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RESEARCH PAPER

A Non-Linear Analysis of the Nature of Quota Violations in the OPEC Members; Results from a Panel Threshold Analysis

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Abstract

The main objective of this paper is to investigate the nature of quota violation behavior in OPEC members. We examined herding behavior (co-movement) and quota violation in a non-linear panel data model for 9 selected OPEC members. In terms of heterogeneity in OPEC member states, the level of dependence on oil revenues (threshold variable) as a country-specific characteristic has been involved in our model. Results showed that there was a positive and significant relationship between the violation of the allocated quota in a country and other members. In other words, there is a co-movement between the violations of the quota among OPEC members. Also, in countries which the level of dependence on oil export revenues is higher than the threshold (54%), the violation of allocated quotas is 1.5 times higher than countries with less dependency on oil export revenues. Increasing the dependence on oil revenues (Mainly due to budget constraints) incentivizes the OPEC members to be violated from established quota and consequently, reduces the efficiency of the quota system.

Keywords: Quota Violation, Co-movement, OPEC, Panel Threshold, Dependence.
JEL Classification: F23, F42, L11, L22.

Introduction

The Organization of the Petroleum Exporting Countries (OPEC) is an inter-governmental organization that generally refers to massive reserves, low costs, and net crude oil exporter countries which their ratio of crude oil exports to total export are dramatically high. Considering the OPEC member's characteristics, OPEC is a heterogeneous group of crude oil exporting countries that cannot properly assess the behavior of OPEC in the global oil market regardless of the characteristics of each country. As Table 1 shows, OPEC countries have major differences in energy and economic-based indicators.

While Gabon and Guinea have less than one percent of the world's crude oil proven reserves, Venezuela and Saudi Arabia account for 20 percent and 18 percent of proven crude oil reserves, respectively. Also, the ratio of crude oil export to production varies from 60 percent in Algeria to 99 percent in Guinea.

Besides, the price of oil is required to balance the budget which reflects the government budget's reliance upon the oil revenues, varied from $ 49.1 for Kuwait to $ 117.5 for Venezuela. Meanwhile, the average oil price for OPEC was $ 74.9. The cost of oil production varies from $ 8.5 for Kuwait to $ 35.4 per barrel for Angola.

Because the concentration on overall balance and performance measure (fiscal balance and GDP growth) gives a misleading picture for the oil exporting country Barnett and Ossowski

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(2002), the Non-Oil Fiscal Balance and Real Non-Oil GDP Growth have been used in this study. Non-Oil Fiscal Balance (percentage of Non-Oil GDP (indicator shows a significant dependency on oil revenue in OPEC member, although the variation range of indicators varies from -8.7 for Iran to -133 percent for Libya. Besides, the Real Non-Oil GDP Growth that reflects the economic performance without oil revenue, represents that the OPEC member's performance is not homogeneous and Real Non-Oil GDP Growth varies from 4.4 percent for Iraq to -3.3 percent to Angola.

Table 1. Economic and Energy Indicators for Selected OPEC Countries (2017)

Indicator	Algeria	Angola	Gabon	Guinea	Iran	Iraq	Kuwait	Libya	Nigeria	Qatar	Saudi Arabia	U.A.E	Venezuela	Selected OPEC Countries
Crude Oil Reserve (% of World)	1	1	<1	<1	10	10	7	3	3	2	18	7	20	82
Crude Oil Export to Production (%)	60	97	90	99	55	85	74	97	85	78	70	80	78	76
oil Price to Budget Balance ($)	64.7	82	66	NA	51.3	54.3	49.1	71.3	139	52.9	83.8	67	117.5	74.9
Cost of Oil Production ($/bbl.)	20.4	35.4	NA	NA	12.6	10.7	8.5	23.8	31.6	12.8**	9.9	12.3	23.5	18.3
Non-Oil Fiscal Balance (% of Non-Oil GDP)*	-22.3	NA	NA	NA	-8.7	-50.0	-56.2	-133*	NA	-26.9	-39.1	-18.3	NA	-44.3
Real Non-Oil GDP Growth (%)	2.4	-3.3	1.7	-2.5	3.99	4.4	2.5	-1*	0.5	4.01	1.01	1.9	NA	1.3

Note: * Last data available for 2014
** Last data available for 2015
Source: Statista, IEA, Rystad Energy, and Fred.

