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EWI Working Paper, No 19/05

July 2019

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ISSN: 1862-3808

The Shift in Global Crude Oil Market Structure:

A model-based analysis of the period 2013–2017

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Abstract

The global crude oil market has gone through two important phases over the recent years. The first one was the price collapse that started in the third quarter of 2014 and continued until mid-2016. The second phase occurred in late 2016, after major producers within and outside OPEC agreed to cut production in order to adjust the ongoing fall in oil prices, which is now known as the OPEC+ agreement. This paper analyzes the effects of these recent developments on the market structure and on the behavior of major producers in the market. To this end, we develop a partial equilibrium model with a spatial structure for the global crude oil market and simulate the market for the period between 2013 and 2017 under oligopolistic, cartel and perfectly competitive market structure setups. The simulation results reveal that, although the oligopolistic market structures fit overall well to the realized market outcomes, they are not successful at explaining the low prices during 2015 and 2016, which instead are closer to estimated competitive levels. Moreover, we further suggest that from 2014 onward, the market power potential of major suppliers has shrunk considerably, supporting the view that the market has become more competitive. We also analyze the Saudi Arabia- and Russia-led OPEC+ agreement, and find that planned production cuts in 2017, particularly of Saudi Arabia (486 thousand barrels/day) and Russia (300 thousand barrels/day), were below the levels of estimated non-competitive market structure setups. This explains why the oil prices did not recover to pre-2014 levels although a temporary adjustment was observed in 2017.

Keywords: crude oil market structure, 2014 oil price decline, OPEC+ agreement, market simulation model, DROPS

JEL classification: C63, D43, Q31, Q41

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1. Introduction

The global oil market went through significant turmoil in recent years. After a period of increasing oil prices in the 2000s, prices sky-rocketed to record highs in summer 2008. Although the credit-crunch put a temporary halt on high prices, the fast recovery of the global economy stabilized the oil prices at an average of \$100 per barrel (bbl) during the period between 2011 and 2013. High oil prices over this period triggered two major developments in global oil markets: First, renewable energy investments were intensified, leading to a decline in future expected demand for all fossil fuels. Second, higher cost resources, especially shale oil in the USA, became an economically viable option for producers, which caused a glut in global oil supply capacity. Both developments had profound effects on the market, particularly beginning with the second half of 2014, represented by the third biggest oil price collapse since the 1980s (Baffes et al., 2015). There have been numerous attempts to analyze the drivers of the 2014 oil market crash.[1] Some researchers have attributed the decline in the price to supply side developments, i.e., high production levels both in non-OPEC (mostly US shale oil) and in OPEC countries (Husain et al., 2015). As correctly noted by Baffes et al. (2015), there were also other factors such as weakening global oil demand, appreciation of the US dollar, OPEC's policy responses to price declines and loosening of geopolitical conflicts (e.g., lifting sanctions on Iran[2]). Although the price collapse has created a shift in the perception on how OPEC's role might evolve in the future, Dale (2016) notes that some of the core principles, such as oil being exhaustible, supply being price inelastic, oil flowing from East to West, and the principle of OPEC being the central force in the market, are still valid for the global oil market.[3]

A significant number of studies in the literature attribute the price collapse to the policy of OPEC and specifically to that of Saudi Arabia.[4] In the aftermath of the 2014 price collapse, OPEC members, and in particular Saudi Arabia, which is generally regarded as the global swing supplier, have not reduced production levels. This was most likely based on the expectation that low prices would decrease shale investments, forcing shale producers out of the market. According to Fattouh et al. (2016), the underlying logic in this decision was to protect market share assuming shale oil supply is price elastic. On the other

[1] e.g. Baffes et al. (2015); Huppmann and Holz (2015); Husain et al. (2015); Dale (2016); Fantazzini (2016); Fattouh et al. (2016); Khan (2017)

[2] Having been significantly affected by the long-lasting sanctions, Iranian oil supply strongly increased after the partial lifting of sanctions in January 2016, rising about an additional 0.5 million barrels per day in the following period in 2016 (Dudlák, 2018).

[3] Analysis of the economic dynamics and the market structure of the oil market as well as the behaviour of OPEC dates back to the oil crises period of 1970s. Please see Crémer and Weitzman (1976), Salant (1976) Adelman (1980), Erickson (1980), Gately (1984), Griffin (1985), Jones (1990), Crémer and Salehi-Isfahani (1991), Dahl and Yücel (1991), Griffin and Neilson (1994), Gülen (1996), Alhajji and Huettner (2000a,b), among others.

[4] e.g.Baffes et al. (2015); Coy (2015); Gause (2015); Huppmann and Livingston (2015); Baumeister and Kilian (2016); Fattouh and Sen (2016); Ansari (2017); Behar and Ritz (2017); Prest (2018)

hand, US shale oil production has increased gradually, mainly thanks to the developments in hydraulic fracturing technologies, which further reduced the break-even prices for shale oil. Hence, OPEC's and particularly Saudi Arabia's strategy to ultimately drive shale oil producers out of the market did not pay off as shale oil proved itself to be more resilient than expected (Behar and Ritz, 2017).

The 2014 price collapse had severe implications for major oil exporters; namely, Russia and OPEC members. Despite that OPEC countries have lower production costs, their government budgets rely heavily on oil export revenues. According to Ramady and Mahdi (2015), the minimum fiscal break-even price for OPEC members is \$60/bbl. Hence, an oil price floating in the \$40–50/bbl range has been a burden for their economies. Both due to the performance of shale oil under the low price regime and diminishing profits of OPEC members in the aftermath of the price collapse, major OPEC members started to shift their strategy from flooding the market to capacity withholding starting from the second half of 2016. On September 28, 2016 (during the 170^{th} OPEC meeting) it was announced that the members had agreed to cut production for the first time in eight years. Afterwards, during the 171^{st} OPEC meeting, a "Declaration of Cooperation" between OPEC and some non-OPEC producers, including Russia, Mexico, Azerbaijan and Brazil, was signed. Within the context of this cooperation (which is now known as the OPEC+ agreement), OPEC members, excluding Iran, should have cut 1.2 million bbl/day effective as of 2017, while their non-OPEC counter-parts were assigned a cut of 0.56 million bbl/day. Saudi Arabia and Russia led the OPEC+ agreement with agreed cut levels of 486 and 300 thousand bbl/day, respectively.

In line with the agreement, OPEC+ participants have shown high compliance levels throughout 2017. As an immediate effect of the OPEC+ agreement, oil prices, once having declined to historically low levels of around \$26/bbl in January 2016, increased up to around \$67/bbl in December 2017.[5] At first glance, the shift from a market flooding strategy of Saudi Arabia and of various other major suppliers within and outside OPEC during 2015 and most of 2016, to a more cooperative capacity withholding strategy within the context of the OPEC+ agreement in 2017, seems to have been successful. Hence, it is also plausible to ask whether the OPEC+ agreement was able to change the market structure back to what it was prior to the price collapse. If this is indeed the case, then it can be said that the agreement was deliberately designed to help major OPEC+ participants, particularly the leaders of the agreement, i.e. Saudi Arabia and Russia, to reclaim market power in the face of shale oil suppliers.

In the light of recent developments in the crude oil market, this paper aims to answer the following research questions: i) How did the market structure evolve over the period 2013–2017? Did a shift in the

[5]For the data source please refer to `https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm`. Access Date: March, 13, 2019.

market structure occur after the 2014 price collapse? ii) How can the behaviour of key suppliers be explained by the estimated market structures during the period following the price collapse? iii) Was it the aim of the OPEC+ agreement to change the market structure, and, if so, was it successful at reclaiming market power for the participants of the agreement? In order to answer those questions, we develop a global oil market simulation model, named DROPS, which is a computable equilibrium model, formulated as a mixed complementarity problem (MCP). MCP based models have been extensively used in the literature for the analysis of energy commodity markets due to their versatility.[6] The advantage of the MCP formulation is that it makes it possible to include multiple agents with different interests each having their own optimization problem, allowing the simulation of markets under various market structure assumptions. Applying our model, we simulate the crude oil market with quarter-yearly resolution during the period between 2013 and 2017 under different market structure setups, such as perfectly competitive, oligopolistic and cartel.[7] By comparing model estimations with historical data, we are able to decide on the best-fitting market structure assumptions for individual periods and can tell whether a shift regarding the market structure and the market power of suppliers occurred during the analyzed time period.

There is a wide stream of literature which deals with the structure of the crude oil market and market power of the suppliers. In many studies, the crude oil market is referred to as a good example of a market in which at least some of the suppliers exert considerable market power (e.g. Alhajji and Huettner, 2000a,b; Dahl, 2004; Smith, 2005). Golombek et al. (2018) for instance, using a parsimonious dominant firm model for the global crude oil market, finds that OPEC has exerted considerable market power between the years 1986 and 2016. Yet, some researchers suggest that the oil market has moved to a more competitive structure in the aftermath of the 2014 price collapse (Baumeister and Kilian, 2016; Prest, 2018). Both Baumeister and Kilian (2016) and Prest (2018) utilize empirical methodologies. While, Baumeister and Kilian (2016), using a structural VAR model, mentions that the main driver of the price collapse was the demand side, Prest (2018) suggests that Saudi Arabia and OPEC have lost market power in the aftermath of the 2014 price collapse. A similar result has been previously provided by Huppmann and Holz (2012), who analyzed the market structure in the crude oil market during the period between 2005 and 2009, suggest that the market was closer to a Stackelberg leader structure between 2005 and 2008 and more competitive after the price decline in 2008 following the global economic crisis.

[6]For example: natural gas markets (Gabriel et al., 2005; Growitsch et al., 2014; Berk and Schulte, 2017; Schulte and Weiser, 2019); coal markets (Trüby, 2013; Hecking and Panke, 2015); and oil markets (Huppmann and Holz, 2012; Langer et al., 2016; Ansari, 2017)

[7]We exclude 2018 data from our analyses due to rather volatile OPEC+ compliance levels during that year, which were also strongly driven by external factors such as the Venezuelan crisis. Refer to Section 5 for more detailed information.

Our paper is one of the few quantitative papers using a computable partial equilibrium model to investigate the 2014 price collapse in the oil market. We are only aware of one other paper, namely Ansari (2017), that uses a similar methodology in order to simulate the global crude oil market around the 2014 price collapse.[8] Ansari (2017), similarly, using computable partial equilibrium models with different market setups, investigates the behavior of major suppliers during the period from the fourth quarter of 2011 to the fourth quarter of 2015 and comes to the conclusion that low prices in 2015 cannot be explained by static competition; rather, they are a result of the dynamic calculus of OPEC, who have possibly pursued a market share strategy. We on the other hand, reaching a similar conclusions for the oil market developments during 2015 and 2016, extend the analyses to cover the developments in 2017, the first year of the OPEC+ agreement. We also focus on the market power potential of OPEC and investigate how it has changed throughout the analyzed time frame. An established approach in the literature on market structure analysis when using spatial models is to compare simulated trade flows to historical flows, which has been commonly used, for instance, in the analysis of coal markets (e.g., Kolstad and Abbey, 1984; Trüby, 2013; Lorenczik and Panke, 2016). The methodology, however, to the best of our knowledge, has so far not been applied to crude oil markets. Therefore, it can be said that another major contribution of our paper is the spatial structure of our model and the simulation of crude oil trade flows in order to decide on best-fitting market structures.

