### GAME THEORETIC MODELING OF THE WORLD OIL MARKET THE RUSSIAN GAINS FROM STRATEGIC BEHAVIOR

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Thesis submitted to Central European University Department of Economics

In partial fulfilment of the requirements for the degree of Master of Arts

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Budapest, Hungary 2007

### Abstract

In this thesis I employ a stylized static oligopoly model of the world oil market in two versions differentiated by the behavior of Russia. In the first version Russia is regarded as a price-taker together with the fringe producers and OPEC is a partial monopolist. In the second version, Russia is a strategic player in a quantity leadership game with OPEC, with the fringe producers behaving competitively. The aim of this thesis is to quantitatively compare the Russian profits in these two behavioral situations. I use multiplicative functional forms for global oil demand and fringe supply, excepting Russia and I construct marginal cost functions for the two main players from the best data available. I use the price elasticities of global oil demand and fringe supply as exogenous parameters, and I solve the models for different combinations of such elasticities. Finally, I compare quantitatively the outcome of the models from the Russian gains point of view. I show that Russia should be indifferent between being a price-taker and behaving strategically, as the gains from the strategic behavior are very low, below 1%. Nevertheless, Russia is able to save some resources, for its supply is on average with 50,000 barrels/day lower in the strategic case. In addition, I show that the price increases in the strategic version of Russia's behavior as compared with the price-taking version. Furthermore, OPEC is always more better-off than Russia when the latter plays strategically.

### Acknowledgments

I express my gratitude for my supervisor, Dr. Andrezej Baniak, for his valuable advice, suggestions and guidance during the elaboration of this thesis. I bring special thanks to László Varró<sup>\*</sup> and Peter Simon Vargha<sup>†</sup> for their help, ideas and materials provided, as well as for their patience and encouragement. I would like to express sincere thanks to Reka Futasz, my Academic Writing supervisor, for carefully reading and correcting my text.

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### Introduction

Nowadays, the biggest world economies would simply stop operating should they experience oil shortages. Oil is a limited resource, and consequently, the increasing demand boosts the oil price every day, putting the big oil consumers into difficulty. On the other hand, a decline in oil demand, and consequently prices, would harshly hit the economies of some oil-producing countries because they rely on oil production as their main source of income. This absolute reliance makes them very vulnerable to the volatility of oil world prices.

For instance, the world oil market has lately exhibited some strange phenomena due to the demand shock which in turn triggered a price jump. The main player of the market, the Organization of Petroleum Exporting Countries (OPEC),<sup>1</sup> found itself threatened by the non-OPEC players,<sup>2</sup> which decided that it was profitable for them to boost their productions for gaining from the price increase. But the supply jump may in turn have the reverse effect of pushing the price downward. In such a situation, Russia, the greatest non-OPEC producer cannot be a passive player, as global oil price stability is a resurgent element for its economy. Moreover, with the state regaining its control over the oil sector, the present political regime in Russia seems to favor the slow-down of the oil production and exports for defending the price level (Boussena and Locatelli, 2005). Such a decision might be intended for Russia to use its oil potential and act as a strategic player, rather

<sup>&</sup>lt;sup>1</sup>Presently, the OPEC countries are: Algeria, Angola, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, Venezuela.

<sup>&</sup>lt;sup>2</sup>Non-OPEC countries: Russia, Canada, Mexico, United States, Argentina, Brazil, Colombia, Ecuador, Norway, United Kingdom, Azerbaijan, Kazakhstan, Oman, Syria, Yemen, Australia, China, India, Malaysia, Vietnam, Egypt, Equatorial Guinea, Gabon, Sudan.

than a price-taker, undermining OPEC's power in setting the price. Moreover, Russia might capture a considerable rent by changing its behavior from a price-taking behavior into a strategic one.

As the state control over the oil companies in Russia is increasing, resulting in the emergence of one single decision maker on oil production, Russia has now the opportunity to change its strategy as a player on the global oil market. In this framework it is evident that the political factor has its role, as the production decisions are not made only by individual profit maximizing companies, but also by the political administration.

This thesis is aimed at searching for game theoretic motivation, in addition to political arguments, for Russia's intentions to use its oil potential as an instrument to transform into a strategic player of the world oil market. Its reliance on the oil industry makes Russia's economy very sensitive to the global oil price, and in consequence, it might not be wiling to act as a price-taker for a prolonged period of time. The high production cost, especially with the production shift toward Eastern Siberia, determines Russia to desire high oil prices more than the Middle East countries do; for them even a price as low as 10 dollars/barrel makes their oil industries profitable. This desirability of a high oil price could also trigger Russia's strategic actions as opposite to the price-taking passive behavior on the world oil market because this is how it can have a role on price formation for this commodity.

Thus, the main task of this study is to answer the question how much Russia can capture from the rent in a Stackelberg leader-follower game with OPEC. The question to be answered it to what extent is Russia economically better-off from using its oil power as an international political tool in its relations with the major powers. For this purpose, I employ the tools of game theory to build a stylized static oligopoly model with three players: OPEC, Russia and the non-OPEC fringe producers.

### Chapter 1

### The Main Players of the Market

The world oil market can be defined as an oligopoly industry, as there are few suppliers and virtually infinite consumers. As acknowledged in the Introduction, two main players distinguish themselves from the pool of the fringe producers on this market: OPEC and Russia. This chapter is devoted to providing a short description of the present state of the Russian oil industry and to motivating the assumption of OPEC as a single player, i.e the cartel assumption.

#### 1.1 The Oil Sector in Russia

Russia is an economy that is highly relying on the oil industry - oil production was 28% of the total industrial output in 2003 and 42% of the exports in 2004 (Tompson). It is now the second largest oil producer after the OPEC block - individually surpassing Saudi Arabia, as the last International Energy Agency (IEA) data shows - with a production close to 9.7 million b/d in 2006, according to the IEA monthly report released in March 2007. Furthermore, there are predictions from international agencies (IEA, World Energy Outlook) that Russia could increase its production close to 10.4 million b/d until 2010 and 10.6 until 2020. (Boussena and Locatelli, 2005). However, Russia's oil industry is characterized by a few drawbacks, among which are high production costs, limited proven reserves in comparison with the Middle East extractors and limited spare capacity, which

may, in addition, reflect its price-taking behavior.

Lately, Russia has reappeared in the global oil market scene as a crucial player. Nevertheless, after the boom in the oil production in the aftermath of the collapse of the Soviet Union, there have been signals from the Moscow administration, which now controls more than 50% of the oil extraction industry, that Russia might curtail its production in the future, although it has the potential of becoming the largest extractor in the world (Low, 2007). Explanations for this stand in political factors, as well as in the limits of the 'brownfield revolution' and the tax regime in Russia, which deters new investments.<sup>1</sup> Particularly, it is still not clear if the decline of the brownfields is a natural result of the depletion or if it is mainly the government's authoritarian will, through its actions of the renationalization of the oil companies, which have shortened further developments of the remaining opportunities in these fields. In addition, the tax burden imposed by the political regime currently in place in Russia discourages the oil companies from investing in new fields, except for the most profitable, less expensive 'brownfields'. But the easy gains coming from the exploration of these fields seems to have come to an end. Moreover, the investment of the new oil companies in Russia are now more directed to the downstream level than to the crude extraction because refined products are more profitable for export than crude export, due to the current Russian export duty system.

Sensitive to world oil price levels, - a 10% increase in oil price brings a 2.2% additional increase in its GNP (Boussena and Locatelli, 2005) - Russia is relying on high oil prices for its economic growth. Therefore, the Russian oil policy is to contribute to maintaining high oil prices and this should involve a better management of output, including increased investments in exploration in order to conserve the oil resource.

All factors mentioned above contribute to a slow-down of crude production growth in Russia. But, on the other hand, with the increase of state control, if the oil production curbs are politically driven, this will be even an easier objective to fulfill. The private oil companies are merely driven by profit maximization, thus producing and exporting

 $<sup>^1\</sup>mathrm{See}$  the Russian and Caspian Energy WATCH, 2005 for a detailed analisys of the Russian oil boom end.

as much as possible at given prices, being also concerned with the cost of their idle capacities. But, unlike the oil companies, the Russian state, as the owner of the resources, has strategic interests in addition to revenue objectives. This means that the state is not only concerned with the revenue from oil extraction, but also with the oil market stability, the future value of the oil reserves and the conservation of oil resources. Hence, what is to be expected is that the state will have different discount rates, and consequently, different production decisions than the private companies. As a result, it is a natural consequence for Russia to change its strategy as a player on the global oil market.

In short, the current reality is that the Russian government is increasing its control over the oil industry and is removing the foreign investors through a variety of means, among which are the discretionary manner of granting exploration and development licenses. This process of taking back the oil sector by the state results in an enhanced control over production, exports and the renewal of resources. A second consequence is that in the framework of a tense world oil market, Russia can play an important geostrategic role to influence the global oil market, seeking to increase its market share and to gain influence on other oil producing regions, namely the Middle East and North Africa.<sup>2</sup> Translated into a game theoretic language, this means that Russia has now the opportunity to behave strategically and to challenge the position of the OPEC cartel.