Since the foundation of OPEC in 1960, one of the mechanisms proposed to prevent increased production and lower oil prices was the issue of establishing OPEC members' share of oil production. This issue was first raised and adopted at the eighth OPEC Conference in 1965. In 1986, OPEC was deeply involved in designing its rationing system in such a way that all members would adhere to it. They considered eight factors that indicate the status of the members in two economic-social and oil-related issues as the factors affecting rationing: volume of stocks, the volume of production, the share of the members, domestic consumption of countries, costs of crude oil production, dependence on oil exports, population, and foreign debt.

Members of the OPEC have established the overall production limit and allocated those ceilings among members on many moments since March 1982 (Gault et al., 1999). The erratically applied quotas in the OPEC are, frequently ignored by members of OPEC, and in most cases, they have a modest effect on actual crude oil production. Various factors can cause a violation in the allocated quotas. Evidence confirms that during the OPEC operation, members of the organization have consistently violated their quotas. The aggregate difference between actual crude oil production and allocated quota in OPEC was presented in figure 1. Quota violations vary significantly among different OPEC members. For instance, Saudi Arabia's over-production has been around 3.2% from 1995 to 2007, however, Qatar's over-production averaged around 18.5% during the same period. Furthermore, Algeria which

deviate from its quota by more than 50% in 13 out of 24 quarters between 2002 and 2006 (Ghoddusi et al., 2017). In this study, members' violations are modeled from the quota envisaged by the organization considering the dependence of member countries on oil exports as a threshold variable.

Regarding the high price volatility of crude oil, OPEC member states are faced with severe imbalances, which prompt these countries to violate their quotas (Ghoddusi et al., 2017). Given the strong dependence on oil revenues in the OPEC members, the finance required to meet the development goals in these countries is mainly driven by oil export revenues (Sayadi and Khosroshahi, 2020). Also, a significant portion of the annual budget of governments is funded with oil revenues. Given the high volatility in global oil prices, management of this volatile revenue has always encountered governments with many challenges.

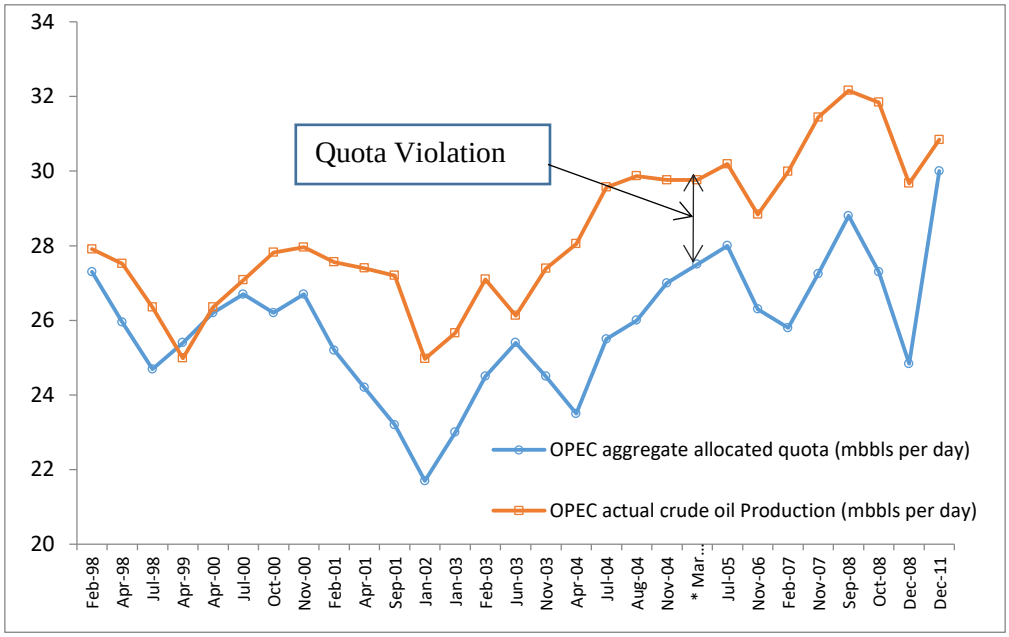

Figure 1. OPEC Actual Crude Oil Production and Allocated Quota
Note: * Since March 2005, Iraq has exited from the OPEC quota system.
Source: OPEC annual Bulletins figures and research calculations.