The main findings of our paper can be summarized as follows: First, according to our model results, while oligopolistic market structures fit best to the observed crude oil market fundamentals throughout the considered time period and are also successful at simulating the prices before the price collapse, they cannot explain the low prices during 2015 and 2016, which instead converge toward the estimated perfectly competitive levels. This leads us to conclude that, despite the market continuing to have an oligopolistic structure, the market structure in the post-2014 price decline has progressed in a more competitive direction. Accordingly, we find that attaining pre-2014 price levels of around $100/bbl is possible only with strong OPEC cartel behaviour. Second, we observe that the market power potential of Saudi Arabia and OPEC as a whole has significantly decreased following the price crash, making it much more likely for them to pursue a market share strategy instead. Moreover, in the case of OPEC, we see that additional profits via cartelization is much more limited, as significant market share is lost to Russia which fills the ensuing supply gap. This, in turn, implies it was necessary to have Russia on board when jointly cutting production; thus, explaining

[8] Previous studies have proposed global oil market simulation models (e.g., Al-Qahtani et al., 2008; Aune et al., 2010; Huppmann and Holz, 2012). Their analyses, however, cover previous developments in the oil market before the 2014 price decline.

the motivation behind the historical OPEC+ agreement. Third, focusing on the OPEC+ agreement, we evaluate whether planned and observed production cut levels within the context of the agreement could be explained by the considered non-competitive market structure setups. We find that both planned and actual cut levels were significantly below those that are estimated by our model. Hence, it can be said the OPEC+ production cuts were not enough to reclaim market power for the participants of the agreement; rather, they were probably aimed at stabilizing the prices at levels which are high enough not to hurt the fiscal regimes of the suppliers, while being low enough not to promote shale supply.

The remainder of the paper is structured as follows: In Section 2, we present the model used for the analysis in detail and discuss the assumptions and the data. In Section 3, we introduce the market structure setups that were investigated in the model and present our results for the period 2013–2017 in the form of simulated prices and statistical analyses to decide on the best-fitting market structure. The 2014 price crash and the behaviour of the major suppliers in the following period is then presented and discussed in Section 4. Section 5 proceeds to highlight the developments that have led to the OPEC+ agreement and presents model results, elaborating on the rationale of the OPEC+ signatories as well as discussing the effects of the deal. Finally, Section 6 concludes with policy implications.

2. Methodology, Assumptions and Data

This section illustrates the methodology employed in this study and provides an overview of the assumptions made and the data used. In this respect, we first briefly describe the model proposed in this study. We then provide a mathematical description of the model, followed by a discussion of the assumptions and an overview of data sources.

2.1. DROPS: A Partial Equilibrium Model for the Global Crude Oil Market

The DROPS model developed in the framework of this study is a partial equilibrium model which allows the simulation of the global crude oil market for a desired time-period. It is formulated as a mixed complementarity problem (MCP) and is implemented and run in the software package GAMS, using the PATH solverFerris and Munson (2000). Being an MCP model, instead of an objective function, the first-order conditions are used to find the optimal solution. Hence, solving the problem corresponds to finding a vector satisfying those conditions. Multiple agents with different interests (e.g. OPEC and non-OPEC suppliers) can be modelled, each of them having their own optimization problem. Such a formulation allows us to simulate various market structures. For instance, an oligopolistic market structure can be simulated where producers have the market power to strategically withhold capacities in order to maximize their profits. In the global oil market, one of the prominent discussions since the foundation of OPEC in 1960 has been how OPEC really functions. Our model is thus capable of simulating some of the common behaviour assumptions for OPEC. The case of a true cartel, or a cartel dominated by core producers, or yet a slightly looser Cournot oligopoly — where each member aims to maximize its individual profit — can be represented with the help of the conjectural variation structure implemented in the model.[9] With this approach, we are able to investigate the historical market conditions and determine the most likely strategy followed by OPEC by deciding on the most fitting market setup.

DROPS considers the spatial structure of the global market for crude oil where the producers and consumers are mapped in a nodal network, similar to the structure of the COLUMBUS model (Hecking and Panke, 2006). Production nodes are assigned to the producing regions and consumption nodes are assigned to the demand centres. The respective nodes are connected by arcs representing pipelines or naval tanker routes, while infrastructure constraints such as pipeline capacities are taken into account. Note that, while the majority of producer countries are assigned single production nodes, countries with multiple distant production regions such as the Russian Federation and the United States are taken into account with multiple production nodes. The model consists of a total of 81 nodes made up of 43 production nodes, 29 consumption nodes as well as 9 straits and choke points which play a key role in the tanker transport of crude oil.

Consumers in the model are represented by their respective inverse linear demand function. The demand function is estimated by using a reference price and a reference demand as well as the elasticity of demand in that country. Producers are assigned a piece-wise linear supply function, with corresponding production capacities allocated to each cost level. Besides consumers and producers, the model also includes exporters which can control one or multiple production nodes. The exporter of a particular production node decides on how much to produce at that node as well as how much quantity to supply to individual demand nodes. By including exporters in the model, we can model market imperfections, particularly monopoly or cartel behaviour, by assigning production nodes in different regions to a single exporter. For instance, OPEC is considered as a single exporter in the case of assuming cartel behaviour. Additionally, the set of exporters also include arbitrageurs which do not possess any production nodes and are defined to be active only at the consumption nodes. Arbitrageurs exploit the price differences between different regions and represent the traders in real life. Inclusion of arbitrageurs is commonly used for pool-pricing in oil market models (see

[9]For detailed explanation of the conjectural variation approach in MCP models see Perry (1982) and Dockner (1992).

for instance, Huppmann and Holz (2012)), in order to control for strong co-integration between different oil price benchmarks.

2.2. Mathematical Structure

In this section, we explain the mathematical structure of the model and present the profit maximization problems of various actors, from which ultimately the Karush-Kuhn-Tucker (KKT) conditions and the binding constraints are derived. The KKT conditions as well as the sets, variables and parameters of the problem are presented in the tables in Appendix A.

Each exporter, $e \in E$, has two maximization problems. They decide not only how much to produce at the corresponding production nodes, $p \in P$, but also how much to supply to each demand node, $d \in D$.

Exporter's problem (1):

The exporter's problem is to maximize its profit over the analyzed time period $y \in Y$, which is formulated as follows:

$$\max_{\iota_{e,d,y}} p_1^e(\iota_{e,d,y}) = \sum_{y \in Y} \sum_{d \in D} \left[Conj_{e,d} \cdot \iota_{e,d,y} \cdot \beta_{d,y}(\sum_{e \in E} \iota_{e,d,y}) + (1 - Conj_{e,d}) \cdot \iota_{e,d,y} \cdot \beta_{d,y} - \lambda_{e,d,y} \cdot \iota_{e,d,y} \right] \quad (1)$$

As can be seen in Equation 1, the exporter maximizes the difference between its revenues and costs, where its revenue is equal to the market price of one barrel of oil β at the corresponding demand node d, multiplied with the volume supplied $\iota_{e,d,y}$ by the exporter to node d. The cost of supply to that node similarly corresponds to the cost λ of bringing one barrel of oil to node d multiplied by $\iota_{e,d,y}$. Furthermore, if the exporter has market power in particular demand nodes, it is represented by the conjectural variation parameter $Conj_{e,d}$. If $Conj_{e,d}$ equals 1 at a node d, the price $\beta_{d,y}$ that the exporter faces becomes a function of the total quantity imported by both that exporter and other exporters. Otherwise it is equal to 0, meaning that the exporter at that demand node is a price-taker.

Exporter's problem (2):

The exporter's second problem is that it needs to minimize the transportation costs of the exported oil by choosing the least-cost flow destination. As indicated in Equation 2, this can be formulated as a maximization problem where the difference between the value of one barrel of oil at the destination node $\lambda_{e,n_1,y}$ and the value at the source node $\lambda_{e,n,y}$ minus the cost of transportation $Cost^{tra}_{n,n_1,y}$ is maximized with respect to the transported volume $\tau_{e,n,n_1,y}$. Transportation can occur via tankers or via pipelines. If transportation is taking place via pipelines, there exists a constraint that the transported volume cannot exceed the exogenous capacity of the pipeline $Cap^{pip}_{n,n_1,y}$. For tankers no capacity constraint is assumed.

$$\max_{\tau_{e,n,n_1,y}} p^e_2(\tau_{e,n,n_1,y}) = \sum_{y \in Y} (\lambda_{e,n_1,y} - \lambda_{e,n,y} - Cost^{tra}_{n,n_1,y}) \cdot \tau_{e,n,n_1,y} \tag{2}$$

$$s.t. \qquad Cap^{pip}_{n,n_1,y} - \sum_{e \in E} \tau_{e,n,n_1,y} \;\geq\; 0$$

Producer's problem:

Each production node in the model represents a single producer which sells its output to a single exporter. The producer at a particular node aims at maximizing its profit as represented in Equation 3, which is defined as the revenue minus the cost of production, summed over the cost function and the respective time period. The revenue is equal to the value of oil at the production node, $\lambda_{e,p,y}$, multiplied with the produced volume, $\pi_{e,p,c,y}$. Similarly, cost of production is equal to the marginal production cost, $Cost^{pro}_{e,p,c,y}$, multiplied with the produced volume. The producer is constrained by the fact that production volumes cannot exceed production capacity.

$$\max_{\pi_{e,p,c,y}} p^{pro}(\pi_{e,p,c,y}) = \sum_{y \in Y} \sum_{c \in C} (\lambda_{e,p,y} \cdot \pi_{e,p,c,y} - Cost^{pro}_{e,p,c,y} \cdot \pi_{e,p,c,y}) \tag{3}$$

$$s.t. \qquad Cap^{pro} - \pi_{e,p,c,y} \;\geq\; 0$$

2.3. Assumptions and Data

There are various assumptions and simplifications made in the model and the associated data. First of all, the demand side is considered by assuming linear inverse demand functions for individual countries and for various country groupings. Each function is obtained using a reference price and an elasticity of crude oil demand for that country, based on the methodology illustrated in Lise et al. (2008). The topic of demand elasticities for crude oil has been widely covered in the literature, where short-term price elasticities in the range of 0.001 to -0.34 having been suggested (e.g., Cooper, 2003; Fattouh, 2007; Hamilton, 2009; Baron et al., 2014). Considering the findings in recent literature on oil demand elasticities (Javan and Zahran, 2015; Caldara et al., 2019), and also in line with the latest oil market model applications in the literature (e.g., Huppmann and Holz, 2012; Ansari, 2017), we assume in our analysis the short-term price elasticity of demand to be equal to -0.1 for all the considered demand regions in the model.

Production data is compiled from Oil, Gas, Coal, and Electricity Quarterly Statistics of the International Energy Agency (IEA). Spare capacities for OPEC members are based on the estimates provided in IEA Medium-Term Oil Market Reports. For non-OPEC producers, we assume that historical production corresponds to 97% of the available capacity and the remaining 3% is taken as their spare capacity, in line with Behar and Ritz (2017) and Ansari (2017). Production costs and investment costs used in the study are acquired from multiple sources such as Aguilera et al. (2009) and BEIS Fossil Fuel Supply Curves (2016) as well as industry professionals. Production costs follow the structure outlined in Golombek et al. (1995), with marginal costs rising greatly as production approaches the capacity limit. We differentiate between transportation via pipeline and tanker shipping, where the costs are assumed to increase linearly with distance. Tanker shipping costs are calibrated according to the Baltic Dry Index (BDI).

We further assume in our model that the crude oil supplied is of homogeneous quality. In reality, crude oil varies considerably in its properties and different regions can prefer to consume a specific type of crude oil. In our model, this issue is indirectly controlled by taking into account the API gravity and sulphur content including a mark-up on the production costs of regions with lower oil quality, as also discussed in Huppmann and Holz (2012) and Ansari (2017). Consideration of quality differences in crude oil would be beneficial if the refinery sector was explicitly modeled. However, since we are concentrating on upstream oil industry only, controlling quality differences by a cost margin serves our purpose.