### 1.2 Assumptions on OPEC's Behavior

There is no consensus in the literature with respect to a single model to be engaged for describing OPEC's behavior. Most often, OPEC's behavior is described using cartel models. However, some researchers (eg. Paul MacAvoy quoted in Griffin, 1985) have considered OPEC as acting in a competitive framework based on supply and demand. There are also two other, less conclusive models of OPEC's behavior, namely the target revenue model, which results in a backward bending supply schedule, and the property

 $<sup>^2 \</sup>mathrm{See}$  for example the 'energy pact' between Russia and Saudi Arabia, September 2003.

rights explanation for oil production. All these models have been tested using empirical data and econometric procedures (Kaufmann et al., Griffin, 1985). Except for the cartel model, all the other models seem not to be supported by the data (see Griffin, 1985). In addition, Griffin (1985) found that the partial cartel model dominates the competitive model in the ability to explain production. At the same time, he could not reject the partial cartel model hypothesis for 11 OPEC countries, whereas rejection is more frequent for the other types of models, namely competitive, target revenue and property rights models.

Furthermore, Gülen (1996) uses cointegration analysis and causality tests to investigate the cartel type behavior of OPEC. The assumption that OPEC is a cartel should be reflected in the long-run coordination of member's production and the total output of OPEC, as well as in the capability of the organization to influence the price by production cutbacks. Thus, Gülen finds evidence of output coordination among the members of the organization, especially during the period of output rationing, i.e. 1982-1993. This is also the period for which the author detected a statistically significant causality from the cartel's output to the oil price, evidence of the OPEC's ability to exercise market power. This causality is consistent with the theory about cartel behavior.

In light of these findings, I will employ a game theoretic model of the world oil market, in which I will assume OPEC behaving as a cartel. However, the model used in this thesis regards OPEC as a black-box, such that the internal disagreements, the different national interests of the member countries and the free-riding incentives are disregarded, as the main objective here is the relationship between OPEC as a whole and Russia. I will model OPEC as a profit maximizing firm rather than a social welfare maximizer, disregarding also the potential political objectives and the domestic market.

If one adopts the cartel model in describing OPEC's behavior, then OPEC is a partial cartel, as it is not comprised of all the oil producing countries. In the literature two types of competition in the industry with a partial cartel are used: the cartel is a Stackleberg leader and the fringe competes à la Cournot (Shaffer, 2001), or the fringe behaves competitively

as a price-taker (Diamantoudi, 2001). One drawback of the above-mentioned cartel models is the assumption that all the firms in the fringe are identical and they have the same cost and production functions. As a consequence of this assumption, the fringe firms will always produce the same quantity, leading to symmetric equilibria. Obviously, this is not a very realistic approach.

Taking into account the total market share of OPEC (approximately 37.4% of the world oil production in February 2007, as reported by the IEA in its report from March 2007) and OPEC's proven reserves (81% of the total 1212.9 billion barrels world's crude oil proven reserves, as reported by the International Monetary Fund, 2005),<sup>3</sup> OPEC is the leader of the world oil market. Moreover, the production costs of the OPEC countries, including the costs for finding and developing fields are well below the costs incurred by the USA or the North Sea countries: \$2 compared to \$10-11 (Vatansever, 2003). Hence, the proven reserves and the low production costs give OPEC the market power to control the production and to be able to keep the price in the range suitable for its members' interests.

On the other hand, Russia is the second largest oil producer in the world (11.36% of the world oil production in 2006) and it is the main supplier for several European countries. At the same time, the high production costs do not allow Russia to behave as a price-taker in case of low prices, since long periods of low prices would put the Russian oil sector into survivorship problems. Therefore, in addition to political motivations, it might be in Russia's pure economic interest to play strategically on the world oil market. Thus, the assumption that the world oil market can be modeled like a Stackleberg game between OPEC as a leader and Russia as the follower and with the fringe acting as a price-taker, is an assumption in line with the world oil market reality.

<sup>&</sup>lt;sup>3</sup>OPEC proven reserves in 2000 were above 800 billion barrels (OECD Economic Outlook No. 76)

### Chapter 2

### Model Inputs

The structure of the model employed in the thesis, together with the analytical solution will be presented in detail in Chapter 3. However, in order to build the model, a number of issues need to be addressed. Firstly, the game theoretic model developed here needs the specification of a global oil demand function and the supply schedule of the competitive fringe excluding Russia. Secondly, assumptions about the production costs and the functional forms of the marginal costs of the main players, Russia and OPEC, have to be considered in detail. I will proceed with the description of the model inputs below.

### 2.1 Crude Oil Global Demand Function

For establishing the crude oil global demand as a function of price, I use econometric studies that estimate oil demand elasticities with respect to price.

In a survey of 46 studies on short-run and 49 studies on long-run estimated oil demand elasticities, Dahl and Roman (2004) find means of 0.11 and 0.43 oil demand elasticities, respectively. Cooper (2003), quoting two sources of econometric estimates of price elasticity of oil demand, reports elasticities ranging between 0.08 and 0.2 for the short-run and 0.56 and 0.6 for the long-run. In the same study, Cooper estimates oil demand functions for 23 countries. He uses a log-linear equation which captures both the long and short run elasticities. He finds elasticities ranging between 0.016 and 0.109 for the short-run and between 0.033 and 0.568 for the long-run.

Dees et al. (2005) develop a structural econometric model of the world oil market, accounting for the specificity of the oil market. The structure of the model encompasses a pricing rule equation, which captures both the cooperative and non-cooperative behavior of OPEC's members inside the cartel, the demand curve and the supply schedule distinguishing between OPEC and non-OPEC supply behaviors. Based on quarterly data from 1984 to 2002, they estimate the demand for ten main regions, including the USA, Japan, UK, the Euro zone, Switzerland, other developed economies, non-Japan Asia, transition economies, Latin America and the rest of the world. They specify and estimate the demand as a log-linear function of real GDP, real oil price and a time trend. From their econometric specification, both the short and long-run price elasticities of oil demand can be obtained. The short-run demand elasticity with respect to real oil price ranges between 0.02 and 0.34.

Following the direction of oil demand function specifications in the empirical studies quoted above, I assume a constant elasticity demand schedule of the form:

$$D(p) = Ap^{\epsilon_w}$$

where  $\epsilon_w < 0$  is the world demand elasticity with respect to price and p is the global oil price. In fact, I assume  $-1 \leq \epsilon_w < 0$  because, as most of the econometric studies show, the oil demand is inelastic both in the short and the long-run. A is a constant to be determined through calibration with real data for the world oil demand and price. I use the data for 2006 published by the IEA in the monthly Oil Market Report from March, 2007. World demand for oil was 84.5 million b/d in 2006 and the price fluctuated around 60 dollars per barrel. Using the demand elasticity as a parameter, with values in the ranges supplied by the IEA.

### 2.2 Fringe Supply Function

Estimating a supply function for the non-OPEC producers could be a difficult task. Moreover, the literature on energy sector suffers from a dearth of results for supply elasticity. Although the crude oil producing countries outside OPEC and Russia can be modeled as price-takers, there is no straightforward relation between their productions and the price of crude. Therefore, other factors must be accounted for. For instance, Dees et al. (2005) employ a mix of political, institutional and economic factors in estimating the supply equation, using a three step methodology. They find supply elasticities between 0.79 and 6.03 for nine non-OPEC regions. Greene et al.(1995), quoting Huntington (1991), report elasticities for the total non-OPEC world supply of the magnitude of 0.03 for the short-run and 0.4 for the long-run. Quoted in the same paper, Al-Sahlawi (1989) reports estimates for the supply elasticity of 0.03 for the short-run and 0.6 for the long-run.

Furthermore, Reynolds (2002) tests the effect of price on production over time for US lower 48 states on data starting from 1900 to 1999. Using a non-time series model, he regresses the current production rate on actual price, lagged price, cumulative production and other control variables. The ordinary least squares estimation shows a very inelastic supply with respect to price. For example, in 1970 the price elasticity of the supply was 0.05. However, this study suggests that the lagged price rather than the current price is a significant determinant of the supply.

Finally, Celta and Dahl (2000) maximize OPEC's social welfare, with a distinction between its internal and export market under two behavioral hypotheses for OPEC: the price leadership model and competitive behavior. They develop static models for both behavioral situations in which they use, for the base case analysis, a world demand elasticity of 0.406 and a fringe supply elasticity equal to 0.384.

With regard to the functional form, as in the case of the world oil demand, I assume an aggregate, constant elasticity supply function of the oil-producing countries outside OPEC and excluding Russia of the form:

$$S_F(p) = Bp^{\epsilon_f}$$

where  $\epsilon_f > 0$  is the fringe supply elasticity with respect to price and p is the world oil price. Again, as the econometric estimations show, the supply of the fringe is inelastic, that is  $0 < \epsilon_f \leq 1$ . B is a constant to be determined through calibration with real data for price and the supply of the fringe countries except for Russia.

For calibration I again use the official statistics for 2006 provided by the IEA in their monthly report in March 2007. The IEA reports a total non-OPEC supply of 50.84 million b/d, from which I subtracted the 9.69 million b/d supplied by Russia in 2006. This results in a non-OPEC less Russia oil supply of 41.15 million b/d. The price for crude averaged around 60 dollars per barrel. Assuming an elasticity measure from the range acknowledged above, these data give an estimate for B and thus the supply schedule for the fringe except Russia.