In the face of lower global oil prices, governments are faced with a budget deficit and are pushed for a larger increase in oil production to offset the budget deficit. Hence, the degree of dependence on oil revenues can play a major role in the extent of the violation of the oil quota of OPEC members.

Despite a great literature discussing the issue which focuses on whether OPEC as an organization behaves in the line with the cartel or not, few studies attempted to model the nature of OPEC behavior. For instance, Griffin (1985) examined the co-movement in crude oil production in OPEC members. Dibooglu and AlGudhea (2007), and Kaufmann, Bradford, Belanger, Mclaughlin, and Miki (2008) investigated the cheating behavior of OPEC members on a country-by-country basis rather than analyzing the nature of quotas violations. Results showed that Quotas were the key factors of crude oil production and their effects generally were symmetric. This indicates that OPEC is an organization that affects crude oil production and prices. During the sample period, Saudi Arabia had the lowest average rate of cheating (1.06) and was one of two OPEC members whom we could not reject a one-to-one long-term relationship with between its crude oil production and its established quota. Their results pointed out that OPEC could affect oil supply through its system of the quotation, without a monitoring system, punishment for cheaters, or central authority. Ghoddusi et al. (2017) suggested a theoretical framework with empirical evidence to illustrate OPEC countries'

incentives for violating quotas. Finding revealed, small members make larger proportional deviations compared to larger producers. Also, capacity restrictions work as a pressure mechanism in good times and OPEC's quota system disciplining its members in bad times.

The main contributions of this study in the OPEC behavior literature are:

- This paper is one of the few studies that have examined the individual behavior of countries, instead of examining the behavior of OPEC as a group.
- Co-movement (herding behavior) and quota violation in the OPEC members are tested in a non-linear model in the panel data.
- In terms of heterogeneity in OPEC member states, the level of dependence on oil revenues (considering as threshold variable) as a country-specific characteristic has been incorporated into the modeling of this paper.

The remainder of this paper is organized as follows: the next section presents the Literature Review in four main categories: a) the cartel behavior models, b) the target behavior models, c) the Dominant firm models, and d) the other models. Section 2 expounds on the Methodology and data. Section 3 illustrates Empirical Results, and finally, Section 4 contains the conclusions and discussion.

Literature Review

As shown in Table 2, Studies on modeling the role and behavior of OPEC in the oil market can be stranded into four main categories (Al-Qahtani et al., 2008).

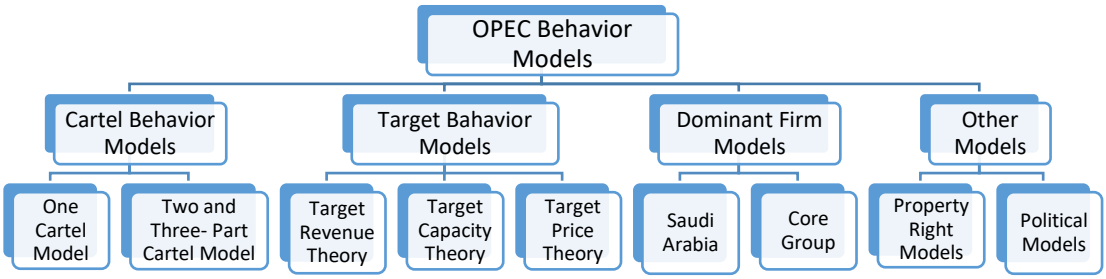

Figure 2. OPEC Behavior Models Categories
Source: Al-Qahtani et al. (2008).