We assume that all exporters in the model are countries, not oil companies. On the other hand, the largest crude oil production is taking place in the USA and is conducted by numerous private companies. Nevertheless, private companies are generally price takers, and thus are unlikely to have market power. Their omission, therefore, does not have a significant impact considering the purpose of our analysis. Additionally, the exporters with the largest potential to withhold capacity — namely Saudi Arabia and other OPEC members as well as Russia — have national oil companies. Therefore, this approach is considered to represent the players in the global crude oil market sufficiently well.

3. A Numerical Application of the Model: Market Structure in the Period 2013–2017

In this section we apply the crude oil market model introduced in the previous section for the period 2013–2017 under different market structure assumptions. The market structure setups and the reasoning behind choosing them are as follows:

i. **Competition**: Perfectly competitive market setup, where each supplier acts as price-taker. Conjectural variation parameter of every supplier is equal to 0.

ii. **Oligo_OPEC**: In this setup, OPEC members are assumed to have market power (i.e. their conjectural variation parameter is equal to one) and to behave as an oligopoly while other suppliers form a competitive fringe (all non-OPEC suppliers have a conjectural variation equal to zero).

iii. **Cournot**: All suppliers can exert market power and they compete against each other in a static Cournot setup.

iv. **Cartel_OPEC**: OPEC members jointly maximize profit as a whole and compete in a static Cournot setup against other suppliers.

v. **Cartel_OPEC_core**: Due to the significant variation in cost structures as well as different political aims of the members, it is common in literature to consider OPEC as two distinct parts; namely, a collusive core group and a non-core rest (e.g., Gülen, 1996; Gately, 2004; Aune et al., 2017). In this market setup, similar to Aune et al. (2017) and Golombek et al. (2018), we consider that OPEC countries which are also members of the Gulf Cooperation Council, namely Saudi Arabia, Kuwait, United Arab Emirates and Qatar[10] form a cartel, while the non-core OPEC as well as the rest of suppliers separately play a Cournot game. The main reasoning behind this is that the core OPEC countries, being producers with low production costs and high GDP per capita, are more likely to have similar interests and therefore are less likely to deviate from the cartel obligations compared to members with higher production costs and weaker economies.

vi. **Cartel_OPEC+**: Signatories of the OPEC+ agreement from 2016 onward are assumed to act as a cartel and jointly maximize profit while every other supplier separately plays a Cournot game. This market structure setup is defined specifically for the analysis of OPEC+ agreement and is considered solely in Section 5.

In Figure 1, crude oil prices[11] from the model simulations for different market setups are plotted against historical Brent crude oil prices for the period 2013–2017. It can be seen that the Cournot and the Competitive market assumptions form a price corridor around the historical prices. The Oligo_OPEC setup, with oligopolistic OPEC members and a competitive fringe, seems to fit the historical prices

[10]Our analyses are based on the period until the end of 2017. Qatar has terminated its OPEC membership starting 1 Jan 2019

[11]For consistency, these prices correspond to the price levels observed in the West Europe demand node in the model.

particularly well for the 2013–2014 period before the price plunge. From the second half of 2014 onward, however, the historical prices move towards the estimated competitive levels. It is only after the second half of 2017, following the implementation of the OPEC+ agreement, that the prices again start increasing in the non-competitive direction. Nevertheless, model results indicate that attaining pre-2014 price levels of around $100/bbl during 2015–2017 is only possible with strong cartel behaviour.

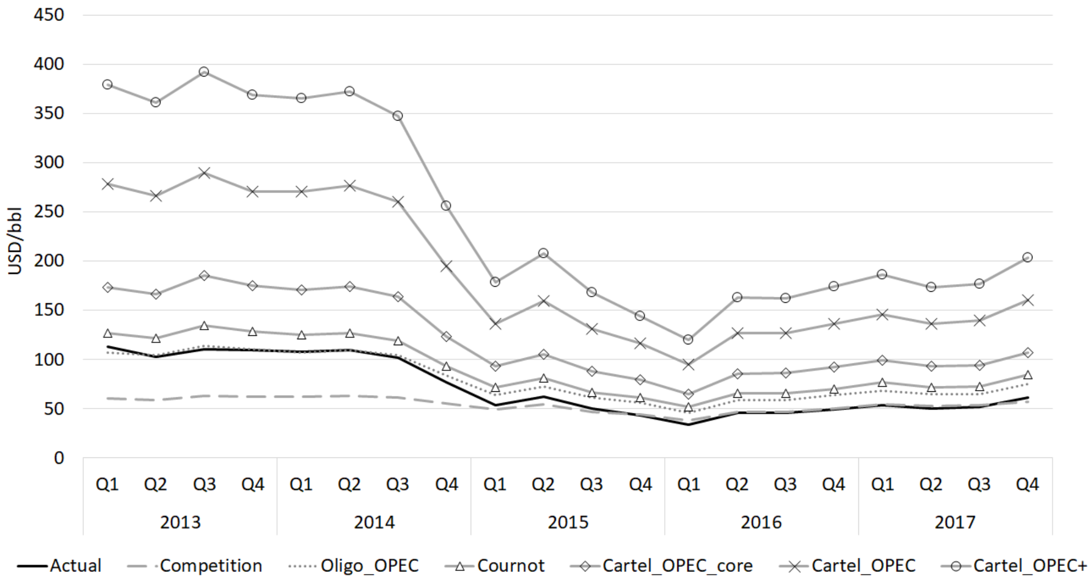

Figure 1: Historical development of the Brent price index and the simulated prices, 2013–2017

Another observation is that historical prices during the period 2015–2017 remain at times below the model estimated competitive levels. This is in parallel with the findings presented in Ansari (2017), implying that in those instances prices possibly fell below marginal costs of production for some producers. However, we should also note that this phenomenon, in our case, is quite cost sensitive. Assuming 30% lower production costs for all producers, for instance, eliminates those instances.[12] Nevertheless, it can be argued that our model, with its static profit-maximization structure, cannot perfectly explain the historical prices in some occasions. It is possible that the rapid scaling potential of the US supply has caused Saudi Arabia to weigh its short-term gains by withholding capacity against long-term losses due to a potentially even larger US oil industry. This dynamic consideration could have played a role in Saudi Arabia's market-share strategy and driven the actual prices, which in this case would differ from the model-estimated prices that are strictly static game theoretic results.

[12]See Appendix C for the results of the sensitivity analysis.

In order to decide on the market structure which is most representative of the considered time period, we would like to see how well the simulated trade flows match the actual flows. For this purpose, we conduct several statistical tests: Linear hypothesis testing, Spearman's rank correlation, and Theil's inequality coefficient.[13]

The idea behind the linear hypothesis testing is to check how well model trade flows conform with actual flows by regressing the simulated flows on the actual flows. In the case of a perfect match, the slope of the linear equation would be equal to one and its intercept would be zero. In order to see whether the slope and intercept are jointly equal to one and zero, respectively, a linear hypothesis test is conducted. The p-values of the test are presented in Table 1 for the individual years.[14] The hypothesis that the perfectly competitive case predicts trade flows is rejected on the 99.9% level for all the considered years. Similarly, the hypothesis with the Cartel_OPEC_core setup can be rejected in every year except 2017. On the other hand, the Cournot setup is not rejected for any year and the Oligo_OPEC setup cannot be rejected except for 2017. Note that Cartel_OPEC_core setup, despite being rejected for the period 2013–2016 period at various significance levels, cannot be rejected for the year 2017. This is also the year when the joint production cuts agreed on OPEC+ deal started being implemented, hence it is possible that a degree of cartelization was prevalent in the market and is thus reflected in the historical trade flows.

Table 1: P-values of the linear hypothesis tests ($\beta_0 = 0$ and $\beta_1 = 1$)

	Competition	Oligo_OPEC	Cournot	Cartel_OPEC_core
2013	0.000 ***	0.411	0.258	0.008 **
2014	0.000 ***	0.214	0.332	0.019 *
2015	0.000 ***	0.201	0.451	0.056
2016	0.000 ***	0.256	0.469	0.034 *
2017	0.000 ***	0.025 *	0.333	0.154

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Figure 2, where Spearman's rank correlation coefficients and Theil's inequality coefficients are plotted, allow us to compare the relative quality of the fit of simulated to actual flows between different models.[15] Throughout the considered years, both of the oligopolistic setups perform better than the Competition setup with respect to the Spearman and Theil coefficients. The Oligo_OPEC setup performs consistently better

[13]See Appendix B for the description of the statistical methods used.

[14]The market structure setups, Perfect, Oligo_OPEC and Cournot, each have 65 observations (i.e. trade flows) for the respective years. The Cartel_OPEC_Core setup has 50. Cartel_OPEC and Cartel_OPEC+ setups are not considered due to limited number of trade flows.

[15]The Cartel_OPEC_core setup is not considered in this analysis due to the smaller sample size.

than the Cournot setup with respect to the considered statistical coefficients. On the other hand, it can be said that the Cournot setup outperforms Oligo_OPEC in the linear hypothesis testing.

Similar to Trüby (2013), we can also confirm that oligopolistic models, because of their higher trade diversification, outperform the perfectly competitive setup with respect to trade flow accuracy. In non-competitive models, since the marginal revenue of an oligopolist at an importing region decreases as its market share in that region increases, diversifying its exports yields higher profits for the oligopolist. As a result, trade with regions occur that typically are not seen in the perfectly competitive case where trade flows occur purely based on cost relationships.

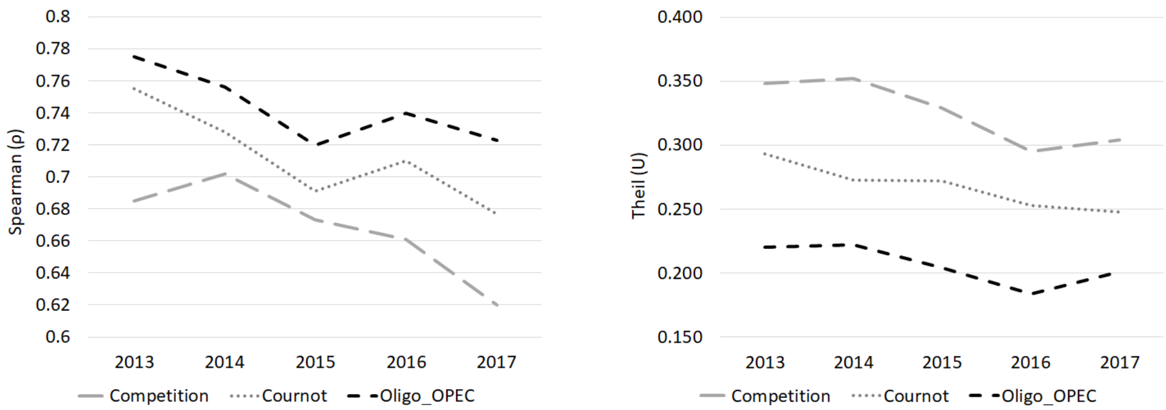

Figure 2: Spearman's correlation coefficients and Theil's inequality coefficients for the analyzed time period of 2013–2017

Our results can be summarized as follows: According to the trade flow analysis, the global crude oil market structure throughout the period 2013–2017 can best be represented by the oligopolistic setups among the market setups considered; i.e. either by the Oligo_OPEC setup, with OPEC oligopoly and competitive fringe; or the Cournot setup, where every supplier acts as a Cournot player. However, while oligopolistic models are successful at explaining prices before 2014, we see that historical prices converge towards the estimated competitive levels during the period 2015–2016. This leads us to conclude that the market structure in the post-2014 price decline has moved towards a more competitive direction, with various suppliers possibly loosing market power, while the market remains to have an oligopolistic structure. This further supports the view in the literature (Ansari, 2017) that the behaviour of OPEC, in particular that of Saudi Arabia, has not become perfectly competitive in the aftermath of the price decline of 2015; rather, it is a reflection of the loss of its market power in the face of strong competition from increasing levels of shale oil supply on the market. The new realities of the market have thus potentially constrained the extent to which the suppliers such as Saudi Arabia and other OPEC members could react. Section 4, where the behavior of major suppliers during the 2014–2016 price collapse are analyzed, illustrates this aspect in more detail.