#### 2.3 Production Costs

Crude oil fields located in different parts of the world are distinguished by geological variations and thus by enormous differences in production costs. The purpose of this section is to establish the production cost functions for OPEC and Russia, as they will be employed later in the model. I will assume the cost as a function of the current rate of production, and I will include only the extraction costs as the exploration and development costs are sunk. Production costs or lifting costs comprise all the expenditures for labor, maintenance, fuel and electricity, as well as the administrative expenses necessary for oil extraction. Severance taxes, royalties, interest payments, amortization, depletion and depreciation expenses are not included in the production costs belong to the OPEC block, with Saudi Arabia as a leader with a production cost of about 2 dollars per barrel. The

Russian greenfield is one of the most expensive field for extraction (9.5 dollars per barrel on average in 2005),<sup>1</sup> being surpassed only by the Canadian sands within the non-OPEC producers with a cost of 14 dollars per barrel.

In order to construct the cost functions, both for Russia and OPEC, I assume stepwise marginal costs and conduct qualitative estimations based on the publications of other authors. In particular, I use the data on upstream cost estimates provided by the Cambridge Energy Research Associates (CERA) in Fagan (2006). This is the most recent data on marginal costs I could find, and in the case of OPEC, this is also the only data available to me. Moreover, because estimates of upstream costs at country level are not consistent from one source to another, I chose to use the same source of data in spite of the fact that the data for four OPEC countries is missing.

Fagan (2006) provides the marginal cost for finding and development, production and total marginal costs in 2005 in nominal dollars per barrel of oil equivalent. Cost is a function of output, hence, in constructing the cost functions I use only the data concerning the production costs and I also adjust for inflation. The cost functions constructed here and used in the model are qualitative estimations, and they can be improved should other, more accurate and complete data be available. Nevertheless, this is an objective beyond the scope of this study.

#### 2.3.1 Production Cost for Russia

In the case of Russia's production, I assume a step-wise marginal cost function with differentiation between the less expensive brownfield and the most expensive greenfield types of oil fields. As mentioned above, in order to construct the cost function for Russia, I use the production cost data for 2005 from Fagan (2006). Thus, the marginal cost of production for Russia will be given by the following step-wise function:

<sup>&</sup>lt;sup>1</sup>For more on production and exploration costs, see Fagan, 2006.

$$MC_R(q_R) = \begin{cases} 4.2, & \text{if } 0 < q_R < 9\\ 13.3, & \text{if } q_R \ge 9 \end{cases}$$

where  $q_R$  is the Russian daily production rate measured in million of barrels.

The discontinuity point at 9 million b/d is assumed to be the current maximum capacity of the brownfields. The upper branch of the marginal cost gives the cost of producing one barrel of oil extracted from a greenfield.

#### 2.3.2 Production Cost for OPEC

Because OPEC's costs are not publicly available, the cost function for this player is the most problematic input of the oil market model developed here. Nevertheless, I use the data provided in Fagan (2006), which gives the marginal production costs for only 8 out of the 12 OPEC countries. For the remaining 4 countries, namely Kuwait, Quatar, the United Arab Emirates and Iraq, I imputed the missing data with the weighted average of the production costs for the 8 countries for which data is available. For imputation, I computed the weighted costs for these countries with their production capacities resulting in an weighted average cost of 3.9 dollars/barrel. Then I ordered the marginal costs from lower to higher, and I calculated the cumulative capacity associated with each cost.

As in the case of the marginal cost for Russia, I assume a step-wise marginal cost function with discontinuity points at the cumulative capacities from 2006 (Oil market report, March 2007). Thus, the marginal cost for OPEC is the following:

$$MC_O(q_O) = \begin{cases} 2.1, & \text{if } 0 < q_O \le 10.8 \\ 2.8, & \text{if } 10.8 < q_O \le 14.75 \\ 4.2, & \text{if } 14.75 < q_O \le 26.54 \\ 6.272, & \text{if } 26.54 < q_O \le 30.58 \\ 7.7, & \text{if } 30.58 < q_O \le 33.28 \\ 14, & \text{if } 33.28 < q_O < 34.23 \end{cases}$$

where  $q_O$  is the daily production rate in million of barrels.

#### 2.3.3 Calibration

For the calibration of the marginal costs I use short-run functions, which capture the capacity constraints of both players. I use the marginal cost data described above and I fit the values on the following functional form:

$$MC_i(q_i) = \frac{b_i}{K_i - q_i},\tag{2.1}$$

where i = R, O denotes Russia and OPEC, respectively,  $b_i$  is positive real parameter to be determined through calibration,  $K_i$  is the production capacity in million barrels per day and  $q_i < K_i$  is the daily production also measured in million barrels per day.

This marginal cost functional form has the property of increasing marginal cost and incorporates the capacity constraints of both players, being thus suitable for a short-run analysis, when capital is assumed to be fixed and no investment in capacity is made. It also has the nice properties of convexity needed to assure the existence of the interior solution of the model. Note that when production approaches capacity, marginal cost approaches infinity, making it unprofitable for the players to produce close to capacity, unless the price is high enough. The current reality is that both OPEC and Russia operate close to their capacities, and there are weak signals that any of the players would increase the



Figure 2.1: Russia's marginal cost calibration

capacity in the near future. For instance, in February 2007 OPEC had only 4 million b/d spare capacity (IEA, 2007). As for Russia, two main problems could prevent investments in new capacity. First, the ratio of proven reserves to explored reserves, which dropped to 26.5% in 2000, and second, the majority of the proven reserves are in the 'difficult to recover' category, according to the IEA (Boussena and Locatelli,2005)

For the calibration of the parameters of this functional form I use the step-wise marginal costs described above. I use a least square errors method to fit the step-wise marginal cost functions on the functional form (2.1). Assuming the production capacities at the levels given by the IEA's Oil Market Report from February 2007,  $K_O = 34.23$ million b/d and  $K_R = 10$  million b/d, I obtained the following marginal cost functions:

$$MC_R(q_R) = \frac{14.68}{10 - q_R}$$

and

$$MC_O(q_O) = \frac{18.52}{34.23 - q_O}$$

for Russia and OPEC, respectively. Figures 2.1 and 2.2 show the shape of the marginal



Figure 2.2: OPEC's marginal cost calibration

costs before and after the calibration to the functional form (2.1).

To summarize, the inputs into the model are multiplicative functional forms for the global demand and the supply of the fringe excluding Russia. In addition, I use increasing and convex marginal costs, which impose capacity constraints for OPEC and Russia. The next chapter provides the description and the solution of the model.

### Chapter 3

### Modeling Russia's Behavior

The purpose of this chapter is to describe the setup of the model employed and to give an analytical solution to the model. The model developed in this thesis is a static short-run oligopoly model of the world oil market, which assumes three players: OPEC, Russia and the fringe producing countries. OPEC is the most important player of the market and in this model it is assumed to behave as a dominant cartel due to reasons acknowledged in Chapter 1, Section 1.2.

One simplification of the model is the non-differentiability of the oil quality. I will assume that all players extract a homogeneous product, crude oil. Another important assumption of the model is that it disregards the domestic market of both OPEC and Russia, meaning that the whole supply of crude is traded on the world market. However, this is a restrictive assumption if one takes into account that at the present Russia trades outside its domestic market only half of its crude production, the other half being refined domestically (Russia Focus, Feb. 2007). Moreover, I will disregard the oil stocks held by the OECD countries and I will model the world market assuming that it clears in all its instances, i.e. the demand always equals the supply.

### 3.1 The Setup of the Model

I devised two parallel versions of the world oil market model, which are differentiated by the behavior of Russia as a player on this market. I start with a simple model of the world oil market, having OPEC as the dominant firm facing the residual demand. In this setting of the model, Russia ignores its potential influence on the market and takes price as given. I then change the assumption about Russia's behavior and model the duopoly competition between OPEC and Russia as a Stackelberg game in quantities, with OPEC as a leader. In both cases I assume the rest of the fringe extractors being price-takers, that is, they operate as if the market was perfectly competitive. Nevertheless, in my analysis I drop the classical assumption of symmetry, and I account for the different production technologies of the main players. This is incorporated in the different, non-linear, nonconstant marginal cost functions.

In the first scenario, I model OPEC behaving as a partial monopolist, which faces a residual demand and sets the price. The fringe producing countries and Russia, as part of the fringe, are price-takers. The timing of the game is simple and consists of two stages: in the first stage OPEC sets the price and in the second stage the competitive fringe observes the price and determines its supply according to its supply schedule. Russia sets its output where price equals marginal cost, reflecting its price-taking behavior.

The second version of the oil market model is a three-stage game in which OPEC is a Stackelberg leader with Russia as a follower and the fringe behaving competitively. A quantity leadership model has been chosen rather than a price leadership for modeling the strategic game between Russia and OPEC since the empirical evidence shows that OPEC announces quotas for each member and allows the price formation on the market. The timing of the game is the following: OPEC chooses its production quota in the first stage and Russia observes OPEC's choice of output and sets its own optimal level of production in the second stage of the game. The first two stages constitute the leader-follower game in quantities between Russia and OPEC. In the last stage the competitive fringe observes the price resulting from the Stackelberg game and determines its supply in accordance with its supply function.

