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OPEC and the Crude Oil Market with Game Theory Applications

I. Introduction

The Organization of the Petroleum Exporting Countries (OPEC) has been a major player in the world market for crude oil ever since the organization's formation in 1960. Since its original intergovernmental arrangement including Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela, the group has increased to 12 countries, all significant exporters of crude oil voted in by the other members. While there are oil-exporting countries that are not members of this organization, their production decisions and opportunities for profit have in the past been greatly affected by the decisions of OPEC. The industry is becoming increasingly complex, however, as non-OPEC countries are picking up ground in oil production. The United States has become the world's leading oil exporter in recent years, and Russia and China are steadily increasing their oil production as well (OPEC Monthly Oil Report, Dec. 2014:47).

OPEC's influence on the prices and production levels of the oil industry are nowhere near the amount of control they had in the 1970s (Gardner, 2003:191). The world is currently experiencing rapidly decreasing oil prices, and OPEC is no longer living up to its "cartel" reputation by attempting to control prices by manipulating production (Ferro, 2014). Saudi Arabian Minister of Petroleum Ali Al-Naimi recently responded to questions about OPEC's plans in wake of the dropping prices by saying that he saw no reason for Saudi Arabia to cut production. Saudi Arabia has a much greater market share and production capacity than its fellow OPEC members, which has lead smaller OPEC producers to become frustrated with Saudi Arabia's lack of cooperation with the group's mission of keeping oil prices stable. Venezuela

Prime Minister Rafael Ramirez told reporters: "Our position on OPEC is that they defend the fair price of our oil. We don't believe in the free market. We must make an effort to reduce overproduction of oil" (Smith, 2014).

Even though OPEC has been viewed as a cartel-like powerhouse in recent decades, Ramirez's statement shows that cooperation is breaking down. While many of the members have indeed consistently exceeded their production quotas agreed upon by the organization, it is becoming increasingly difficult for the countries to work together at all. In the context of game theory, recent literature has struggled to determine the "rules of the game" regarding OPEC's recent performance and the strategies its member countries are "playing". This paper will begin by summarizing recent research and game theory analysis of the crude oil industry. Next, it will discuss the Prisoner's Dilemma game and apply it to the production and strategy options for each player, and it will calculate relative payoffs and total market output in a setting where Saudi Arabia acts as a Stackelberg leader. Additionally, the development of trigger strategies will be applied to OPEC's current situation in an attempt to describe the subgame perfect equilibrium in which the member countries can sustain collusion.

II. Literature Review

This paper will focus mostly on possible strategies, outcomes, and payoffs of OPEC members, but non-OPEC countries are also a major player in the industry and cannot be ignored from analysis. Yi et al. (2012) studied the relationship between OPEC and non-OPEC countries in the context of game theory with the goal of finding an effective way to forecast oil supply in the complex market. Following their statistical analysis, they concluded that non-OPEC countries have a dominant strategy of increasing their oil supply, whether prices are high or low. OPEC countries, however, can act as "price makers", according to the researchers, and have

different strategies depending on whether prices are high or low. In a high price scenario, the best strategy for OPEC is to increase supply in order to increase their market share. Then, as the price drops, non-OPEC producers will see declining profits, and some of those countries may even be forced out of the market, which is to OPEC's advantage. In a low-price scenario, on the other hand, it is in OPEC's best interest to reduce supply in an effort to move the price back up. This conclusion matches Venezuela's prime minister's statement; when prices drop too low, even OPEC countries are susceptible to drastic reductions in profits.

While the previous group of researchers generalized that OPEC had two single dominant strategies, one for a high price scenario and one for the low price scenario, Fattouh and Mahadeva (2013) conclude that there is no single model that will predict OPEC's behavior; rather, the organization's pricing power will vary over time based on market conditions. Recognizing that many models attempting to explain OPEC's behavior have been constructed over the past several decades, Fattouh and Mahadeva show that different models can be applied to various noteworthy events in the history of the oil market. Additionally, when attempting to forecast OPEC's behavior, it must be split up by country or by groups of countries with similar circumstances regarding production capacity, discount rates, and other factors because history has proven that the producers rarely act as one entity.

There has been some evidence of collusion in OPEC's history, such during the 1970s. Seeking to further increase prices during a period of increasing demand for oil, OPEC as a whole decided to cut production by five percent in October 1973, followed by an additional five percent production cut that December. The price of Arabian Crude increased from $5.119 to $11.651 per barrel, and OPEC saw its market share increase to 51 percent (Fattouh and Mahadeva, 2013: 5). Beginning in the 1980s, however, OPEC has not been able to collaborate so successfully.

Increasing oil demand and the emergence of significant non-OPEC suppliers contributed to the reduction of OPEC's market share to 28 percent, and disagreements between member countries began to surface. The nations struggled to agree not only on total production amount but also how to divide it, and there was no formal system in place to monitor cheating on production quotas. This presented a major issue if OPEC were to act as a monopolist or cartel; therefore, various researchers have described the oil industry as competitive during this time period (2013:11).