4. A Shift in the Crude Oil Market: The 2014–2016 Oil Price Plunge

The global crude oil market went through quite a volatile period over the last decade as can be observed in Figure 3. A major shift in the crude oil market occurred in the second half of 2014, culminating in two important turning points: First, thanks particularly to the shale oil revolution, the USA became the largest crude oil producer, surpassing Saudi Arabia. By the end of 2018, crude oil production in the USA increased to around 16.2 million bbl/day, while Saudi Arabian and Russian production stayed at levels of 12.4 million bbl/day and 11.8 million bbl/day, respectively. Second, oil prices collapsed from around \$110/bbl to historically low levels of around \$35/bbl during the period from the second half of 2014 until the beginning of 2016.

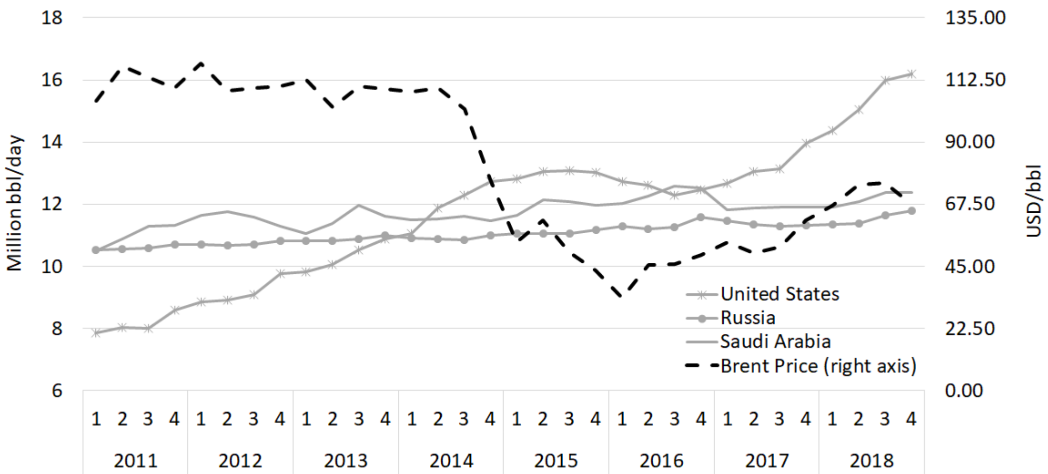

Figure 3: Crude Oil Production in the USA, Saudi Arabia and Russia (in million bbl/day on the left-axis) and Brent Prices (in USD/bbl on the right-axis), over the period between 2011 and 2018

The reasons and implications of the 2014–2016 oil price collapse have been extensively discussed in the literature. Some researchers have attributed the plunge in oil prices to the increase in the non-OPEC supply, particularly to the shale oil production capacity in the USA (see for instance, Husain et al. (2015)). Yet, as suggested by previous literature (Behar and Ritz, 2017; Ansari, 2017) and as can clearly be seen in Figure 3, US production has increased quite gradually for some time while the oil prices collapsed abruptly. Hence there is still room to be skeptical of this reasoning. Another suggested driver behind the price collapse was OPEC's, mainly Saudi Arabian, policy not to cut production in the wake of price collapse but rather keep flooding the market. As can be observed in Figure 3, Saudi Arabia continued to increase the production level gradually until the first quarter of 2016 in contrast to expectations that it would withhold significant amount of capacity in order to increase the prices. In fact, Saudi Arabia did not cut production before early 2017, at the time when the OPEC+ agreement had finally become active.[16]

Various reasons behind Saudi Arabia's policy of flooding the market have been mentioned in the literature; namely, (i) testing shale oil resilience and ultimately driving shale producers out of the market (Behar and Ritz, 2017), (ii) gaining political advantage in the Syrian conflict against Russia and Iran by weakening their economy with low oil prices (OGJ, 2014), (iii) inner-OPEC related issues, i.e., Saudi Arabian expectation from other members to also withhold capacities (Fattouh et al., 2016; Fattouh and Sen, 2016) and (iv) inner Saudi Arabian politics, i.e., crown prince Bin Salman's vision to relieve the country's economy from oil revenue dependency.[17] Whereas in reality the Saudi Arabian strategy was likely a result of various simultaneous factors combined together as mentioned above, we investigate how the transformation in market structure as well as a potential loss of market power could have nevertheless limited the options for other types of strategies.

[16]Please see Section 5 for detailed discussion on the OPEC+ agreement and its implications on the market.
[17]Please see https://vision2030.gov.sa/en/foreword, accessed on 21.02.2019

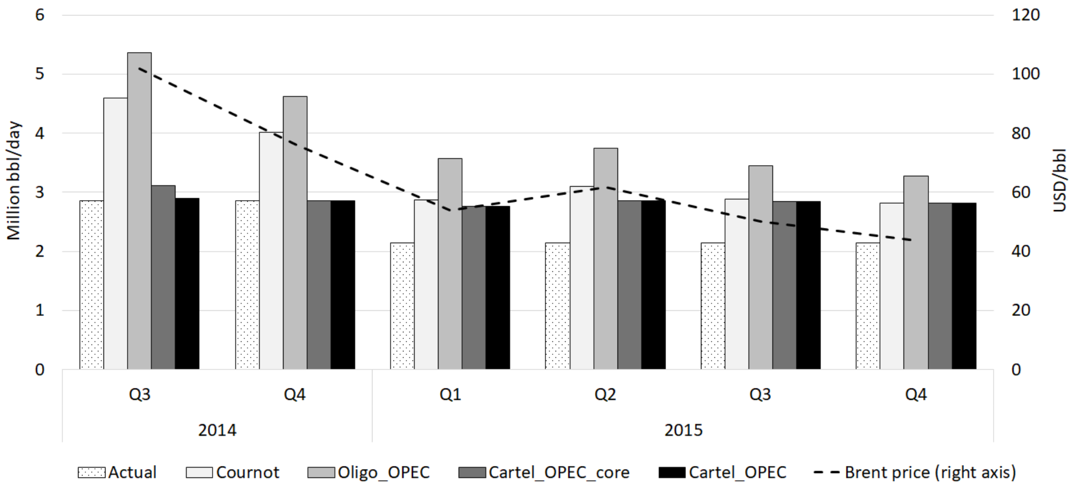

Figure 4: Realized and simulated spare capacity of Saudi Arabia vs. actual crude oil price

Notes: Spare capacity is calculated as the difference between exogenous production capacity assigned to the supplier and simulated production volumes.

Figure 4 plots actual and model-estimated spare capacities of Saudi Arabia under different market structure assumptions. Starting with the third quarter of 2014, Saudi Arabia would have cut more volumes (i.e. withheld more capacity) in all non-competitive assumptions in the aftermath of the price collapse, compared to their historical capacity withholding.[18] Nevertheless, the capacities that would have been withheld in non-competitive assumptions have significantly declined in 2015, especially in the Cournot and Oligo_OPEC variants, which were previously shown to represent the underlying market structure most successfully. This implies that, after 2014, Saudi Arabia's potential of capacity withholding for profit maximization was actually relatively limited, which was due to a combination of slower demand growth and increasing US shale oil capacities. This made it, therefore, more likely for Saudi Arabia to shift its policy towards a market-share protection strategy instead, as also mentioned by Fattouh et al. (2016) and of Ansari (2017).

[18]Spare capacities in the perfectly competitive case are not presented in Figure 4 for the sake of clarity. In the case of Saudi Arabia, it does not withhold any capacity when behaving as a price-taker due to its significantly lower production costs.

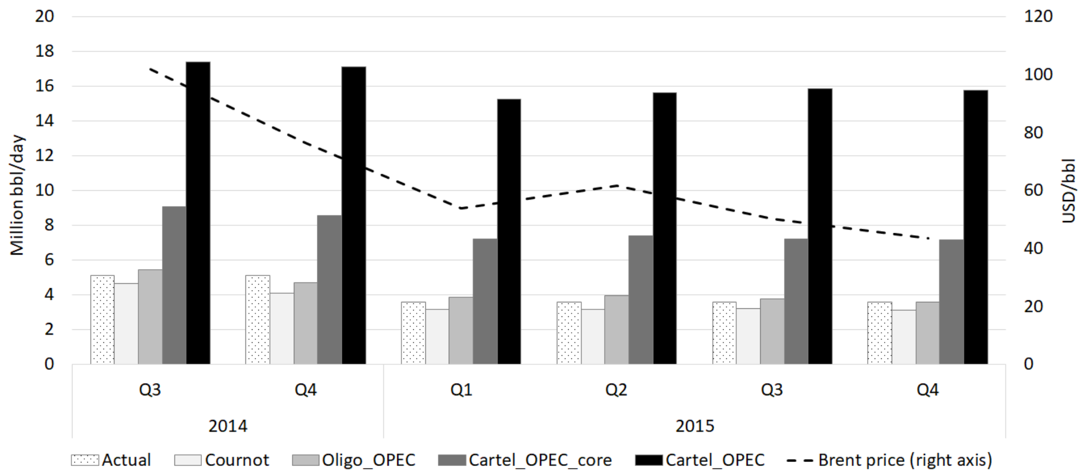

Figure 5: Realized and simulated spare capacity of OPEC vs. actual crude oil price

Since the oil crises periods in 1970s, there has been a long-lasting debate on whether OPEC behaves as a cartel in the oil market.[19] It has even been referred to by some as a "clumsy-cartel" (Adelman, 1980). The behaviour of OPEC after the 2014 price crash also comprises an important part of our research question. In this regard, realized and estimated spare capacities of OPEC members in total are plotted in Figure 5 from the third quarter of 2014 till the fourth quarter of 2015. It can be seen that OPEC has historically withheld significantly less capacity after the price collapse, compared to previous periods. Moreover, OPEC's historical capacity withholding is quite comparable with levels observed in Cournot and Oligo_OPEC scenarios. Figure 5 also indicates that if OPEC had acted as a joint Cartel (i.e. as in the Cartel_OPEC setup), the capacity withholding would have been more than three times that of the historical levels. Such a high level of cooperation and cartelization is of course very unlikely in reality due to OPEC members each having different economic and political interests. Nevertheless, the hypothetical Cartel_OPEC_core market structure, where only OPEC countries who constitute the low-cost producers of OPEC and who share similar GDP per capita levels[20] are assumed to act as a cartel, reflects theoretically a more probable case. Even in this theoretically more realistic, weaker cartel setup, we see that OPEC would still have withheld much higher capacities than it actually did. Our findings therefore lead us to rule

[19] See for instance, Adelman (1996); Alhajji and Huettner (2000a,b); Gately (1984); Griffin and Neilson (1994); Gülen (1996); Smith (2005); Brémond et al. (2012); Huppmann and Holz (2015); Golombek et al. (2018), among others.