The aim of the two oil market scenarios described above is to quantitatively compare the outcome resulting, in terms of the Russian gain. Playing as a follower of OPEC in the quantity game, Russia has strategic power; hence, what is to be expected from the outcome of the model is that Russia will gain a positive rent from playing strategically. It remains to assess the magnitude of this gain for different price elasticities of the global demand and the supply of the fringe producers excluding Russia, in Chapter 4.

#### 3.2 Solution of the Model

In this section I give an analytical solution to the model for the general case where the input functions into the model have no specific form. However, I make the assumption that Russia's cost function is continuous and twice differentiable. Additionally, I assume that the global demand and the fringe less Russia supply are differentiable functions with respect to price.

Let us first introduce some notation. We denote by  $q_O$  and  $q_R$  the output for OPEC and Russia, respectively. We have then the global demand function D(p) and the supply schedule of the fringe excluding Russia,  $S_F(p)$ . Finally,  $C_O(q_O)$  and  $C_R(q_R)$  denote the cost functions of OPEC and Russia, respectively. The solution of the oil market model in the two scenarios is presented below.

#### 3.2.1 Russia as a Price-taker

This is the scenario when OPEC is assumed to be a partial monopolist facing the residual demand from Russia and the rest of the fringe. In this case, Russia, being a price-taker, as is the rest of the fringe, will choose to produce where price equals its marginal cost, i.e.

$$p = C'_R(q_R) \tag{3.1}$$

Equation (3.1) gives Russia's supply curve:

$$q_R(p) = (C'_R)^{-1}(p) \tag{3.2}$$

Then OPEC faces the residual demand,  $RD(p) = D(p) - S_F(p) - (C'_R)^{-1}(p)$ , and chooses  $q_O$  and p to maximize its profit under the market equilibrium constraint:

$$\max_{p,q_O} \pi_O = \max_{p,q_O} pq_O - C_O(q_O)$$
  
s.t.  
$$q_O \le D(p) - S_F(p) - (C'_R)^{-1}(p)$$

In fact OPEC will produce the whole residual demand, such that the constraint will be satisfied with equality, i.e.  $q_O(p) = D(p) - S_F(p) - (C'_R)^{-1}(p)$  and substituting for  $q_O$  in the objective function, OPEC has to solve the following problem:

$$\max_{p} \quad \pi_{O} = \max_{p} \quad p \left[ D(p) - S_{F}(p) - (C_{R}')^{-1}(p) \right] - C_{O} \left( D(p) - S_{F}(p) - (C_{R}')^{-1}(p) \right)$$
(3.3)

The above maximization problem gives the equilibrium price of the market for the case when Russia is a price-taker.

#### 3.2.2 Russia as a Strategic Player

In this setting of the model, OPEC, together with Russia, face the residual demand from the competitive fringe:

$$q_O + q_R = D(p(q_O, q_R)) - S_F(p(q_O, q_R))$$
(3.4)

Assuming a differentiable cost function for Russia we can solve for the equilibrium of the Stackelberg game between Russia and OPEC. As usual, the solution is found by backward induction. Firstly, Russia maximizes its profit function with respect to its quantity and taking  $q_O$  as given:

$$\max_{q_R} \quad \pi_R = \max_{q_R} \quad p(q_O, q_R)q_R - C_R(q_R)$$

The first order condition:

$$\frac{\partial p(q_O, q_R)}{\partial q_R} q_R + p(q_O, q_R) - C'_R(q_R) = 0$$
(3.5)

embodies Russia's reaction function,  $q_R(q_O)$ , to OPEC's quantity. Solving (3.5) for  $q_R$  one can get Russia's reaction function,  $q_R = q_R(q_O)$ .

Taking the derivative with respect to  $q_R$  in (3.4), it can be solved for  $\frac{\partial p(q_O, q_R)}{\partial q_R}$ :

$$1 = \frac{\partial D}{\partial p} \frac{\partial p}{\partial q_R} - \frac{\partial S_F}{\partial p} \frac{\partial p}{\partial q_R}$$
(3.6)

$$\Rightarrow \frac{\partial p}{\partial q_R} = \left[\frac{\partial D}{\partial p} - \frac{\partial S_F}{\partial p}\right]^{-1} \tag{3.7}$$

Substituting (3.7) in (3.5) yields the equivalent first order condition for Russia:

$$\left[\frac{\partial D}{\partial p} - \frac{\partial S_F}{\partial p}\right]^{-1} q_R + p - C'_R(q_R) = 0$$
(3.8)

Market equilibrium condition (3.4) can be solved for  $q_R$ :

$$q_R = D(p) - S_F(p) - q_O$$

and substituted in (3.8) yields:

$$\left[\frac{\partial D}{\partial p} - \frac{\partial S_F}{\partial p}\right]^{-1} \left(D(p) - S_F(p) - q_O\right) + p - C'_R(D(p) - S_F(p) - q_O) = 0$$
(3.9)

Note that equation (3.9) combines the reaction function for Russia with the market equilibrium condition. It constitutes the constraint for OPEC's optimization problem. OPEC maximizes its profit function accounting for Russia's reaction function and market equilibrium constraint through equation (3.9). These give the following constrained maximization problem for OPEC:

$$\max_{p,q_O} \quad \pi_O = \max_{p,q_O} \quad pq_O - C_O(q_O)$$

s.t.

$$\left[\frac{\partial D}{\partial p} - \frac{\partial S_F}{\partial p}\right]^{-1} \left(D(p) - S_F(p) - q_O\right) + p - C'_R \left(D(p) - S_F(p) - q_O\right) = 0 \quad (3.10)$$

#### **3.3** Specific Functional Forms

In particular, let us formulate the two scenarios for the functions described in Chapter 2 as inputs into the model. Let us recall the global demand function,  $D(p) = Ap^{\epsilon_w}$ , the supply schedule for the fringe,  $S_F(p) = Bp^{\epsilon_f}$ , and the marginal cost functions,  $MC_O(q_O) = \frac{b_O}{K_O - q_O}$  and  $MC_R(q_R) = \frac{b_R}{K_R - q_R}$  for OPEC and Russia, respectively.

From the marginal cost functions, the total cost functions can be derived. Hence,  $C_O(q_O) = a_O - b_O \ln(K_O - q_O)$  and  $C_R(q_R) = a_R - b_R \ln(K_R - q_R)$  are the total cost functions for OPEC and Russia, respectively, and  $a_O > 0$  and  $a_R > 0$  are the constants from the integration of the marginal costs, which, in addition, incorporate the fixed costs.

Then, problems (3.3) and (3.10) boil down to the following optimization problems:

$$\max_{p} \left[ Ap^{1+\epsilon_{w}} - Bp^{1+\epsilon_{f}} - K_{R}p + b_{R} - a_{O} + b_{O} \ln(K_{O} - Ap^{\epsilon_{w}} + Bp^{\epsilon_{f}} + K_{R} - b_{R}p^{-1}) \right]$$
(3.11)

for Russia as a price-taker, and

$$\max_{p,q_O} \left[ q_O p - a_O + b_O \ln(K_O - q_O) \right]$$

s.t.

$$p - \frac{b_R}{(K_R - Ap^{\epsilon_w} + Bp^{\epsilon_f} + q_O)} + \frac{(Ap^{\epsilon_w} - Bp^{\epsilon_f} - q_O)}{(A\epsilon_w p^{\epsilon_w - 1} - B\epsilon_f p^{\epsilon_f - 1})} = 0$$
(3.12)

for Russia as a strategic player. In both scenarios I assume the total demand and the

supply of the fringe inelastic to the oil price, such that,  $-1 \le \epsilon_w < 0$  and  $0 < \epsilon_f \le 1$ .

For a mathematical analysis of the existence of the solutions for the above problems, see Appendix A. However, solving for the equilibrium of the market in an analytical closed form is not feasible for any of the scenarios for Russia's behavior, given the inputs chosen for the model. The problem comes mainly from the impossibility of solving analytically for the inverse residual demand. Therefore, in order to generate the numerical results, problems (3.11) and (3.12) were solved with the help of the Optimization Toolbox in Matlab, using numerical methods for constraint nonlinear optimization problems. Note that problem (3.11) is a nonlinear optimization problem in one variable, the price, while problem (3.12) is a nonlinear optimization problem in two variables, price and OPEC quantity.

### Chapter 4

### Numerical Results

The numerical results were generated solving (3.11) and (3.12), using the price elasticity of global demand and fringe supply as exogenous parameters. For different combinations of such parameters, I solved numerically for the market equilibrium price and quantities for each player.<sup>1</sup> Table 4.1 shows a synthesis of the changes of the variables of interest from the price-taking to the strategic scenario, for various combinations of price elasticities of demand and fringe supply.

Firstly, it must be noted that the numerical results are in line with what theory and intuition would suggest: Russia is better-off acting strategically as compared with the price-taking behavior, i.e. the profits in the strategic case are higher than in the pricetaking scenario.<sup>2</sup> However, the gains are only in qualitative terms as the quantitative measure shows an insignificant difference: for any elasticity scenario Russia's gains are well below 1%. In addition, the strategic behavior allows Russia to save its oil resources as it reduces its oil supply with about 50,000 barrels daily on average, while the price increases from the price-taking to the strategic scenario (see Tabel 4.1). Indeed, the

<sup>&</sup>lt;sup>1</sup>For the complete numerical results of the model the reader is referred to Appendix B.

