www.ft.com/intl/cms/s/0/da44fb1c-d485-11e5-8887-98e7feb46f27.html#axzz40yODOHxk or http://www.bloomberg.com/news/articles/2016-02-16/saudi-arabia-and-russia-agree-oil-output-freeze-in-qatar-talks

price level is sufficiently high, the shale producers will be motivated to flock back into the market. With the production technology on a higher level than before, and with already bored wells which have been conserved and remain untapped for now, chances are high that the comeback of shale producers will be much faster and stronger than their rise which has led to the current oil price slump. For us as consumers, however, this is principally good news, because it implies that the oil prices are bound to be stabilized around the level which allows the shale producers to be in the market as well, while at the same time not exceeding it significantly. The price of oil, provided that there is no unforeseen change on either the demand or the supply side, will most probably remain well under the magical threshold of $100 per barrel in the near future.

5 Conclusion

In this thesis, we have looked at the global oil industry through the perspective of game theory. The global oil industry has been chosen, as explained in the thesis, because oil is a scarce resource which has served as an indispensable source of energy for a great part of modern history. Today, about one third of all energy consumed worldwide comes from petroleum, and most vehicles use fuel based on oil. With the ever increasing population, economic growth and consumption, it is clear that oil will remain in focus in the coming years as well, and it is thus vital to understand the oil industry in greater detail. Recognizing the importance of the oil industry, we wanted to see in this thesis if it is indeed true that *"no one can set the price of oil – it's up to Allah"* as Ali al-Naimi, Saudi oil minister, wants us to believe, indicating that no player in the market can influence the prices of oil. Or, more specifically, we wanted to verify that al-Naimi's claim is nothing more than *smoke and mirrors*, an unsubstantiated explanation covering and hiding the factual market power of the oil producers.

First, we have looked at the basics of game theory, which is a branch of economics which studies strategic interaction. We have shown what is understood under the term *game* in this context, and that there are several types of games, such as sequential and simultaneous, cooperative and non-cooperative. The elements of the games were outlined, and we looked in greater detail at different types of strategies that the players of the games can play. These game-theoretic foundations have enabled us to dive deeper into one of the topics this branch of economics covers, namely the theory of oligopolies.

Oligopolies are a market structure which is characteristic for an industry where there are only few supplying firms (or countries in our case), and where the firms interact strategically. In this chapter, we have covered models of both collusive and non-collusive oligopolies ranging from the Cournot and Bertrand model to cartel and price leadership model. The order in which the models are presented was designed so that the flow of the thesis is logical and coherent, and aimed at showing the similarities as well as contrasting the differences of the models. With the oligopoly models presented to the reader, the following two chapters used these models in describing and assessing the behavior of the players in the global oil market throughout the history and nowadays.

A classic author once wrote, "*My friend, all theory is grey, and green the golden tree of life.*"[29] In the first of the two practical chapters we therefore focused at finding out which of the theoretic oligopoly models (if any) can be used to capture and explain the complexity of the behavior of OPEC countries in the global oil industry in different development stages of the organization. Firstly, we have discussed the possibility of explaining the price development in the oil market by non-oligopoly models. Secondly, we have looked at the global oil market in the light of oligopoly theory, including both collusive and non-collusive models. As was said before, the Organization of the Petroleum Exporting Countries has undergone quite a few changes during its development from the early 1960s, throughout the oil shocks and crises in 1970s and 1980s until today. Given all the changes that occurred both inside the organization and in the market as a whole, it is clear that the behavior of OPEC can hardly be captured in one, standard theoretical model. At the same time, it can be concluded that some of the models are suited for specific times in the history of OPEC, while other periods in the development indicate a similarity to another one.

In line with this, evidence has been exhibited to support the application of target revenue model which explains the stabilization of increased oil prices in the mid 1970s. In contrast to what many people might suspect, we have seen evidence that rather than being a price fixing cartel, OPEC could be characterized as a market sharing cartel in a great part of the 1970s and 1980s. Evidence has also been collected to support the theory that the role of Saudi Arabia within the organization could be described as the role of a dominant player in the non-collusive price leadership model. Finally, we have concluded that the strategy that the Saudi Kingdom has played in the past has been that of the swing producer within OPEC, provided that the country's earnings exceed Cournot-game profits. If the Kingdom is not able to earn this level of profits, the country resorts to tit-for-tat strategy. Regarding the objective of the third chapter, we can conclude that the theoretic models presented above can indeed be used for understanding the past behavior of the OPEC member states, and that in different periods of time the organization's functioning was changing.

[29] Johann Wolfgang von Goethe's Faust, Part 1. As translated by David Luke in Goethe, J. W., & Luke, D. (2008). *Faust*. Oxford: Oxford University Press.

The objective of the last chapter was to explain the current oil market crisis through applications of game theory and the models included in the second chapter and to see if the crisis could be solved using game theory. The crisis has been manifested by the steady decrease in prices which has begun in 2014 and is still happening as of early 2016. The crisis itself was caused by the supply side of the market exceeding the demand, caused by the fast growing production of US shale producers. This makes the crisis different from the previous ones (e.g. the one in the early 1980s), which were caused by a drop on the demand side.

With this in mind, the possibilities that the biggest OPEC producer, Saudi Arabia, is currently facing have been assessed. The Kingdom has to make a decision without having full visibility on the factors that will influence the outcome of the decision, so it has to decide under uncertainty about the price elasticity of US shale producers supply. The best option for the country, as shown above, is therefore abandoning the swing producer role, which the country had followed in the beginning of this crisis, and a clear strategy of not changing the output. The expected payoff of such strategy is higher for the Saudis than in the situation which would involve output cuts. It remains true, however, that the low oil prices might force the shale producers out of the oil market for a while, but they will most probably flock back into the market once the price is high enough for them to cover their production costs, which should be possible at levels of about $50-60 per barrel. The current prices of oil are devastating for national economies of many oil exporting countries, and they are therefore not sustainable for them for a long time. With the possibility of shale producers' comeback and rise, the prices should remain relatively low and stabilized at a level which allows the more cost-efficient shale producers to be present in the market as well. The price of oil, provided that there is no unforeseen change on either the demand or the supply side, will most probably remain closer to the levels of $50-60 in the near future, well under the magical threshold of $100 per barrel.

As we have seen in this thesis, the game theoretic models are a valuable tool for analyzing the past behavior of the players in the oil market, and help us understand how the industry worked in a particular period of time. The usefulness of these models for predictions, on the other hand, is limited, since they tend to oversimplify a lot of the complexities that the real world has. Also, the models do not take into account other motives of the countries, such as how much political power the country possesses. The author nevertheless believes that the application of game theory on the global oil industry has proven insightful and priceless in understanding the decision interdependency of the players and the limited possibilities they effectively have.

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