[20] The considered OPEC producers are also members of the Gulf Cooperation Council; namely Saudi Arabia, United Arab Emirates, Kuwait, and Qatar.

out strong cartel behaviour for OPEC during the considered period, implying an OPEC structure as an oligopoly or a very loose cartel was most possibly the prevalent structure.

A similar analysis on Russia would also shed some light on how a major non-OPEC supplier behaved over the same period (Figure 6). Findings suggest quite comparable results to that of Saudi Arabia, such that, one would expect significantly higher levels of capacity withholding from Russia, particularly during 2015, if Russia had behaved as a Cournot supplier. Hence, in line with Ansari (2017), we suggest that instead of short-term profit maximization behavior, other strategic concerns such as market-share protection must have interfered with Russian oil supply dynamics. It is also plausible that Russia would not choose a bilateral production cut without the back-up from Saudi Arabia and other OPEC members.

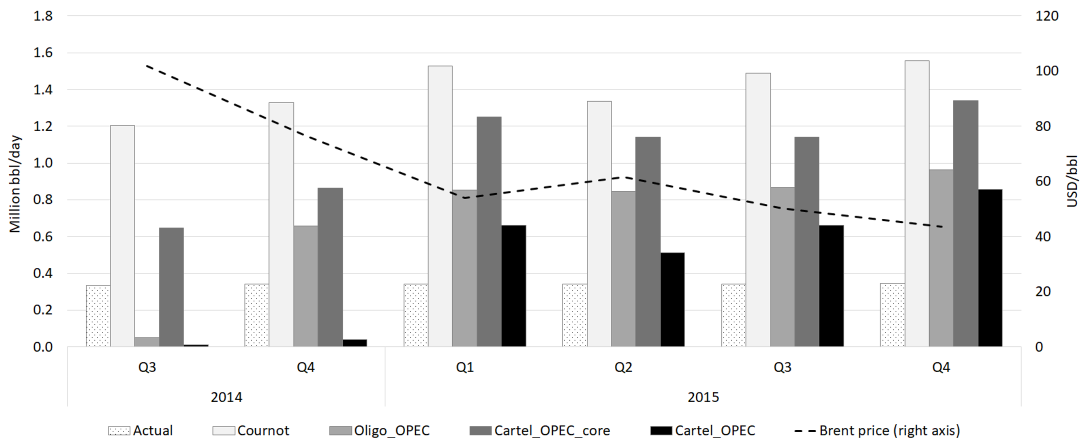

Figure 6: Realized and simulated spare capacity of Russia vs. actual crude oil price

The findings discussed so far suggest that major suppliers in the oil market would have cut more production during the 2014–2016 oil price plunge if they had exerted market power to full extent. This could lead to a conclusion that, while at least some of the crude oil market suppliers could exert market power, market became relatively more competitive after the price crash. Prest (2018) points out this development by stating: “In summary, there is little evidence supporting the claim of strategic behavior by Saudi Arabia, and economic theory suggests many reasons why such behavior would be irrational. Rather, it is more plausible that Saudi Arabia’s recent behavior is consistent with that of a competitive supplier”. Prest (2018) based his conclusions on the fact that over the recent years demand side of the market, rather than the supply side, has become more determining on the price movements in the oil market as also suggested by Kilian (2009). Using a structural VAR model Baumeister and Kilian (2016) similarly found that demand side expectations due to a weakening global economy have been the main driver behind the 2014 oil price collapse. After FED and ECB abandoned monetary easing policies pursued in the aftermath of the global crisis in 2008, short-term capital inflows that financed high growth rates of developing economies started to slow down. This brought expectations on slower than expected energy demand growth globally (IEA, 2015, 2016).

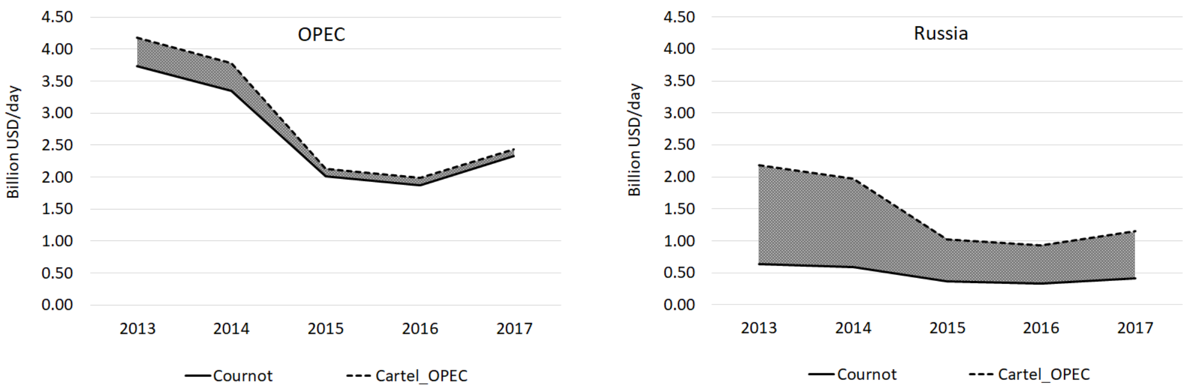

Figure 7: Development of the simulated profits of OPEC and Russia

We can observe how the 2014 oil price collapse diminished the market power potential of the major suppliers by also looking at how their estimated profits change over the years. As can be seen in Figure 7, OPEC members and Russia experienced substantial profit losses in the years following the price decline. Whereas cartelization is estimated to yield substantial profits for OPEC as a whole in 2013, additional profit gains for OPEC by collusion are quite limited in the post-2014 era. Cutting production as a unified cartel strongly benefits Russia, as Russia fills the ensuing supply gap and grabs OPEC market share. Hence, we can say that the diminished market power of Saudi Arabia and OPEC in the post-price collapse period, combined with the potential loss of market share to Russia in the case of capacity withholding, meant that it was necessary for Saudi Arabia and other OPEC members to take Russia on boat for implementing effective production cuts. These factors formed the driving force behind the OPEC+ agreement, which we discuss and analyze in detail in the following section.

5. The Change in Saudi Arabian Policy and the OPEC+ Agreement

Another turning point in the oil market since 2014 occurred in the second quarter of 2016 when oil prices began to rise again after a long-lasting decline. This date corresponds to a shift in the Saudi Arabian strategy from waiting and flooding the market to a more cooperative capacity withholding strategy, which eventually led to announcements of production cuts by several OPEC and non-OPEC suppliers within the context of the Saudi Arabia and Russia led OPEC+ agreement in November 2016. Although market share protection seemed to be a reasonable strategy in the aftermath of the price collapse, it also seems that strong resilience of US shale along with pressures on the fiscal budget emerged as important dynamics of the shift in the strategy of Saudi Arabia.

According to Ansari (2017), on the other hand, this shift in Saudi strategy was not entirely due to defense against shale, but rather due to the fact that circumstances supported such a decision. As previously mentioned, different studies suggested that Saudi Arabia would consider cutting production only if other major OPEC and non-OPEC suppliers are also on board with the Kingdom (Fattouh et al., 2016; Fattouh and Sen, 2016). This is in line with our findings so far, such that even if Saudi Arabia would have unilaterally cut production following the 2014 price collapse, prices as well as profits would have remained below pre-2014 levels due to the diminished market power potential. Production cuts with OPEC acting as a joint cartel, on the other hand, would not have been as effective in the new post-2014 era as it was during pre-2014, unless Russia also agreed to cooperate and jointly cut production. From this perspective, Saudi Arabia's waiting strategy seems to have paid off, since with the OPEC+ agreement, in parallel with the increase in oil prices, market power potential of suppliers, the profits of Saudi Arabia, of other OPEC members and of Russia increased. Accordingly, this section evaluates the historical background of the OPEC+ agreement and its implications for the oil market in 2017, the first year of production cuts.

Although the OPEC+ agreement became effective in 2017, signals pointing at the necessity to take precautionary steps to decrease volatility in the market were already mentioned by OPEC officials in 2015 during the 167^{th} and 168^{th} OPEC meetings. Yet, it was not until the 169^{th} OPEC meeting on June 2, 2016 when the importance of OPEC and non-OPEC cooperation to ensure market stability was emphasized. It took almost four more months for OPEC to agree on a production cut, for the first time in eight years, at the 170^{th} Extraordinary OPEC meeting that took place on September 28, 2016 in Algiers, Algeria. During this meeting, the "High Level Committee" (HLC) to develop consultations between OPEC and non-OPEC suppliers was established. This establishment, which is now known as the "Algiers Accord", was an important turning point in the oil market, such that it was during the HLC's first meeting which was held one month later in Vienna with the participation of six non-OPEC countries — namely, Azerbaijan, Brazil, Kazakhstan, Mexico, Oman and Russia — that the first traces of an OPEC+ agreement became apparent. Finally on November 30, 2016 during the 171^{st} OPEC meeting, the "Declaration of Cooperation" (known as the OPEC+ agreement) was signed. According to the agreement, OPEC members were allocated a total production cut of 1.2 million bbl/day and non-OPEC participants were to cut 558 000 bbl/day starting from January 1, 2017. Moreover, due to the continuing turmoil in the market throughout 2017, OPEC announced on November 30, 2017 the extension of the OPEC+ agreement over the year 2018.[21]

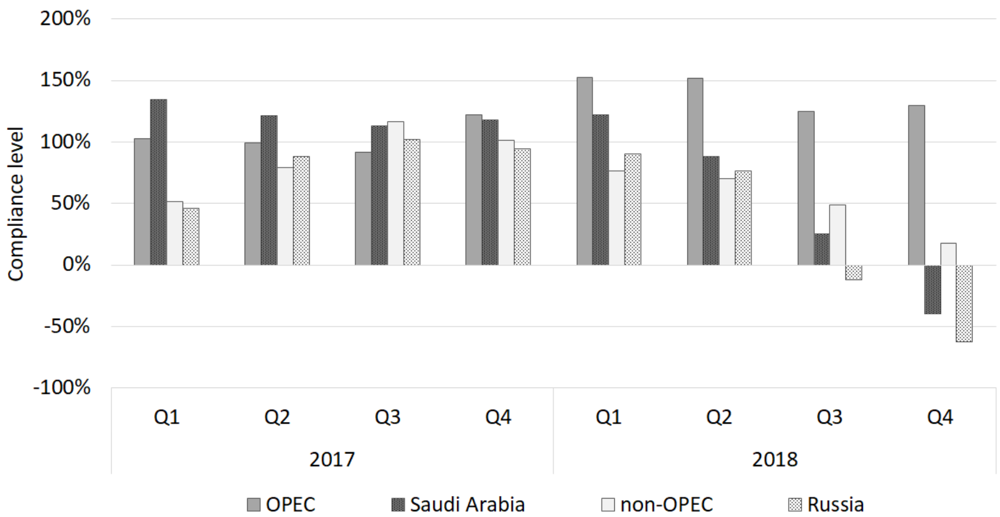

Figure 8: Production cut compliance levels of OPEC and non-OPEC participants of the OPEC+ agreement

Note: OPEC compliance includes Saudi Arabia and non-OPEC compliance includes Russia.