<sup>&</sup>lt;sup>2</sup>For the calculation of the profits I assumed total costs having zero fixed costs for both players. The motivation is that in short-run fixed cost does not influence the production decision, since this only depends on the marginal cost. Moreover, for the purpose of this thesis, i.e., comparing gains in two behavioral situations, adding a constant to both terms does not mathematically influence the outcome. Thus, the total costs obtained from the integration of the marginal costs, and used in calculations are  $C_O(q_O) = 18.52 \ln 34.23 - 18.52 \ln (34.23 - q_O)$ , for OPEC and  $C_R(q_R) = 14.68 \ln 10 - 14.68 \ln (10 - q_R)$ , for Russia.

		Elasticity	sensitivity	
	Both High	Demand Low,	Demand High,	Both Low
		Supply High	Supply Low	
Price	0.042%	0.081%	0.078%	0.081%
Russia Profit	0.022%	0.040%	0.040%	0.065%
<b>OPEC</b> Profit	0.044%	0.087%	0.082%	0.214%
<b>Russia Supply</b>	-0.340%	-0.495%	-0.469%	-0.785%
<b>OPEC</b> Supply	0.001%	0.005%	0.002%	0.036%
Fringe Supply	0.028%	0.053%	0.018%	0.084%
Total output	- $0.025\%$	-0.029%	-0.045%	-0.039%

Table 4.1: Percentage change from the price-taking to the strategic scenario (averages)

Russian oil supply decline, as predicited by the model, is in accordance with the Russian president's intentions to limit the oil extraction in the future (Low, 2007).

Secondly, in the strategic case, the price is always higher than in the price-taking scenario. Only for very low demand and supply elasticities, i.e the residual demand<sup>3</sup> faced by Russia together with OPEC is greater than 1, but very close to 1 in absolute value, is the price higher than the base case of 60 dollars/barrel, used in the calibration of the demand and fringe supply functions. Nevertheless, in all the cases, the price is not higher than a few cents per barrel in the strategic game. In all the scenarios analyzed, the price span is from 60 to 62 dollars per barrel, except for the cases where both demand and fringe supply are very inelastic. In this range of elasticities, the price reaches 89 dollars per barrel in both scenarios. The fact that currently the price has not reach this value indicates that very inelastic demand and fringe supply elasticities might not be realistic assumptions.

For instance, if the global demand elasticity was 0.406 and the fringe supply elasticity was 0.384 - the base case in Celta (2000)-, Russia's strategic behavior would drive the price up with only 7 cents per barrel. At first glance, this seems to be a counterintuitive

<sup>&</sup>lt;sup>3</sup>Residual demand faced by OPEC and Russia can be computed using the following formula:  $\epsilon_{rd} = \frac{1}{s_O + s_R} [\epsilon_w - \epsilon_f s_f]$ , where  $\epsilon_{rd}$  is the price elasticity of the residual demand,  $s_O$  and  $s_R$  are the market shares of Russia and OPEC, respectively and  $s_f$  denotes the market share of the fringe excluding Russia. It is easy to see that the residual demand elasticity will always be greater, in absolute value, than the total demand elasticity. Note that, all else equal, the absolute value of the residual demand is lower, the lower is  $\epsilon_f$ , and the lower is  $\epsilon_w$  in absolute value. Thus, we expect that for very inelastic global demand and fringe supply, residual demand will be inelastic.

result, as the theory predicts a higher price in the monopoly case than in the Stackelberg competition. The explanation in this case stands in the fact that when Russia is a part of the fringe, OPEC, as a monopolist, faces a different residual demand than the one faced by both players in the Stakelberg game. In other words, the monopoly and quantity leadership are played on different quantities, and the difference is given exactly by Russia's supply. The same explanation can be applied to the results concerning the total market output, which is lower in the strategic case.

Thirdly, in both scenarios Russia produces very close to its capacity; on average, its spare capacity is below 0.3 million barrels per day, as the model implies. The small production capacity, less than one third of OPEC's capacity, suggests that Russia is still a small player, with limited strategic power. Hence, Russia's small gain is the consequence of its output reduction, which is 6 to 10 times higher than the price increase, for any combination of elasticities (see Table 4.1). Thus, from the technical point of view, the capacity constraint makes Russia's game with OPEC more difficult because the relatively small production capacity, as well as the high production costs, hinders this producer from boosting its production for benefiting enough from the price increase. At the same time, as shown by the outcome of the model, Russia does not have enough power to influence the price sufficiently such as to maintain higher spare capacity. On the other hand, in both versions of the world oil market, OPEC has over 1 million b/d spare capacity, unless both the demand and the fringe supply elasticities are high (over 0.5 in absolute value). In addition, for low values of the residual demand, OPEC's spare capacity can reach 10 million b/d. Obviously, this is a result consistent with the leading position of OPEC.

Finally, OPEC produces more as a leader, in the Stackelberg game with Russia, than as a monopolist, and for any elasticity pairs it has higher gains than Russia. This is not surprising since OPEC has the first move in the Stackelberg game and moreover, its marginal cost is lower than Russia's. As it can be seen in Table 4.1, its gains are almost twice as large as Russia's. Figure 4.1 shows the shape of the relative profits in the strategic scenario as compared with the price-taking scenario, for the two players, as functions of



Figure 4.1: Profit change for OPEC and Russia in percentages

the price elasticity of the global demand and fringe supply, respectively. It is easy to see that OPEC's profit gains are skewed with a peak towards low elasticities, mainly because for these elasticity values both its supply and the equilibrium price increase the most among all elasticity combinations. Russia's profit gains have the same behavior but at a halved scale.

Let us now turn the discussion towards the third player of this market, the fringe producers. The fact that this player takes the price as given is reflected in its upward sloping supply curve, which is unsurprisingly confirmed by the numerical results. Thus, the natural consequence of a higher price in the strategic version of the world oil market is a higher supply of the fringe. In both scenarios, the fringe has a market share in the range of 50% to 55%, but its supply never surpasses the threashold of 42 million b/d, for reasonable choises of its supply and global demand elastiticities. Nevertheless, the supply increase of OPEC together with the fringe cannot offset Russia's supply curbs, resulting in a total world oil supply reduction from the case when Russia is part of the fringe to the case when it is a follower in the quantity leadership game. This reduction amounts to 13,000 to 40,000 b/d depending on the elasticities values, with higher reductions for lower elasticities values.

Hence, the stylized model devised in this thesis shows that from the economic point of view, Russia does not have sufficient strategic power to be able to capture a considerable rent in a strategic game with OPEC, albeit individually Russia is the second largest oil producer in the world. In all behavioral, as well as elasticity scenarios, Russia's market share, resulting from the model, is only around 11%. This result is consistent with the real data: as shown by the IEA in its monthly report from April, 2007, Russia has a market share of 11.6%. Hence, Russia is still a small player compared with the market leader, OPEC, which has a market share of around 40%. Briefly, Russia's major weaknesses captured by the static model consist of high marginal cost and low production capacity compared with its rival, OPEC.

In addition, Russia's change of behavior, apart from being politically driven, might still have economic grounds. Possibly, it is not the financial interest that Russia is after, but rather some resource saving intentions, at the same time keeping its oil revenue relatively constant. As it can be seen in Table 4.1, profit gains are lower than the production curbs. Hence, a strategic behavior allows Russia to influence the price in such a manner as to save its resources without hurting its most important export revenue, the oil export revenue.

Elasticity sensitivity analysis shows that, in the price-taking model, keeping demand elasticity constant, OPEC supply should increase as the fringe supply becomes less inelastic. This comes as a result of the residual demand elasticity, which increases in absolute value. Conversely, Russia's output, the price and the fringe supply should decrease as the fringe supply elasticity becomes higher. In addition, holding the fringe supply elasticity fixed, OPEC's quantity reduces, but the price, Russia's supply and the fringe supply increase as world demand becomes more inelastic. These are expected results, for they correspond to the microeconomic theory of the dominant firm, and to the relationships between the price and the demand elasticity, and between the price and the supply of a price-taker.

In the strategic case, all else the same, the price increases and also the fringe supply, in conformity with its price-taking behavior, as demand elasticity decreases in absolute value. In the opposite direction, OPEC's output and Russia's supply decrease as the demand becomes more inelastic. For low fringe supply elasticities, below 0.2, Russia's output exhibits a convex shape relative to this parameter. When the demand elasticity is kept constant, price slopes downwards and OPEC's quantity slopes upwards while the fringe supply elasticity increases. The fringe supply starts declining, following the price reduction, reflecting again the fact that this player takes the price as given. However, for very low elasticities, below 0.1, the fringe supply has a downward slope as its supply becomes more inelastic, mainly because, due to the price jump, the total demand falls for these elasticities values. Thus, the fringe supply has a concave shape relative to its supply elasticity, with a peak around 0.1-0.2 elasticity values. Russia's production has an increasing trend when keeping the demand elasticity constant and varying the fringe supply elasticity towards higher values. In contrast, for very low supply elasticities, less than 0.2, and low demand elasticities, less than 0.4, Russia's supply decreases with the fringe supply elasticity. The explanation for this is the low residual demand elasticity for the Stackelberg game between Russia and OPEC.