Cartel Behavior Models

The first and most famous category is Cartel Behavior Models (CBM), which assumes OPEC as grouped into two or three parts. In the case of One-Part Cartel Models (OPCM) which initiated by Griffin (1985), try to systematically examine OPEC market behavior across the existing competing hypothesis involving cartel, target revenues, competitive, and property right models (Griffin, 1985). He introduced a log-log form for individual OPEC countries' crude oil production as a function of crude oil price, and other countries' production. Several updates on data and explanatory variables to Griffin's (1985) study were executed to examine the OPEC cartel hypothesis (Jones, 1990; Loderer, 1985; Youhanna, 1994; Al-Sultan, 1993; Gülen, 1996; Böckem, 2004; Almoguera et al., 2011; and Asker, 2018). The empirical studies in the OPCM remain largely inconclusive.

A small body of studies in literature attempted to analyze the OPEC behavior in the oil market as a two-part or three-part cartel coordinating and limiting crude oil production to adjust prices and achieve a maximum of profits. One of the early works by Hnyilicza and Pindyck (1976) tested the pricing policies for OPEC assuming that the cartel comprises two blocks: spenders and savers. As illustrated by Hnyilicza and Pindyck (1976), spenders are

countries with large cash requirements, and savers are countries with a small requirement for cash. According to their findings, the optimal path depends on the production shares that whether they are fixed or subject to change. If production shares are fixed, then the optimal price path will be the optimal monopoly price path. Otherwise, the optimal paths will depend on the relative bargaining power of savers and spenders. Using the same approach and classification, Aperjis (1982) achieved the similar results as Hnyilicza and Pindyck (1976) did. Testing the OPEC's cartel hypothesis continues to be the subject of study by a lot of researchers. Some main recent studies on test the cartel behavior hypothesis of OPEC include Kisswani (2016), Okullo and Reynès (2016), Escrihuela-Villar and Gutiérrez-Hita (2018), and Parnes (2019). However, the results obtained in these papers are various in to testing the OPEC cartel hypothesis.

Target Behavior Models

The second category of the studies that try to modeling OPEC market behavior use the target behavior models (TBM). The TBM involves target revenue models (TRM), target capacity models (TCM), and target price models (TPM). The TRM firstly introduced by Adelman (1982) indicated that the backward bending supply curve could describe OPEC behavior in the short run. The TRM supposes that OPEC countries attempt to obtain certain oil revenue levels to meet their government's internal budgetary commitments. Teece (1981) described OPEC behavior as a TRM and concluded that the relationship between the price and output is best described by a backward bending supply curve. Several modifications to Griffin's (1985) TRM described earlier, which the results at least partially supported the target revenue hypothesis, rejected the competitive hypothesis for all OPEC countries (Salehi-Isfahani, 2000; Alhajji and Huettner, 2000; Ramcharran, 2001; Ramcharran, 2002; Hemmati and Zamani, 2007; Claes, 2018a; and Parnes, 2019).

The TCM assumption indicates that OPEC sets and attempts to maintain a certain capacity utilization target. If this target is overreached, then oil prices will increase as OPEC reduces the crude oil production to match their established capacity utilization level. The higher price will then reduce the requirements and OPEC capacity utilization. Boug, Cappelen, and Swensen (2016) presented several alternative specification models in the literature. The result was in line with the imperfect competition in the oil market.

Suranovic (1993) by the adoption of the Energy Information Administration (EIA)'s Oil Market Simulation model entitled OMS92 to test whether the target capacity utilization rule satisfies OPEC economic objectives. The model has seven regions including the USA, Canada, Japan, Europe, formerly Centrally Planned Economies (CPEs), OPEC, and others. In the OMS92, OPEC, CPEs, and the USA government for strategic petroleum reserves are considered exogenous while the demand for the remaining five regions is determined using the geometric Koyck-lag demand function estimated using reduced form equations with coefficients derived from largescale EIA and non-EIA macroeconomic models. Similarly, the supply from the CPEs is considered exogenous while supply from other regions is determined by using a geometric Koyck-lag supply function which with coefficients derived from large scale macroeconomic models.