Source: https://www.bloomberg.com/graphics/opec-production-targets (Accessed on 23.01.2019)

Figure 8 presents overall compliance[22] to agreed production cuts within the context of OPEC+ agreement by OPEC members, non-OPEC participants and by two major producers; namely, Saudi Arabia and Russia. As can be seen, overall compliance levels of the participants were quite high during 2017 and stabilized at almost 100% in the fourth quarter of 2017. Given that participants of the OPEC+ agreement, particularly OPEC members, showed almost 100% compliance during 2017, the question is whether the OPEC+ agreement was meant to change the market structure back to what it was during the pre-collapse period and help certain exporters such as Saudi Arabia and Russia reclaim market power potential. In order to address this question, we compare the planned production cuts with the actual production cuts,

[21] The main source for the information provided in this paragraph is the OPEC website on press releases. Please refer to `https://www.opec.org/opec_web/en/press_room/28.htm` for further details. The OPEC+ agreement was effective at the time of writing this paper as on December 7, 2018 during the 175^{th} OPEC meeting the agreement was further expanded to cover the first 6 months of 2019. It is yet to be decided if a further extension would be made at the next OPEC Meeting, which will be held in June 2019.

[22] Compliance means the ratio of actual cuts to planned cuts. A compliance over 100% means cutting more than the planned, whereas a compliance below 100% is cutting less than planned i.e. cheating the agreement. Negative compliance means the supplier, instead of cutting, has actually increased production.

as well as with the model estimated cuts that would have occurred under different market structure setups for selected suppliers.[23] Along with the two market setups that were shown to represent best the historical market structure, namely the Cournot and Oligo_OPEC setups, we also consider a hypothetical Cartel_OPEC+ setup, in which participants of the OPEC+ agreement behave strictly as a cartel and jointly maximize profit while other suppliers are competing against the cartel in a Cournot setup. The rationale behind this market setup is to understand whether the OPEC+ agreement was meant to create a new cartel formed by OPEC members and some non-OPEC suppliers including Russia.[24]

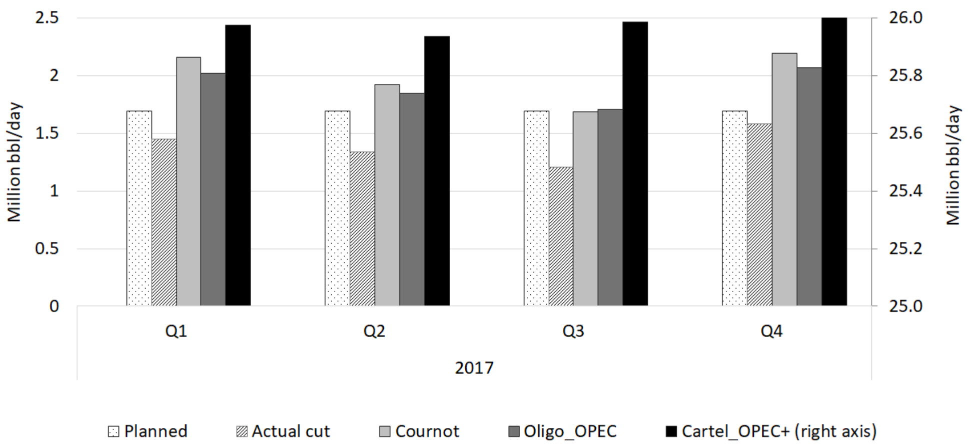

Figure 9: Planned, Actual and Estimated Cuts for major OPEC+ participants

Notes: These participants include Russia, Mexico, Oman, Azerbaijan, Kazakhstan and Malaysia in addition to OPEC members. We are forced to exclude Bahrain, Brunei, South Sudan and Sudan, whose data is not available as there is no production node defined in the model for these countries. Yet, mentioned countries had only a planned cut of 26 thousand bbl/day in 2017; hence they are negligible.

In Figure 9, we compare planned, actual and simulated production cuts for all OPEC+ participants. According to the OPEC+ agreement that was signed in November 2016, production cut targets for 2017 were established relative to the observed November 2016 production levels of the participants. Model cut estimates, therefore, correspond to the difference between production estimates in the respective quarter of

[23]We exclude 2018 data from our analyses because of the rather volatile trend of the compliance levels during that year. For instance, in the second quarter of 2018, compliance of OPEC members in total reached around 150%. On the other hand, over-compliance during 2018, particularly of OPEC, were attributed to various external factors such as the Venezuelan crisis (Halff et al., 2018) rather than deliberately made decisions. Moreover, due to high compliance levels it seems that Saudi Arabia and Russia started to cheat the agreement during the fourth quarter of 2018, which created another big oil price decline. According to the EIA, Brent oil prices declined by 41% from $85.63/bbl in October 2, 2018 to $50.57/bbl in December 27, 2018.(`https://www.eia.gov/dnav/pet/hist/RBRTED.htm`).

[24]Please note that Iran was not included in the OPEC+ agreement. We, therefore, also exclude Iran from the Cartel_OPEC+ setup.

2017 and the historical production levels that were observed during the the first quarter of 2016. The planned cut for all OPEC+ participants together was around 1.7 million bbl/day, whereas the average actual cut was 1.39 million bbl/day during 2017. On the other hand, under the Cartel_OPEC+ setup, model results indicate that the members as a whole would have cut as much as 26 million bbl/day on average. This indicates that if the OPEC+ agreement was indeed meant to create a new form of cartel structure in the oil market, the planned cuts should have been vastly larger than what they actually are. Hence, this extreme scenario can be ruled out. Similarly, the cuts that occur under the previously best-performing Oligo_OPEC (1.91 million bbl/day) and Cournot (1.99 million bbl/day) market structure setups also lie above the planned and actual cuts, indicating that OPEC+ cuts were neither planned nor implemented to fully exert market power. In order to understand the underlying reasons why the OPEC+ agreement was not designed for higher level of output cuts, we analyze the behavior of leading producers taking part in the agreement, namely Saudi Arabia and Russia.

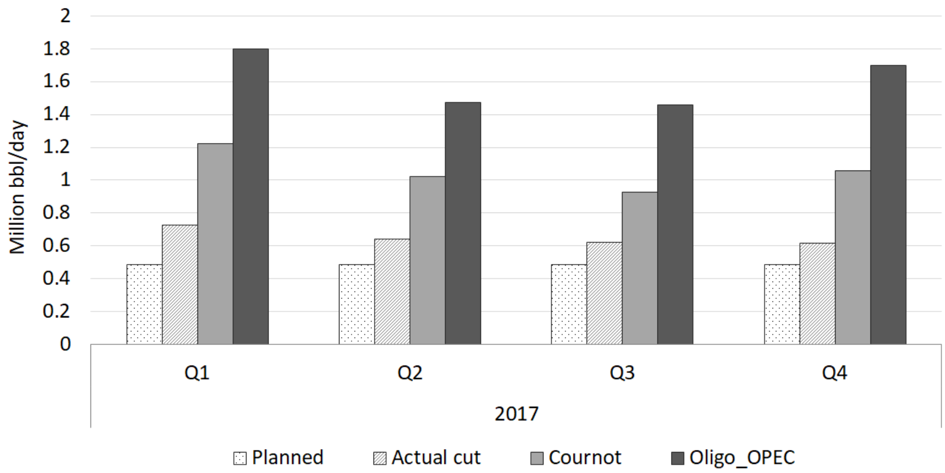

Figure 10: Planned, Actual and Estimated Cuts for Saudi Arabia in 2017

We present the planned, actual and simulated production cuts by Saudi Arabia in Figure 10 for each quarter in 2017 for the best-performing setups. While the planned production cut of Saudi Arabia was only 486 thousand bbl/day, the actual average production cut was significantly higher with 730 thousand bbl/day in the first quarter, which then declined to 640 thousand bbl/day in the second quarter. The realized cut remained relatively stable in the third and fourth quarters of 2017 with 620 thousand bbl/day. Model results, on the other hand, indicate that, during 2017, the required average Saudi production cut would have actually been 1.06 million bbl/day and 1.61 million bbl/day within Cournot and Oligo_OPEC market setups, respectively. A similar analysis is provided for Russia in Figure 11, the other leading country in OPEC+ agreement. While the planned production cut agreed upon by Russia was 300 thousand bbl/day, the actual cut averaged around 230 thousand bbl/day during 2017. In contrast, in the Cournot and Oligo_OPEC market setups, Russia cuts significantly higher volumes on average, amounting to 1.45 million bbl/day in the Cournot and 730 thousand bbl/day in the Oligo_OPEC setup. Hence, for both Saudi Arabia and Russia, we see that the planned and actual production cuts within the OPEC+ agreement have been significantly lower than their production cut potential estimated by the model.

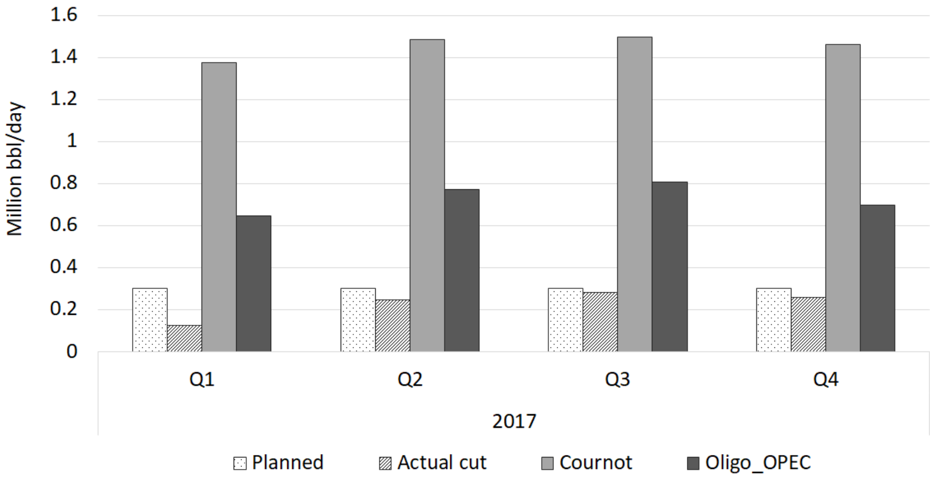

Figure 11: Planned, Actual and Estimated Cuts for Russia in 2017

The OPEC+ deal has so far demonstrated itself to be a successful tool to rebalance the oil market in the short-run as oil prices started to increase in the second quarter of 2016, with the Saudi Arabian efforts eventually having led to the agreement. Moreover, according to Economou and Fattouh (2018), OECD crude oil stocks declined below their five-year averages at the end of 2017. Although several officials indicated OPEC's interest in sustaining and even "institutionalizing"[25] the cooperation in the long-run, our results suggest that the production cuts that are planned within the context of the deal were not enough for a long-term structural change in the crude oil market. This leads us to conclude that the OPEC+ agreement,

[25]During the 174^{th} OPEC meeting, Suhail Mohamed Al Mazrouei, the president of the conference, explicitly stated that OPEC would be further interested to "institutionalize this cooperation in order to adapt ongoing market dynamics". Although it is not clear what Mr. Al Mazrouei meant by the term "institutionalizing", our results under the Cartel_OPEC+ market setup rule out the possibility of institutionalizing meaning to form a new Cartel in the oil market. Please see: https://www.opec.org/opec_web/en/press_room/5071.htm. Access date: 01.06.2019

instead of changing the market structure, was possibly conceived to keep the prices within an acceptable range.

6. Conclusions and Policy Implications

This paper investigates recent developments in the global crude oil market which have had substantial impact; namely, the 2014–2016 price crash and the following Cooperation of Declaration (i.e. the OPEC+ agreement) signed between the OPEC and non-OPEC suppliers which resulted in the production cuts of 2017. In the light of these developments, we investigate whether a shift in the market structure has occurred and how the behavior of major suppliers has been affected. To this end, we present a global upstream oil market simulation model; DROPS, a partial equilibrium model formulated as a mixed complementarity problem (MCP) with a spatial structure. We simulate the oil market under different market structure setups for the period between 2013 and 2017: perfectly competitive, Cournot competition, OPEC oligopoly with competitive fringe, as well as OPEC as a cartel, and a cartel being formed by a core group of OPEC.