At this point, it is worth providing a comparison of the model's result with the real market data. I use again the IEA's data from March 2007 report, and I am referring to the 2006 data, as this is the data I used in the calibration of the demand and fringe less Russia supply functions. Thus, according to my static model, Russia under-supplied in 2006 in the price-taking version, as its actual supply for 2006 was of 9.69 million b/d, and the model suggests that under the price-taking scenarios it should have supplied over 9.75 million b/d for any combination of elasticities. From the point of view of Russia's output, the strategic scenario is closer to the real data, and moreover, the figure reported by the IEA corresponds to the optimal solution of the model for demand elasticity in the range of 0.4 to 0.5 with a fringe supply elasticity of 0.3 to 0.4.

With reference to OPEC, the model shows that its supply<sup>4</sup> was lower than the optimal supply for any of Russia's behavioral situations. OPEC's supply in 2006 was around 29.72 million b/d, whereas the static model predicts that it should have supplied over 30 million b/d, unless the fringe supply elasticity is very low - below 0.1 - and the global demand is under 0.34, in which cases it should have supplied between 23 and 29 million b/d, as the model suggests. OPEC's under-supply complies with the organization's aim of preventing a price collapse acting as a 'swing producer'. Turning to the non-OPEC, non-Russia supply, in both versions, the model predicts figures very close to the actual non-OPEC less Russia supply from 2006, of 41.15 million b/d.

As already mentioned above, the price does not exhibit a significant sensitivity to elasticity parameters, except for the case when the demand elasticity is less than 0.5 in absolute value and the fringe supply elasticity is below 0.2. In this range the price can jump from 60 to 89 dollars per barrel. In all the other cases, price is floating around 60 dollars per barrel in both scenarios in which Russia might behave. This is lower than the reported Energy Information Association (EIA) average Brent spot price of crude, an average of 65.16 dollars per barrel for 2006. This price difference, together with the difference between OPEC's actual supply and its optimal supply as resulted from the model, shows that the cartel is driven by other interests than profit maximization only, most likely political interests. In addition, it is evident that OPEC still has the power to decide and control the world oil price in spite of any attempt of Russia to gain some influence on oil price formation.

Concluding, the outcome of the static model reveals that, from the monetary stand point, Russia should be indifferent in choosing between the two behavioral strategies. Nevertheless, the rent it might capture should be assessed against the costs it incurs in case of a strategic game with OPEC. Despite the fact that the strategic behavior does not bring a considerable gain in the short-run, Russia could still benefit from behaving strategically in the long-run. From the financial point of view, Russia is a healthy economy,

<sup>&</sup>lt;sup>4</sup>Angola is included in the fringe as it joined OPEC only as from January, 2007

with a surplus in its current account and enough reserves, both in foreign accounts and in its stabilization fund, thus, being not very much constrained by raising more money from oil production. On the other hand, reducing its production, as suggested by a strategic behavior, could increase its value in the future. Leaving more oil in the ground now might prove to be very important in the future, since there are fears among analysts that oil production will reach a plateau before 2015.

### Chapter 5

### Conclusions

Motivated by the recent change of structure in the Russian oil industry, where the state is regaining control over exploration and production, I employed a stylized model to quantitatively compare the Russian gains in two behavioral situations: Russia as a pricetaker and Russia as a strategic player in a leader-follower quantity game with OPEC. I used constant elasticity global oil demand and fringe supply functions, and I assessed the gain of Russia from the strategic behavior against the price-taking behavior, under capacity constraint. In addition, I used the price elasticity of world oil demand and fringe supply as parameters, and I found that in monetary terms Russia has very low gains, but instead the strategic behavior enables it to save resources. Furthermore, I found that OPEC, the market leader, is more better-off than Russia, if Russia plays strategically.

Thus, it becomes apparent that Russia's change of behavior since 2004, when the process of the oil industry renationalization started, has been driven more by political reasons than by pure economic interests. As the oil industry is now state-dominated, the government emerges as the only decision maker using the energy policy to push Russia on a major position in the international arena. The expansion of the Russian influence and presence in the oil industry of the Middle East and the North African regions is one instance of the Russian international policy that involves its oil potential.

The numerical results of the model show that Russia under-supplied in 2006, if we assume a price-taking scenario, since its optimal output in this case is above 9.69 million

b/d, as reported by the IEA. In contrast, if we assume a strategic behavior for Russia, the outcome of the model is closer to the real market data, showing that Russia might indeed play strategically. In addition, in both scenarios Russia produces very close to its capacity suggesting that its relatively low production capacity prevents this producer from gaining enough strategic power. Concerning OPEC, the model predicts higher supply than the actual data for 2006 shows; it supplied around 30 million b/d in 2006, while the model implies an optimal output with at least 2 million b/d more than the reported figure. On the other hand, in 2006 the fringe producers less Russia had a supply very close to the data provided by the model. This is explained by OPEC's and Russia's supplies, which were lower than the optimal quantities predicted by the model.

Comparing the two versions of the world oil market, OPEC has both the supply and the relative profits higher than Russia's when Russia plays strategically. Additionally, the fringe supply is higher, but Russia extracts less oil in the strategic game, while the price increases relative to the price-taking version of the world oil market. Overall, the total market supply declines as Russia changes its behavior from a price-taker to a quantity follower of OPEC.

Elasticity sensitivity analysis shows that, in the price-taking model, the results correspond to the microeconomic theory of the dominant firm: the price decreases when the demand and the fringe supply become more elastic, the quantity supplied by OPEC increases, while Russia and the fringe supply less. In the strategic case, the price decreases under the same conditions as above, OPEC's and Russia's quantity increase, but the supply of the fringe decreases because this player is a price-taker.

However, all the results presented in Chapter 4 must be regarded with caution, as they are subject to the limitations of the model through which they were derived. Firstly, the limitations of the results presented in this study come mainly from the inputs into the model. The most problematic one is the sensitivity of the results to the calibration of the marginal cost functions. A more precise estimation, as well as more accurate data on marginal costs for the two main players could assure the robustness of the predictions with respect to the potential gain of Russia in the strategic scenario. Therefore, more work is needed in testing for the sensitivity of the model to its input parameters. For example, instead of a short-run setup involving capacity constraints for both players, my model can be extended for a long-run analysis employing long-run cost functions with no constraint on capacity. Moreover, a dynamic model could give the production paths in which the players maximize their discounted profits over time, rather than being concerned with only one point in time.

The second limitation comes from the assumptions on global demand and fringe supply functional forms, along with their calibration around one single price-quantity point on the curve. The third limitation of the model is the fact that it does not capture the noneconomic interests which may affect the oil price. Being a stylized microeconomic model, it only highlights the optimal rational behavior of the players. Other interests triggered by, for example, political tensions and instability in the oil-producing countries, as well as the frequent terrorist attacks that boost the oil price, are not included in the model.

However, the benefit of this study is to show that in the actual context and under short-run conditions, Russia does not have sufficient market power to undermine OPEC's dominance on the world oil market. Nevertheless, with more investments in raising its crude extraction capacity, as well as in lowering its production costs, Russia could improve its strategic power. Thus, under different circumstances resulting in different inputs into the model, i.e. lower production costs and higher capacity, the model might show significant monetary gains for Russia playing strategically.

### Appendix A

#### **Optimization Problems**

We can analyze problems (3.11) and (3.12) more closely. In what follows, I assume  $\epsilon_w \in [-1, 0]$  and  $\epsilon_f \in [0, 1]$ , since the demand and fringe supply are inelastic.

Note that (3.11) is an unconstrained optimization problem. To maximize OPEC's profit we have to differentiate with respect to p and get the first order condition for this problem:

$$A(1+\epsilon_w)p^{\epsilon_w} - B(1+\epsilon_f)p^{\epsilon_f} - K_R + b_O \frac{-A\epsilon_w p^{\epsilon_w-1} + B\epsilon_f p^{\epsilon_f-1} + b_R p^{-2}}{K_O - Ap^{\epsilon_w} + Bp^{\epsilon_f} + K_R - b_R p^{-1}} = 0$$
(A.1)

Rearranging (A.1), yields:

$$\frac{A(1+\epsilon_w)p^{\epsilon_w} - B(1+\epsilon_f)p^{\epsilon_f} - K_R}{A\epsilon_w p^{\epsilon_w - 1} - B\epsilon_f p^{\epsilon_f - 1} - b_R p^{-2}} = \frac{b_O}{K_O - Ap^{\epsilon_w} + Bp^{\epsilon_f} + K_R - b_R p^{-1}}$$
(A.2)

Denoting by  $TR_O = pq_O(p)$  the total OPEC's revenue and taking into account that  $q_O(p) = Ap^{\epsilon_w} - Bp^{\epsilon_f} - K_R + b_R p^{-1}$ , one can compute the marginal revenue for OPEC as:

$$MR = \frac{\partial TR_O}{\partial q_O} = \frac{\frac{\partial TR_O}{\partial p}}{\frac{\partial q_O}{\partial p}}$$

Thus, in (A.2) one can recognize on the left-hand side the marginal revenue and on the right-hand side the marginal cost of OPEC. This is the standard condition for the



Figure A.1: OPEC as a dominant firm for  $\epsilon_w = -0.34$  and  $\epsilon_w = 0.384$ 

profit maximizing choice of output for a monopolist, where marginal revenue must equal marginal cost. Figure A.1 shows the optimal price and quantities in this scenario for a particular choice of price elasticity of demand and price elasticity of fringe supply.