The model conclusion illustrated that "the target capacity utilization rule comes closest to optimum either when there are no lags" in supply and demand "or when OPEC optimizes subject to a minimum revenue constraint.

A few more attempts assume that OPEC targets a determined level of price or a price band and then defends it through crude oil production adjustments. The three studies reviewed in this part of the literature involved Hammoudeh (1997) in which applied the literature on target zone and speculative attack to examine the crude oil price dynamics in two models: two-sided

target zone model and asymmetric tolerance zone model. Their modeling results illustrate that OPEC credibility to intervention is directly related to crude oil price sensitivity to changes in both the output and price expectations. Hammoudeh (1997) conducted a similar work and argued the price solutions for single and multi-target zone models. He concluded that under normal conditions, market participants form expectations that cause crude oil price fluctuation in anticipation of OPEC interventions while under other circumstances, OPEC shifts the target zone when it fails to hold the line with previous targets. Furthermore, Tang and Hammoudeh (1997) examined the same model and the crude oil price behavior for the period 1988-1999. Their findings illustrate that OPEC attempt to maintain a weak target zone regime for the oil price that the crude oil price is influenced by both OPEC behavior and the market's expectation of OPEC behavior and they also suggested that OPEC became more explicit in adopting a target price zone model. The Pierru, Smith, and Zamrik (2018) is one of a recent study is try to examine the hypothesis of OPEC behavior based on the target capacity model. Their result confirms the role of capacity in forming the OPEC behavior in Oil Market.

Dominant Firm Models

Another category of studies in the modeling of OPEC behavior is the Dominant Firm Models (DFM) that has been a major contributor to the studies. The studies under this category can be divided into first, Saudi Arabia as a DFM and, second, a Core Group as a DFM. In the group of Saudi Arabia as a DFM, Mabro (1975) perceiving "OPEC is Saudi Arabia" and Erickson (1980) are some of the early works concluding that Saudi Arabia is the dominant producer within OPEC and that remaining OPEC and non- OPEC members are a competitive fringe. Similarly, Plaut (1981) notes "OPEC does not follow the cartel pattern of restricting supply and allocating output. It behaves more like an oligopoly with Saudi Arabia as a price leader and largest crude oil producer". Adelman (1990; 1993) believed that OPEC is best described as a "cartel", noting that "Saudis have acted like what they are: the leading firm in the world oil market." Alhajji and Huettner (2000) in an attempt to examine OPEC behavior investigated the presence of certain economic literature characteristics in six different commodity cartels including OPEC. These characteristics involved quota system, punishment mechanism, monitoring system, cartel authority, side payments, large market share, and additional differences. They found that none of these "economic literature characteristics" fit OPEC and concluded that neither statistical tests nor economic theory supported modeling OPEC as a cartel or as a competitive model and that OPEC is mainly Saudi Arabia, the dominant producer, and some other sub-groups. also, Nazari et al. (2018), and Dagoumas et al. (2018) recently try to analyzing the behaviors of Saudi Arabia in OPEC and global oil market. They conclude, Saudi Arabia's behavior has been against Cartel's rules and it was based on competition. Moreover, the probability of Saudi Arabia's staying in the competitive regime is more than its being in the collusion regime. Saudi Arabia has a long-term market sharing strategy, resilient to short-run price fluctuations.

The second group of studies in A Core Group as DF models suggests that OPEC core members including Saudi Arabia, Kuwait, UAE, and Qatar are where OPEC power is focused while the remaining OPEC and non-OPEC producers act as a competitive fringe. Such literature involves works by Singer (1983), Dahl and Yücel (1991), and Hansen and Lindholt (2008), Golombek et al. (2018).

Other Models

The fourth strand of literature review on OPEC behavior involves the smaller stream supposing that the crude oil market to be more competitive and referring the price changes to

reasons other than market power. This stream involves political models (PM) and property rights models (PRM). Although empirical studies by Griffin (1985), Jones (1990), Dahl and Yücel (1991), and Gülen (1996) cannot be verified the hypothesis that OPEC behavior in line with a competitive firm, in the PM, several works involving Ezzati (1976), Moran (1981), MacAvoy (1982) suggested that the crude oil market be competitive and that significant crude oil price movements be relevant to the market power. In the recent studied, Claes (2018b), and Hunter (2019) try to analysis the combination of political and economic power of OPEC members in world oil market.