Fattouh and Mahadeva (2013) suggest that OPEC can achieve greater than Cournot profits as long as there is a way to enforce punishment for those who diverge substantially from production quotas. Saudi Arabia, which holds the largest reserve base and is known as the dominant producer among OPEC countries, has often taken responsibility for punishing the cheaters by employing a "tit-for-tat" strategy. If cheating becomes flagrant, Saudi Arabia, using its excess production capacity, will increase output until all producers' profits are reduced to Cournot levels. Researchers cite 1998 as one example in which Saudi Arabia punished Venezuela's rapidly increasing production by increasing their own supply as well. While some see Saudi Arabia as embracing its "punisher" role in order to maintain at least minimal cohesiveness of OPEC, Fattouh and Mahadeva point out that some evidences supports that Saudi Arabia "sets output in anticipation of the reaction of the fringe and maximizes its profits based on residual demand" (2013:12).

Gately's description of Saudi Arabia's actions in 1986 fall into both categories described by Fattouh and Mahadeva; the country increased its own profits by drastically increasing its supply, and in doing so, cut oil prices in half, which resulted in many other OPEC nations suffering huge decreases in revenue (1986:237). Prior to the price collapse, Saudi Arabia's

warnings that the other countries should stop exceeding their quotas were not taken seriously, but Saudi Arabia proved its threat to be credible once it took action. Overall, Saudi Arabia's relatively strong ability to adapt its production levels allows it to be the most independent of the OPEC countries. In this view, it acts as the Stackelberg leader, and the other OPEC leaders are left to react accordingly.

Huppmann and Holz (2012) recognize the possibility that Saudi Arabia is a Stackelberg leader, and they design several models forecasting output and price for various market scenarios. They then compare actual prices with estimated prices for years 2005 to 2009 in cases of perfect competition, simultaneous Cournot equilibrium, OPEC successfully operating as a cartel, and Saudi Arabia acting as Stackelberg leader of a non-cooperative oligopoly. As expected, they found that estimated cartel prices were the greatest, followed by Cournot prices. Real world prices recorded from 2005 to 2009 were above projected perfect competition levels and below Stackelberg Cournot. With the Stackelberg model's estimates falling closest to observed prices, Huppmann and Holz concluded that the oil market is best described by this game. They find additional supporting evidence that Saudi Arabia is the Stackelberg leader by analyzing actual production totals; they show that the country is producing an amount greatly exceeding what it would supply in the Cournot equilibrium.

III. Stackelberg Cournot Game

In the Stackelberg Cournot game, firms compete based on quantities of an identical product, and one firm is able to credibly commit to its production level first. As explained by Fattouh and Mahadeva, Gately, and Huppmann and Holz, Saudi Arabia is the leader in this case, setting its crude oil output based on predicted reactions from the other countries. The setup for this situation and the process of determining the Stackelberg leader's output is as follows:

Assume inverse demand $P = Int - Q \Rightarrow \quad P = Int - (q_{SA} + q_i)$, where $q_{SA} = Saudi\ Arabia\ output$ and $q_i = output\ of\ all\ other\ countries.$

1. Find the reaction function accounting for all other oil producing countries by setting marginal cost equal to marginal revenue. While it is incredibly unrealistic to assume identical marginal costs for all countries other than Saudi Arabia, this analysis will represent the average marginal cost of all other producers as MC_i.

$$MR_i = Int - q_{SA} - 2q_i = MC_i \Rightarrow q_i = \frac{Int - q_{SA} - MC_i}{2}$$

2. Substitute the other countries' output into the demand equation.

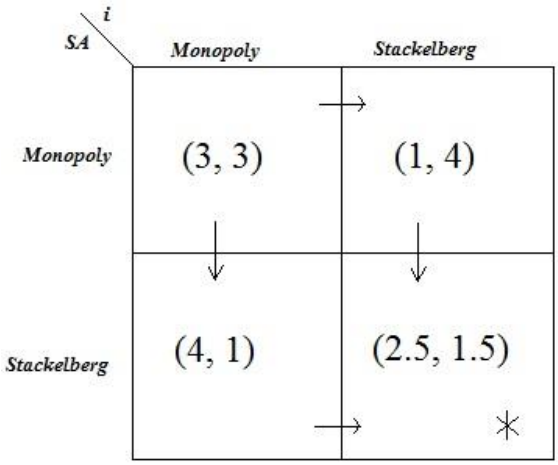
$$P = Int - q_{SA} - \frac{Int - q_{SA} - MC_i}{2} = \frac{Int}{2} - \frac{q_{SA}}{2} + \frac{MC_i}{2}$$

3. Solve for Saudi Arabia's output by setting its marginal revenue equal to its marginal cost.

$$MR_{SA} = \frac{Int}{2} - q_{SA} + \frac{MC_i}{2} = MC_{SA} \Rightarrow q_{SA} = \frac{Int}{2} + \frac{MC_i}{2} - MC_{SA}$$

4. To solve for the total output q_i of the other countries, substitute Saudi Arabia's output q_{SA} into their reaction function.