The second order condition must assure the concavity of the profit function and thus, the existence of a maximum for the objective function:

$$A\epsilon_{w}(1+\epsilon_{w})p^{\epsilon_{w}-1} - B\epsilon_{f}(1+\epsilon_{f})p^{\epsilon_{f}-1} + b_{O}\frac{(-A\epsilon_{w}(\epsilon_{w}-1)p^{\epsilon_{w}-2} + B\epsilon_{f}(\epsilon_{f}-1)p^{\epsilon_{f}-2} - 2b_{R}p^{-3})(K_{O} - Ap^{\epsilon_{w}} + Bp^{\epsilon_{f}} + K_{R} - b_{R}p^{-1})}{(K_{O} - Ap^{\epsilon_{w}} + Bp^{\epsilon_{f}} + K_{R} - b_{R}p^{-1})^{2}} - b_{O}\frac{(-A\epsilon_{w}p^{\epsilon_{w}-1} + B\epsilon_{f}p^{\epsilon_{f}-1} + b_{R}p^{-2})^{2}}{(K_{O} - Ap^{\epsilon_{w}} + Bp^{\epsilon_{f}} + K_{R} - b_{R}p^{-1})^{2}} \leq 0$$
(A.3)

which is true for  $b_R > 0$  and all  $\epsilon_w$  between -1 and 0 and all  $\epsilon_f$  between 0 and 1, i.e. inelastic demand and fringe supply, because each term of the summation is negative.

Problem (3.12) is a constrained maximization problem in two variables, p and  $q_O$ , and with one equality constraint. The equality constraint is the market equilibrium condition.



Figure A.2: OPEC's profit function shape for  $\epsilon_w = -0.34$  and  $\epsilon_w = 0.384$ 

Hence, we can define the Lagrangian function:

$$L(p, q_O, \lambda) = q_O p - a_O + b_O \ln(K_O - q_O) - \lambda \left[ p - \frac{b_R}{(K_R - Ap^{\epsilon_w} + Bp^{\epsilon_f} + q_O)} + (Ap^{\epsilon_w} - Bp^{\epsilon_f} - q_O)(A\epsilon_w p^{\epsilon_w - 1} - B\epsilon_f p^{\epsilon_f - 1})^{-1} \right]$$

The maximizing point,  $(p^*, q_O^*)$ , must satisfy the first and second order conditions. The first order conditions are:

$$\begin{aligned} \frac{\partial L}{\partial p} &= q_O - \lambda [1 + \frac{b_R (-A\epsilon_w p^{\epsilon_w - 1} + B\epsilon_f p^{\epsilon_f - 1})}{(K_R - Ap^{\epsilon_w} + Bp^{\epsilon_f} + q_O)^2} + 1 - \\ (Ap^{\epsilon_w} - Bp^{\epsilon_f} - q_O) (A\epsilon_w (\epsilon_w - 1)p^{\epsilon_w - 2} - B\epsilon_f (\epsilon_f - 1)p^{\epsilon_f - 2}) (A\epsilon_w p^{\epsilon_w - 1} - B\epsilon_f p^{\epsilon_f - 1})^{-2}] = 0 \\ \frac{\partial L}{\partial q_O} &= p - \frac{b_O}{K_O - q_O} - \lambda [\frac{b_R}{(K_R - Ap^{\epsilon_w} + Bp^{\epsilon_f} + q_O)^2} - (A\epsilon_w p^{\epsilon_w - 1} - B\epsilon_f p^{\epsilon_f - 1})^{-1}] = 0 \\ \frac{\partial L}{\partial \lambda} &= p - \frac{b_R}{(K_R - Ap^{\epsilon_w} + Bp^{\epsilon_f} + q_O)} + (Ap^{\epsilon_w} - Bp^{\epsilon_f} - q_O) (A\epsilon_w p^{\epsilon_w - 1} - B\epsilon_f p^{\epsilon_f - 1})^{-1} = 0 \end{aligned}$$
(A.4)

The second order sufficient conditions require that for the stationary point  $(\bar{p}, \bar{q}_O)$ of the Lagrangian function  $L(p, q_O, \lambda)$  to be a local maximizer, there must be a real  $\lambda$ satisfying the first order conditions (A.4), such that, the Hessian matrix of the Lagrangian function,

$$D^{2}_{(p,q_{O})}L(\bar{p},\bar{q_{O}}) = \begin{pmatrix} \frac{\partial^{2}L}{\partial p^{2}} & \frac{\partial^{2}L}{\partial p\partial q_{O}} \\ & & \\ \frac{\partial^{2}L}{\partial q_{O}\partial p} & \frac{\partial^{2}L}{\partial q_{O}^{2}} \end{pmatrix},$$

be negative semidefinite on the subspace of the directions tangent to the constraint surface. If this is satisfied, then  $(\bar{p}, \bar{q}_O)$  is a local constrained maximizer.

The second order conditions are verified if

$$\frac{\partial^2 L}{\partial p^2} \le 0 \tag{A.5}$$

and

$$\begin{vmatrix} \frac{\partial^2 L}{\partial p^2} & \frac{\partial^2 L}{\partial p \partial q_O} \\ \\ \frac{\partial^2 L}{\partial q_O \partial p} & \frac{\partial^2 L}{\partial q_O^2} \end{vmatrix} = \frac{\partial^2 L}{\partial p^2} \frac{\partial^2 L}{\partial q_O^2} - \left[ \frac{\partial^2 L}{\partial p \partial q_O} \right]^2 \ge 0$$
(A.6)

Checking the sufficiency condition for a local maximum in this case is computationally complicated. Alternatively, we can check the behavior of the objective function graphically. Figure A.2 depicts the shape of OPEC's profit, as a function of its output and price for  $\epsilon_w = -0.34$  and  $\epsilon_f = 0.384$ . In particular, we have  $A = 84.5 \times 60^{0.34}$  and  $B = 41.15 \times 60^{-0.384}$ . The graph illustrates a concave surface in the area of interest, such that the objective function to be maximized is well-behaved and a constrained maximizing point can be found. Moreover, the optimum point for these elasticity parameters is  $q_O = 33.06$  and p = 60.8, as indicated in Figure A.2.

## Appendix B

### Numerical results

This Appendix includes the numerical results of the model for the main variables: price, the quantities supplied by the two main players, OPEC and Russia, and the quantity supplied by the competitive fringe, for different elasticities scenarios.

### RUSSIA AS A PRICE-TAKER

Price (US dollars)	fringe	supply	elasticity									
total demand elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	89.62652	84.46744	75.03825	65.48887	62.22901	61.20365	61.08204	60.78801	60.58366	60.32692	60.17913	59.98794
0.340	74.99270	72.11300	67.07161	62.66101	61.23569	60.71999	60.65359	60.48665	60.36416	60.20105	60.10141	59.96439
0.406	63.89754	63.20038	62.05598	60.99209	60.53462	60.32728	60.29797	60.22089	60.16095	60.07568	60.01992	59.93771
0.430	62.48729	62.09434	61.41873	60.72864	60.40172	60.24493	60.22225	60.16195	60.11434	60.04543	59.99957	59.93069
0.500	60.87117	60.76682	60.56435	60.31298	60.16943	60.09248	60.08082	60.04908	60.02320	59.98438	59.95755	59.91580
0.560	60.41429	60.36828	60.27391	60.14557	60.06541	60.01991	60.01285	59.99338	59.97725	59.95253	59.93513	59.90776
0.600	60.25529 <sup>5</sup>	60.22598	60.16445	60.07740	60.02079	59.98783	59.98266	59.96829	59.95629	59.93778	59.92463	59.90407
1.000	59.91135 <u>3</u>	59.91009	59.90731	59.90307	59.90022	59.89863	59.89840	59.89780	59.89736	59.89692	59.89693	59.89873
	CEU eTD Col			Table B	.1: Equili	brium prio	ce in the p	price-taking	g scenario			

$\begin{array}{c} {\rm Quantity} \\ {\rm OPEC} \ ({\rm mb}/{\rm d}) \end{array}$	fringe	supply	elasticity									
total demand elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	23.43079	24.57377	27.13134	30.65725	32.21348	32.77279	32.84320	33.01905	33.14760	33.32132	33.43245	33.60809
0.340	27.09832	28.05209	29.96671	31.98800	32.75365	33.06083	33.10261	33.21107	33.29484	33.41512	33.49708	33.63630
0.406	31.37017	31.71110	32.29967	32.89475	33.17906	33.32088	33.34206	33.39969	33.44700	33.51999	33.57363	33.67329
0.430	32.07169	32.27825	32.64783	33.05481	33.26846	33.38135	33.39862	33.44618	33.48586	33.54829	33.59513	33.68449
0.500	32.96652	33.03060	33.15923	33.33103	33.44010	33.50490	33.51532	33.54479	33.57029	33.61216	33.64513	33.71211
0.560	33.25951	33.29151	33.35955	33.45954	33.52941	33.57364	33.58095	33.60196	33.62051	33.65186	33.67729	33.73113
0.600	33.37340	33.39563	33.44408	33.51841	33.57274	33.60821	33.61415	33.63139	33.64679	33.67316	33.69492	33.74202
1.000	33.72188	33.72493	33.73214	33.74509	33.75637	33.76480	33.76630	33.77083	33.77510	33.78295	33.78999	33.80739