Comparing simulated trade flows and price levels with historical values, we observe that among the considered market setups, oligopolistic market structure assumptions (i.e. Cournot competition, and OPEC oligopoly with competitive fringe) perform best at representing the market throughout the period 2013–2017. Oligopolistic market structure setups, however, even though being highly successful at simulating prices before the 2014 price collapse, cannot predict the prices after the collapse, which instead, are closer to the estimated competitive levels. We also see that reaching pre-2014 price levels around $100/bbl is possible only under strong cartelization. Our results thus indicate that although the market continued to have an oligopolistic structure, it has moved in a more competitive direction after the 2014 price decline.

We further analyze the behaviour of major suppliers during the 2014–2015 period, a phase with increased shale oil supply and reduced oil demand growth expectations, and observe how their market power potential has developed. For this purpose, we compare the simulated and historical production spare capacities under different market structure setups. Our findings are as follows: Despite their production levels still being best explained by oligopolistic behaviour, we see that the market power potential of OPEC and Saudi Arabia has significantly decreased after the price collapse. This explains why Saudi Arabia, instead of cutting production, continued to increase its supply since a unilateral production cut would not have had the desired effect. It is therefore much more likely that Saudi Arabia followed a market share protection strategy instead, with the ultimate aim of driving shale producers out of the market which is also mentioned by (Fattouh et al., 2016; Behar and Ritz, 2017). On the other hand, in the case of a joint OPEC action, our model results indicate that profit gains by collusion are much more restricted. Any unilateral production cut by OPEC results in a loss of market share to Russia; thus, significantly limiting profit gains. This is why Saudi Arabia and other OPEC members were reluctant to hold capacity unilaterally and rather waited for cooperative production cuts with non-OPEC producers, which eventually was agreed upon with the realization of the OPEC+ agreement in November 2016.

Provided that Saudi Arabia and Russia lead the OPEC+ agreement with the largest planned production cuts, one would expect them to have planned the production cuts such that they would reclaim market power. Yet, according to the model-estimated production cuts, in reality, both Saudi Arabia and Russia have withheld significantly less capacities than they do under the non-competitive market structure assumptions. Hence, rather than helping some of the producers to exert market power to full extent, the OPEC+ agreement seems to have been designed to put a halt on tumbling oil prices. Apparently, Saudi Arabia, and Russia to a certain extent, did not push for more cuts within the OPEC+ agreement as the collapsing profits would have motivated them to do so. In this sense, it can be said that the OPEC+ productions cuts have aimed to stabilize the prices in an acceptable margin, which would be high enough to support the governmental budgets of oil-export dependent countries but low enough not to further promote shale oil investments in the USA. This price range is also referred to as the "sweet price range" (Fattouh, 2017).

Our modelling approach, to some degree, is an abstraction from reality and includes various assumptions and simplifications. Nevertheless, we can say that the method used provides a scientific approach to answer important questions and helps us gain insight into the recent developments in the crude oil market. In future work, the methodology used in this paper could be extended to analyze the dynamic interdependencies in the upstream crude oil market and simulate the development of production capacities under different market structure assumptions. Implementing a temporal structure for the development of production costs, especially in the case of non-conventional crude oil sources, would further help in a realistic simulation of investment decisions.

Acknowledgements

We are grateful to Marc Oliver Bettzüge and Felix Höffler for valuable input and inspiring discussions. Furthermore, we would like to thank Simon Schulte, Christian Growitsch, Niklas Hinkel and Max Schönfisch for the helpful comments. The DROPS model, used in this study, was developed at Energy Economics Institute (EWI) at the University of Cologne and benefited from the project "Turkey's potential as Future Energy Hub – Economic Developments and Political Options", funded by the Mercator foundation.

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Appendix A. Model Structure

Appendix A.1. Model Sets, Variables and Parameters

Sets	
$n \in N$	Nodes
$p \in P \in N$	Production regions
$d \in D \in N$	Demand regions
$e \in E$	Exporters
$c \in C$	Cost levels
$y \in Y$	Time step
Variables	
$\beta_{n,y}$	Marginal cost/price of one barrel of oil at node n
$\lambda_{e,n,y}$	Marginal cost of physical supply of one barrel of oil at node n controlled by exporter e
$\pi_{e,n,c,y}$	Production at node n and cost level c controlled by exporter e
$\tau_{e,n,n_1,y}$	Transportation from node n to node n_1 by exporter e
$\iota_{e,n,y}$	Import decision of exporter e to node n
$\mu_{e,n,y}$	Production capacity dual variable
$\phi_{n,n_1,y}$	Pipeline capacity dual variable
$a_{e,n,y}$	Amount bought by the arbitrageur at demand node n
Parameters	
$Cost^{pro}_{e,n,c,y}$	Production cost
$Cost^{tra}_{n,n_1,y}$	Transportation cost
$Conj_{e,d}$	Conjectural variation
Cap^{pro}	Production capacity
Cap^{pip}	Pipeline capacity
$Intercept_{n,y}$	Inverse demand function intercept
$Slope_{n,y}$	Inverse demand function slope

Appendix A.2. First Order Conditions

KKT Conditions

$$-\lambda_{e,n,y} + Cost^{pro}_{e,n,c,y} + \mu_{e,n,c,y} \geq 0 \quad \perp \quad \pi_{e,n,c,y} \tag{1}$$

$$-\lambda_{e,n_1,y} + \lambda_{e,n,y} + Cost^{tra}_{n,n_1,y} + \phi_{n,n_1,y} \geq 0 \quad \perp \quad \tau_{e,n,n_1,y} \tag{2}$$

$$Conj_{e,n} \cdot Slope_{n,y} \cdot \iota_{e,n,y} - \beta_{n,y} + \lambda_{e,n,y} \geq 0 \quad \perp \quad \iota_{e,n,y} \tag{3}$$

$$-\lambda_{e,n,y} + \beta_{n,y} \geq 0 \quad \perp \quad a_{e,n,y} \tag{4}$$

Physical Flow Balances

$$\frac{Intercept_{n,y} - \beta_{n,y}}{Slope_{n,y}} + \sum_{e \in E} a_{e,n,y} - \sum_{e \in E} \iota_{e,n,y} = 0 \quad \perp \quad \beta_{n,y} \tag{5}$$

$$\sum_{c \in C} \pi_{e,n,c,y} + \sum_{n_1 \in N} \tau_{e,n_1,n,y} + a_{e,n,y} - \sum_{n_1 \in N} \tau_{e,n,n_1,y} + \iota_{e,n,y} = 0 \quad \perp \quad \lambda_{e,n,y} \tag{6}$$

Capacity Constraints

$$Cap^{pro}_{e,n,c,y} - \pi_{e,n,c,y} \geq 0 \quad \perp \quad \mu_{e,n,y} \tag{7}$$

$$Cap^{pip}_{n,n_1,y} - \sum_{e \in E} \tau_{e,n,n_1,y} \geq 0 \quad \perp \quad \phi_{n,n_1,y} \tag{8}$$

Appendix A.3. List of included countries

Country	Consumption node	Production node
United States	US_East_cons	US_PADD1_prod
	US_West_cons	US_PADD3_prod
	US_Midwest_cons	US_PADD2_4_prod
		US_PADD5_prod
China	CN_cons	CN_prod
Japan	JP_cons	
India	IN_cons	IN_prod
Russia	RU_cons	RU_WestSiberia_prod
		RU_Fareast_prod
		RU_VolgaUral_prod
		RU_NorthWestArctic_prod
		RU_EastSiberia_prod
Brazil	BR_cons	BR_prod
Saudi Arabia	SA_cons	SA_prod
Canada	CA_cons	CA_prod
South Korea	KR_cons	
Mexico	MX_cons	MX_prod
Iran	IR_cons	IR_prod
Indonesia	ID_cons	ID_prod
Italy	IT_cons	
Australia	AU_cons	AU_prod
Egypt	EG_cons	EG_prod
Turkey	TR_cons	TR_prod
South Africa	ZA_cons	
United Kingdom	UK_cons	UK_prod
Ireland	UK_cons	UK_prod
Spain	SP_PT_cons	
Portugal	SP_PT_cons	
Belgium	West_Europe_cons	
Germany	West_Europe_cons	
France	West_Europe_cons	
Netherlands	West_Europe_cons	
Switzerland	West_Europe_cons	
Luxembourg	West_Europe_cons	
Austria	Central_Europe_cons	
Czech Republic	Central_Europe_cons	
Hungary	Central_Europe_cons	
Slovakia	Central_Europe_cons	
Slovenia	Central_Europe_cons	
Sweden	North_Europe_cons	North_Europe_prod
Finland	North_Europe_cons	North_Europe_prod
Denmark	North_Europe_cons	North_Europe_prod
Norway	North_Europe_cons	NO_prod
Greece	East_Europe_cons	
Romania	East_Europe_cons	

Country	Consumption node	Production node
Bulgaria	East_Europe_cons	
Croatia	East_Europe_cons	
Serbia	East_Europe_cons	
Poland	North_East_Europe_cons	
Ukraine	North_East_Europe_cons	
Belarus	North_East_Europe_cons	
Lithuania	North_East_Europe_cons	
Singapore	South_East_Asia_cons	
Thailand	South_East_Asia_cons	
Taiwan	South_East_Asia_cons	
Malaysia	South_East_Asia_cons	MY_prod
Vietnam	South_East_Asia_cons	
Hong Kong	South_East_Asia_cons	
Philippines	South_East_Asia_cons	
New Zealand	South_East_Asia_cons	
Bangladesh	South_East_Asia_cons	
Sri Lanka	South_East_Asia_cons	
Argentina	South_America_cons	AR_prod
Venezuela	South_America_cons	VE_prod
Chile	South_America_cons	
Colombia	South_America_cons	CO_prod
Ecuador	South_America_cons	EC_prod
Peru	South_America_cons	
Cuba	South_America_cons	
Puerto Rico	South_America_cons	
Panama	South_America_cons	
Virgin Islands, US.	South_America_cons	
Dominican Republic	South_America_cons	
Iraq	Middle_East_cons	IQ_North_prod
		IQ_South_prod
United Arab Emirates	Middle_East_cons	AE_prod
Kuwait	Middle_East_cons	KW_prod
Israel	Middle_East_cons	
Qatar	Middle_East_cons	QA_prod
Syria	Middle_East_cons	SY_prod
Oman	Middle_East_cons	OM_prod
Jordan	Middle_East_cons	
Yemen	Middle_East_cons	
Lebanon	Middle_East_cons	
Nigeria		NG_prod
Angola		AO_prod
Algeria		DZ_prod
Kazakhstan		KZ_Caspian_prod
		KZ_other_prod
Azerbaijan		AZ_prod
Turkmenistan		TM_prod
Libya		LY_prod

Appendix B. Statistical Measures

An important aspect for determining the accuracy of a spatial model is to compare actual and model-predicted trade flows. In this regard, we follow a commonly applied methodology (Kolstad and Abbey, 1984; Bushnell et al., 2008; Trüby, 2013; Lorenczik and Panke, 2016) that is used to validate models that are of similar types to ours, where we consider three different statistical measures: linear hypothesis testing, Spearman's rank correlation, and Theil's inequality coefficient. In what follows, we will be introducing these measures and discussing their application. We will also indicate possible shortcomings for the respective statistics.