Another segment of the literature suggesting the crude oil market to be more competitive tries to describe the market power using PRM. These models conclude that the producing countries have much lower discount rates than international oil companies (IOC) and that the lower the discount rate, the lower the preferred production. This implies that producing countries value future productions more than the IOCs and therefore decide to save reserves for future generations rather than now (Mead, 1979; and Odell and Rosing, 1983).

As reviewing the relevant literature revealed, the majority of studies try to model the OPEC behavior as an organization and very few studies have examined the nature of the OPEC members' behavior and, in particular, the violation of established quotas. In this regard, the main contribution of this paper is to introduce a formal model to examine quota violations and herding behavior in OPEC members considering the country-specific characteristics in a non-linear panel data model.

Methodology and Data

Theoretical Background

The Target Revenue Theory (TRT) is a prominent and non-collusive description for OPEC member's behavior (Ezzati, 1976; Teece, 1981). As discussed by Griffin (1985), the necessity for the internal investment specifies the oil revenue necessity significantly and determines the level of oil production. While oil revenues satisfy the investment target needs, there is no main incentive to produce oil more. The TRT argues that oil production cutback occurs in response to rising oil prices to equate oil revenues with investment needs. If I_{it}^{*} shows investment needs, the target revenue can be represented:

$$I_{it}^{*} = P_t Q_{it} \tag{1}$$

If assume oil prices are exogenous to oil producers, so we take logarithms and represent the equation (1) as:

$$lnQ_{it} = \propto_i + \beta_i lnP_t + \gamma_i lnI_{it}^{*} + e_{it} \tag{2}$$
$$i = 1, \dots, n; \quad t = 1, \dots, T$$

An increase in investment needs, ceteris paribus, result in proportionate $(\gamma_i = 1)$ increase in production. For given investment needs, a price increase results in a proportionate production decrease$(\beta_i = -1)$. This implies the "strict version" of the TRT, if OPEC members are heavily influenced by target revenue considerations, but occasionally produce in excess of investment needs, it can be test for a "partial version" of the TRT $(\beta_i < 1), (\gamma_i > 1)$).

Threshold Regression Model

The threshold regression model introduced by Hansen in 1999 tries to answer the question of whether regression functions are uniformly across all observations in a certain sample or they fall into discrete classes (Hansen, 1999).

To analyze the nonlinear relationships, two methods can be used. In the first method, sample was divided into two groups based on individual preferences. Given the fact that the location of the threshold is optional, in this method the accuracy of the results and the estimated parameters is questionable because it is largely dependent on the choice of the point where the break occurs.

In the second method with the use of the regression method or regression tree, the number and location of the thresholds are totally endogenous and determined by the use of sorting existing data Lee and Wong (2005). In this way, personal judgements do not interfere with the formation the type of a nonlinear relationship, and it is not necessary for any definite nonlinear functional form to examine nonlinear relations.

Assume the data are from a balanced panel are $\{y_{it}, a_{it}, x_{it} : 1 \leq i < n, 1 \leq t < T\}$ that i and t represent the individual and time, respectively. y_{it} defines the dependent variable and is a scalar, a_{it} is the threshold variable and is a scalar, and x_{it} define the independent variables vector, is a k vector. The structural form of model is:

$$y_{it} = \alpha i + \beta_1' x_{it} I(a_{it} \leq \gamma) + \beta_2' x_{it} I(a_{it} > \gamma) + \varepsilon_{it}; \quad \varepsilon_{it} \sim iid(0, \sigma^2) \tag{3}$$

in which I(.) denote the indicator function.

Observations are based on the fact that the threshold variable a_{it} is less than or greater than γ, divided into two regimes. These regimes are characterized by differences in slope regression β_1 and β_2:

$$y_{it} = \begin{cases} \alpha i + \beta_1' x_{it} + \varepsilon_{it} & a_{it} \leq \gamma \\ \alpha i + \beta_2' x_{it} + \varepsilon_{it} & a_{it} > \gamma \end{cases} \tag{4}$$

in addition to x_{it}, threshold variable a_{it} is also not time invariant to the identification of slope regression β_1 and β_2 (Hansen, 1999).