 Table B.2: Equilibrium OPEC quantity in the price-taking scenario

Quantity Russia (mb/d)	fringe	supply	elasticity									
total demand elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	9.83621	9.82621	9.80437	9.77584	9.76410	9.76015	9.75967	9.75851	9.75769	9.75666	9.75606	9.75528
0.340	9.80425	9.79643	9.78113	9.76572	9.76027	9.75823	9.75797	9.75730	9.75681	9.75615	9.75575	9.75519
0.406	9.7702 <u>6</u>	9.76772	9.76344	9.75931	9.75749	9.75666	9.75654	9.75623	9.75599	9.75564	9.75541	9.75508
0.430	9.7650	9.76359	9.76098	9.75827	9.75696	9.75633	9.75624	9.75599	9.75580	9.75552	9.75533	9.75505
0.500	9.7588 <b>3</b>	9.75842	9.75761	9.75660	9.75602	9.75571	9.75566	9.75553	9.75543	9.75527	9.75516	9.75499
0.560	9.7570 <b>Ů</b>	9.75683	9.75645	9.75593	9.75560	9.75541	9.75539	9.75531	9.75524	9.75514	9.75507	9.75496
0.600	9.756 <b>£</b>	9.75625	9.75600	9.75565	9.75542	9.75528	9.75526	9.75520	9.75515	9.75508	9.75503	9.75494
1.000	9.75493	9.75497	9.75495	9.75494	9.75493	9.75492	9.75492	9.75492	9.75491	9.75491	9.75491	9.75492
	CE		Table	<b>B.3</b> : E	auilibriu	n Russia	quantity	in the pr	ice-taking	scenaric	)	

 Table B.3:
 Equilibrium Russia quantity in the price-taking scenario

$\begin{array}{c} {\rm Fringe} \\ {\rm Supply} \ ({\rm mb/d}) \end{array}$	fringe	supply	elasticity									
total												
demand elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	41 64841	41 85976	42 08070	41 87676	41 60278	41 46506	41 44525	41 39233	41 34966	41 28438	41 23596	41 14173
0.340	41.42627	41.53010	41.61104	41.50869	41.40243	41.33892	41.32872	41.29986	41.27469	41.23268	41.19867	41.12557
0.406	41.22777	41.25706	41.28888	41.28519	41.25966	41.23605	41.23162	41.21810	41.20516	41.18113	41.15956	41.10728
0.430	41.20017	41.22065	41.24628	41.24946	41.23246	41.21442	41.21090	41.19995	41.18919	41.16869	41.14980	41.10247
0.500	41.16780	41.17614	41.18854	41.19284	41.18483	41.17434	41.17216	41.16514	41.15795	41.14357	41.12962	41.09225
0.560	41.15850	41.16259	41.16875	41.16995	41.16345	41.15524	41.15353	41.14796	41.14220	41.13046	41.11885	41.08674
0.600	41.15524	41.15774	41.16126	41.16061	41.15428	41.14679	41.14524	41.14021	41.13501	41.12439	41.11381	41.08421
1.000	41.14817	41.14691	41.14364	41.13670	41.12946	41.12329	41.12211	41.11844	41.11479	41.10757	41.10050	41.08055

Table B.4: Equilibrium fringe quantity in the price-taking scenario

#### RUSSIA AS A STRATEGIC PLAYER

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Price (US dollars)	fringe	supply	elasticity									
total demand elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	89.9381	84.7210	75.2066	65.6086	62.33731	61.29911	61.17501	60.87329	60.66427	60.39282	60.23523	60.02449
0.340	75.2175 .	§ 72.3078	67.2231	62.7806	61.33480	60.80461	60.73576	60.56160	60.43283	60.25914	60.15112	59.99742
0.406	64.0503	<u>8</u> 63.3425	62.1786	61.0888	60.61348	60.39476	60.36357	60.28110	60.21641	60.12317	60.06107	59.96589
0.430	62.6222	62.2212	61.5293	60.8168	60.47405	60.30715	60.28279	60.21767	60.16579	60.08972	60.03810	59.95737
0.500	60.9677 g	60.8589	60.6469	60.3807	60.22629	60.14216	60.12929	60.09404	60.06505	60.02088	59.98968	59.93870
0.560	60.4894	o 60.4405	60.3396	60.2007	60.11245	60.06151	60.05352	60.03133	60.01275	59.98383	59.96293	59.92800
0.600	60.3199	g 60.2883	60.2215	60.1259	60.06260	60.02505	60.01908	60.00242	59.98834	59.96619	59.95002	59.92278
1.000	59.9331	ر 59.9314	59.9276	59.9215	59.91701	59.91423	59.91378	59.91254	59.91150	59.90997	59.90901	59.90848

 Table B.5:
 Equilibrium price in the strategic scenario

$\begin{array}{c} {\rm Quantity} \\ {\rm OPEC} \ ({\rm mb}/{\rm d}) \end{array}$	fringe	supply	elasticity									
total demand elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	23.46147	24.60894	27.17241	30.68915	32.22960	32.78213	32.85170	33.02555	33.15086	33.32474	33.43486	33.60925
0.340	27.11868	28.07489	29.99007	32.00189	32.76121	33.06580	33.10723	33.21488	33.29797	33.41738	33.49879	33.63720
0.406	31.37574	31.71702	32.30516	32.89869	33.18184	33.32305	33.34413	33.40150	33.44860	33.52126	33.57466	33.67391
0.430	32.07492	32.28168	32.65134	33.05754	33.27055	33.38304	33.40024	33.44762	33.48716	33.54935	33.59601	33.68504
0.500	32.96749	33.03168	33.16042	33.33219	33.44112	33.50580	33.51620	33.54560	33.57103	33.61281	33.64569	33.71249
0.560	33.26000	33.29206	33.36018	33.46020	33.53003	33.57421	33.58152	33.60250	33.62104	33.65232	33.67770	33.73143
0.600	33.37374	33.39601	33.44452	33.51889	33.57320	33.60865	33.61460	33.63181	33.64720	33.67352	33.69523	33.74227
1.000	33.72192	33.72497	33.73220	33.74515	33.75645	33.76487	33.76638	33.77091	33.77518	33.78303	33.79007	33.80747

Table B.6: Equilibrium OPEC quantity in the strategic scenario

Quantity Russia (mb/d)	fringe	supply	elasticity									
total demand elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	9.72323	9.71621	9.70075	9.68355	9.68268	9.68672	9.68762	9.69049	9.69333	9.69856	9.70315	9.71361
0.340	9.70051	9.69523	9.68599	9.68205	9.68648	9.69132	9.69223	9.69500	9.69762	9.70235	9.70645	9.71581
0.406	9.6819 <b>2</b>	9.68175	9.68301	9.68834	9.69410	9.69852	9.69931	9.70165	9.70383	9.70775	9.71114	9.71899
0.430	9.6822	9.68291	9.68536	9.69118	9.69672	9.70087	9.70160	9.70379	9.70582	9.70947	9.71264	9.72003
0.500	9.6894	9.69067	9.69357	9.69888	9.70349	9.70687	9.70746	9.70924	9.71090	9.71390	9.71653	9.72275
0.560	9.69642	9.69747	9.69997	9.70444	9.70829	9.71113	9.71163	9.71313	9.71454	9.71709	9.71935	9.72478
0.600	9.700 <b>52</b>	9.70145	9.70367	9.70763	9.71106	9.71360	9.71405	9.71540	9.71666	9.71897	9.72102	9.72600
1.000	9.72378	9.72409	9.72488	9.72634	9.72767	9.72870	9.72888	9.72945	9.73000	9.73102	9.73196	9.73439
	CE		Tab	le B.7:	Equilibri	um Russi	a quantit	v in the s	strategic	scenario		

 Table B.7: Equilibrium Russia quantity in the strategic scenario

Fringe Supply (mb/d)	fringe	supply	elasticity									
total												
elasticity	0.03	0.05	0.1	0.2	0.300	0.384	0.400	0.450	0.500	0.600	0.700	1.000
0.300	41.65274	41.86604	42.09014	41.89206	41.62449	41.48988	41.47047	41.41845	41.37716	41.31144	41.26286	41.16680
0.340	41.42999	41.53570	41.62043	41.52452	41.42252	41.36103	41.35110	41.32288	41.29816	41.25654	41.22252	41.14823
0.406	41.23072	41.26169	41.29703	41.29827	41.27577	41.25375	41.24956	41.23664	41.22414	41.20066	41.17931	41.12661
0.430	41.20284	41.22486	41.25370	41.26143	41.24727	41.23076	41.22747	41.21711	41.20681	41.18691	41.16829	41.12076
0.500	41.16976	41.17925	41.19415	41.20209	41.19650	41.18741	41.18544	41.17901	41.17230	41.15859	41.14505	41.10796
0.560	41.16003	41.16505	41.17323	41.17749	41.17312	41.16619	41.16468	41.15967	41.15437	41.14334	41.13220	41.10062
0.600	41.15657	41.15986	41.16517	41.16726	41.16288	41.15660	41.15523	41.15075	41.14600	41.13609	41.12600	41.09704
1.000	41.14862	41.14765	41.14503	41.13922	41.13292	41.12740	41.12634	41.12300	41.11964	41.11294	41.10631	41.08723

 Table B.8: Equilibrium fringe quantity in the strategic scenario

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