While this description is unrealistic in multiple aspects, such as by assuming crude oil demand can be simplified to a linear model and marginal cost and revenues are the sole determinants of production levels, these equations convey the basic setup of the Stackelberg game. Multiple payoff matrices can then be constructed to model this type of situation, but for this example, Saudi Arabia is given the strategies of cooperating with other OPEC countries to act as a cartel or using its reaction function to increase its output. The other OPEC countries are grouped together and given the strategies of cooperating with Saudi Arabia or increasing output to Cournot levels. The normal form is shown on the following page.



The numbers for each outcome on the diagram represents relative payoffs and are not exact calculations of profits or utilities. Rather, they show that total utility is maximized when Saudi Arabia and the rest of OPEC can successfully collude with monopoly (or cartel) output, and total utility is minimized when they settle on Stackelberg output. Each country always has the incentive to increase output to the Stackelberg level, resulting in an inefficient Nash equilibrium {Stackelberg, Stackelberg} where total utility is minimized considering the available strategies. This situation qualifies as a Prisoner's Dilemma game; the unique Nash equilibrium is inefficient and occurs when each player plays its strictly dominant strategy. Even though this result does not maximize the payoff for either player, neither has the incentive to change its strategy in this one-shot equilibrium.

IV. Infinitely Repeated Stackelberg Cournot Game

While the solution of this game played once is inefficient and results in Saudi Arabia and its fellow OPEC members cheating by increasing their output, the oil market operates much differently. With millions of barrels of crude oil produced each day and updated production projections released each month (OPEC, 2014), the oil industry represents an infinitely repeated Prisoner's Dilemma, simply modeled by the above payoff matrix. Unlike in the one-shot version of this game, in the infinitely repeated Prisoner's Dilemma, cooperation can be sustained if there

are appropriate discount factors and sufficient trigger strategies. A grim trigger strategy may be effective, but it is not likely to be used in this situation. Considering two players in this simplified Stackelberg game, Saudi Arabia and all of the other countries, each would have the same trigger strategy:

1. Collaborate with "Monopoly" output in the first round.
2. Continue to produce "Monopoly" output as long as the previous round resulted in {Monopoly, Monopoly}. If the result was any other outcome, produce "Stackelberg" output forever.

As Fattouh and Mahadeva (2013) explained, however, cheating is common and even expected of the OPEC countries. When this overproduction has prompted Saudi Arabia to react, the leader has employed more of a "tit-for-tat" strategy for punishment, as seen in 1986 and 1998, for example. This trigger strategy for Saudi Arabia is loosely described as follows:

1. Collaborate with "Monopoly" output.
2. Continue to collude if the other countries cooperated with "Monopoly" output; produce "Stackelberg" output if the other countries cheated in the previous round.
3. Return to "Monopoly" output.

Another trigger strategy would need to be developed for the other countries to punish Saudi Arabia in the instance of excessive cheating, but this would be more complicated to develop due to Saudi Arabia's higher production capacity (Huppmann and Holz, 2012:10). If a strategy could be developed to stably maintain cooperation in the long run, OPEC could maximize total profits and better achieve their mission of "[securing] an efficient, economic and regular supply of petroleum" (OPEC, 2014). However, non-OPEC players and their growing presence in the global oil industry present additional complications that cannot be forgotten. The

analysis required to develop strategies and models that take into consideration the implications of non-OPEC production and pricing go beyond the scope of this paper, and as previous studies have explained, the decisions of OPEC countries cannot be consistently explained by a single model (Fattouh and Mahadeva, 2013).

V. Conclusion

While OPEC still holds 81 percent of the world's proven crude oil reserves, the emergence of non-OPEC countries as major suppliers has contributed to a decrease in OPEC's market share, which averaged out at 43.6 percent during 2013 (OPEC, 2014). With the crashing prices as of late as well as conflicting goals expressed by Saudi Arabia and Venezuela, on the surface, OPEC's situation might look bleak. However, non-OPEC countries are not immune to diminishing profits, and the rapidly decreasing prices could end up working in OPEC's favor. If crude oil prices drop to low enough levels, producers like the United States may be forced to abandon their some of their more expensive production options (Faucon et al., 2014). How far prices drop will be influenced heavily by the upcoming decisions of OPEC; if Saudi Arabia and other producers begin restricting output, prices may begin to increase, but the actions of these countries cannot be predicted with certainty.

In reality, numerous factors affect the extent of OPEC's success; their ability to collude and adapt to the actions of their competitors represents only a small part of the complexity of the oil industry. As in any industry, issues such as war, political unrest, and natural disasters as well as the emergence of substitutes will have an effect on production decisions. The development of alternative sources of fuel, for example, has the potential to eliminate some of the demand for OPEC's crude oil in the near future. Whether or not OPEC feels the effect of the decreasing demand for its product will depend partially on the investment decisions of the non-OPEC

countries. This newer area of technology along with intensifying competition in the crude oil industry will likely make for an eventful next few years for OPEC, characterized by significant decisions and the possibility for change in how the organization operates.

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