In order to determine how well the values of the simulated trade flow matrix match with the actual flows a linear hypothesis test can be conducted. The idea here is that in the case of a perfect fit between the actual and simulated flows, plotting the values in a scatter-plot would form a line starting at zero and having a slope that is equal to one. We can therefore regress the actual trade flows A_f on the simulated flows S_f to test for the accuracy of the model. The set f stands for the trade flows between exporting regions $e \in E$ and importing regions $d \in D$.

$$A_f = \beta_0 + \beta_1 \cdot S_f + \epsilon_f \tag{B.1}$$

Equation B.1 is estimated with ordinary least squares (OLS). To be able to conclude whether simulated trade flows are consistent with actual flows, it is necessary that the joint null hypothesis of $\beta_0 = 0$ and $\beta_1 = 1$ cannot be rejected at conventional significance levels. Even though this approach is commonly used due to its advantage of allowing hypothesis testing, it is considerably sensitive to outliers.

As a second statistical measure, we use the Spearman's rank correlation coefficient (Spearman's rho) to evaluate how well the market shares of exporters in demand regions in the model estimations correlate with those in actual cases. This corresponds to comparing the ranking of actual trade flows with respect to volume with the ranking of simulated flows. Spearman's rho is defined as in Equation B.2.

$$rho = 1 - \sum_{f \in F} k_f^2/(n^3 - n) \tag{B.2}$$

Here, k_f is the difference in the ranks of the simulated and the actual trade flows and n is the sample size. The maximum value that Spearman's rho can take is equal to one and a large value for rho is desired, indicating a good simulation of market shares. However, Spearman's rank correlation should be interpreted with caution since it does not provide a direct comparison of simulated and actual trade flows in terms of volumes. As an example, consider two trade matrices which are equal which therefore have a rho equal to one. Multiplying one of the matrices by two does not change the ranking of the trade flows and rho remains to be equal to one, despite that the trade volumes are now double the initial volumes.

The third statistical measure we use is Theil's inequality coefficient, U. The inequality coefficient corresponds to the root-mean-squared error of the simulated trade flows S_f and the respective actual trade flows A_f. We apply the scaled version in which U lies between 0 and 1, as can be seen in Equation B.3.

$$U = \frac{\sqrt{\sum_{f \in F} (S_f - A_f)^2}}{\sqrt{\sum_{f \in F} S_f^2} + \sqrt{\sum_{f \in F} A_f^2}} \tag{B.3}$$

A U value equal to 0 means that simulated flows are equal to actual flows. A large value close to 1, on the other hand, indicates that the simulated flows strongly differ from the actual ones. Therefore, a lower U is desired as the goal is to have simulated trade flows which are consistent with the actual flows.

Appendix C. Sensitivity Analyses

In model-based analyses of the crude oil market, a common source of uncertainty is the large variation of production cost estimates found in the literature. Therefore, in order to check the robustness of our analysis, we conduct sensitivity analyses by varying the production costs of the suppliers; considering a low cost case with 30% lower costs, and a high cost case with 30% higher costs. Figure C.12 depicts the simulated prices of the sensitivity analyses where the lower edge of the areas correspond to the prices obtained in the low cost case and the upper edges correspond to the high cost case. Similarly, the production levels for the default case as well as for the sensitivities are presented in Table C.2. We can observe that our findings are robust with respect to the assumed cost levels.

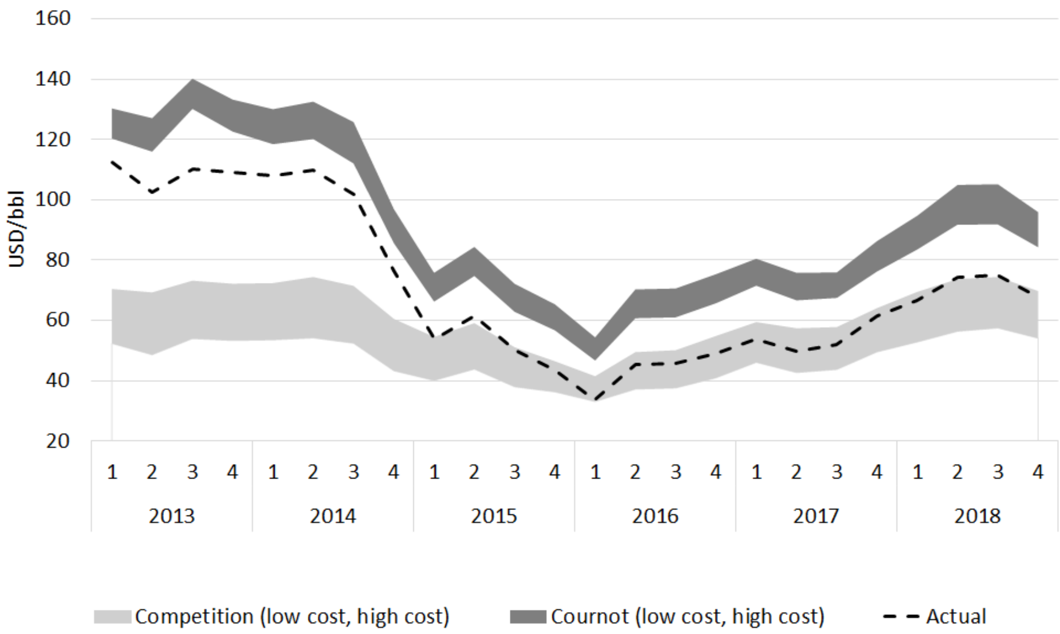

Figure C.12: Actual crude oil price levels and the simulated prices for the perfectly competitive and Cournot setups for the respective production cost sensitivities

Table C.2: Historical production capacities, actual production levels, and model production estimates for the default case as well as cost sensitivities for the considered market structure setups.

	Capacity	Actual	Competition			Oligo_OPEC			Cournot			Cartel_OPEC_core			Cartel_OPEC		
			Low	Default	High	Low	Default	High	Low	Default	High	Low	Default	High	Low	Default	High
2013																	
United States	10.64	10.32	9.87	9.60	9.22	10.64	10.50	10.09	10.64	10.64	10.33	10.64	10.64	10.64	10.64	10.64	10.64
Russia	11.21	10.88	10.56	10.37	10.23	11.21	11.17	10.62	10.11	9.90	9.90	10.78	10.43	10.34	11.21	11.20	11.18
Saudi Arabia	14.36	11.50	14.36	14.36	14.36	8.23	8.62	9.10	9.28	9.53	9.74	10.85	11.02	11.13	11.49	11.49	11.49
Other OPEC	27.18	24.91	27.11	27.06	26.90	27.18	27.11	27.11	27.18	27.12	27.11	21.33	21.33	21.33	12.77	12.80	12.88
Others	26.70	25.13	26.04	25.83	25.67	26.40	26.31	26.10	25.75	25.75	25.57	25.70	25.70	25.70	25.76	25.76	25.76
TOTAL	**90.09**	**82.74**	**87.93**	**87.22**	**86.37**	**83.66**	**83.71**	**83.02**	**82.95**	**82.95**	**82.65**	**79.30**	**79.12**	**79.14**	**71.87**	**71.88**	**71.94**
2014																	
United States	12.36	11.99	11.48	11.05	10.65	12.36	11.96	11.63	12.36	12.20	11.81	12.36	12.36	12.23	12.36	12.36	12.36
Russia	11.25	10.91	10.55	10.38	10.26	11.24	11.05	10.55	10.23	10.00	9.93	10.89	10.53	10.33	11.25	11.23	11.08
Saudi Arabia	14.38	11.52	14.38	14.38	14.38	8.63	9.17	9.58	9.58	9.95	10.20	11.12	11.31	11.44	11.50	11.50	11.50
Other OPEC	27.15	24.87	27.08	27.03	26.87	27.12	27.06	27.02	27.15	27.08	27.03	21.27	21.31	21.39	12.79	12.83	12.96
Others	27.17	25.58	26.44	26.23	26.07	26.86	26.65	26.47	26.18	26.11	25.92	26.14	26.14	26.09	26.19	26.19	26.19
TOTAL	**92.30**	**84.87**	**89.93**	**89.06**	**88.23**	**86.21**	**85.91**	**85.26**	**85.50**	**85.33**	**84.90**	**81.79**	**81.65**	**81.48**	**74.09**	**74.12**	**74.10**
2015																	
United States	13.39	12.99	12.14	11.29	10.80	12.73	12.08	11.47	12.99	12.30	11.75	13.39	12.68	12.33	13.39	13.39	13.07
Russia	11.43	11.09	10.55	10.24	10.14	10.93	10.55	10.35	10.10	9.95	9.88	10.51	10.21	10.10	11.35	10.76	10.62
Saudi Arabia	14.10	11.96	14.10	14.10	14.10	10.04	10.59	10.96	10.73	11.18	11.36	11.28	11.28	11.28	11.28	11.28	11.28
Other OPEC	27.16	25.69	27.04	26.89	26.89	27.08	26.88	26.85	27.08	26.92	26.87	22.28	22.74	22.85	14.03	14.36	14.59
Others	27.51	25.92	26.65	26.39	26.21	26.96	26.68	26.47	26.39	26.08	25.86	26.61	26.28	26.09	26.66	26.67	26.51
TOTAL	**93.59**	**87.66**	**90.47**	**88.91**	**88.15**	**87.74**	**86.78**	**86.10**	**87.29**	**86.44**	**85.71**	**84.07**	**83.19**	**82.66**	**76.72**	**76.46**	**76.07**
2016																	
United States	12.91	12.52	11.49	10.64	10.15	12.12	11.44	10.81	12.28	11.60	10.90	12.76	11.97	11.69	12.91	12.76	12.38
Russia	11.69	11.34	10.74	10.47	10.29	10.97	10.74	10.47	10.26	10.09	10.04	10.69	10.43	10.27	11.49	10.94	10.74
Saudi Arabia	14.17	12.36	14.17	14.17	14.17	10.40	10.86	11.24	11.05	11.40	11.66	11.34	11.34	11.34	11.34	11.34	11.34
Other OPEC	27.98	26.53	27.87	27.74	27.72	27.85	27.69	27.66	27.90	27.76	27.69	23.19	23.59	23.68	14.63	14.98	15.21
Others	26.86	25.36	25.97	25.65	25.49	26.26	25.97	25.72	25.71	25.40	25.11	25.97	25.59	25.41	26.09	26.03	25.85
TOTAL	**93.62**	**88.11**	**90.24**	**88.67**	**87.83**	**87.59**	**86.71**	**85.90**	**87.21**	**86.25**	**85.40**	**83.94**	**82.91**	**82.40**	**76.45**	**76.04**	**75.52**
2017																	
United States	13.62	13.21	12.60	11.86	11.23	13.13	12.54	11.96	13.41	12.61	11.94	13.62	13.08	12.63	13.62	13.62	13.49
Russia	11.71	11.36	10.88	10.62	10.44	11.32	10.85	10.70	10.27	10.13	10.07	10.75	10.43	10.34	11.67	11.03	10.83
Saudi Arabia	14.08	11.88	14.08	14.08	14.08	10.38	10.93	11.24	11.14	11.48	11.73	11.27	11.27	11.27	11.27	11.27	11.27
Other OPEC	27.92	26.70	27.86	27.70	27.70	27.85	27.75	27.67	27.87	27.85	27.71	23.32	23.77	23.99	14.96	15.25	15.47
Others	25.39	23.94	24.58	24.24	24.14	24.90	24.58	24.27	24.39	24.04	23.82	24.54	24.30	24.08	24.60	24.60	24.54
TOTAL	**92.72**	**87.09**	**90.01**	**88.50**	**87.60**	**87.59**	**86.66**	**85.84**	**87.07**	**86.11**	**85.26**	**83.50**	**82.85**	**82.30**	**76.12**	**75.78**	**75.61**