The coefficient β can be estimated by ordinary least squares (OLS), and the vector of regression residuals can be show as:

$$\hat{\varepsilon}^*(\gamma) = Y^* - X^*(\gamma)\hat{\beta}(\gamma) \tag{5}$$

based on Chan (1993), and Hansen (1999), least squares can be used to estimate the γ. In fact, it is easier to achieve by minimization of the concentrated sum of squared errors. Therefore, the least squares estimator of γ is:

$$\hat{\gamma} = \text{argmin } S_1(\gamma) \tag{6}$$

It is undesirable for a threshold $\hat{\gamma}$ to be selected which sorts too few observations into one or the other regime. This possibility can be excluded by restricting the search in above equation to values of γ such that a minimal percentage of the observations (1% or 5%) lie in each regime. After $\hat{\gamma}$ is obtained, the estimated slope is $\hat{\beta} = \hat{\beta}(\hat{\gamma})$, and vector of residual is $\hat{\varepsilon}^* = \hat{\varepsilon}^*(\hat{\gamma})$ and variance of residual is:

$$(\hat{\sigma})^2 = \frac{1}{n(T-1)}\hat{\varepsilon}^{*'}\hat{\varepsilon}^{*} = \frac{1}{n(T-1)}S_1(\hat{\gamma}) \quad (7)$$

That value of threshold variable should be selected because it has the minimum possible variance.

Empirical Model Specification

The model used in this paper is presented with a basic modification to the model provided by Griffin (1985) for testing the co-movement among OPEC members. In our model, a violation of the quota by an OPEC member is a function of the quota violations by other members and its level of dependency on oil revenue. The threshold panel model has been presented as follows:

$$LQV_{it} = \beta_0 + \beta_1 LQVT_{it} + \beta_2 LEX_{it} * I(a_{it} < \gamma) + \beta_3 LEX_{it} * I(a_{it} > \gamma) + U_{it} \quad (8)$$

In which, LQV_{it} is the amount of quota violation for country i at time t. $LQVT_{it}$ is the sum of the violation of other OPEC members from the quota allocated for those members at time t (This variable is considered to investigate the existence of herding behavior among OPEC members in violation of the determined quota). Also, LEX_{it} indicates the level of dependence on oil revenues in country i at time t (the share of oil revenues to total exports revenues was considered as an indicator of dependence on oil revenues in the OPEC members). As indicated, the observations are categorized based on the fact that they are higher or lower than the optimal threshold parameters (γ), and β_2 and β_3 are slope regressions in each regime. U_{it} represent the error term and, I(.) as the indicator function can be shown:

$$I(I(LEX_{it} > \gamma) = \begin{cases} 1 & \text{if } LEX_{it} > \gamma \\ 0 & \text{if } LEX_{it} \leq \gamma \end{cases} \quad (9)$$

Data

The annual time series of data set utilized in this paper involve LQV_{it}, $LQVT_{it}$, and LEX_{it} covers the period 1982 to 2015. The annual time series data used for LEX_{it} covers the period 1980 to 2015 for 9 OPEC countries Including Algeria, Iran, Libya, Kuwait, Qatar, United Arab Emirate, Saudi Arabia, Nigeria, and Venezuela. The reason for considering this time period is inclusion of the period of OPEC's quota system. Table 2 describes the operational definition of variables and the sources, respectively. All variables use in logarithm form.

Table 2. Data Description and Sources

VARIABLES	OPERATIONAL DEFINATION	SOURCE
LQV_{it}	The quota violation has been calculated as the ratio of actual crude oil production to the quotas allocated by the OPEC (%)	OPEC Annual Statistical Bulletins
$LQVT_{it}$	The ratio of sum of actual crude oil production to sum of the violation of OPEC members (other than country i) at time t (%)	OPEC Annual Statistical Bulletins
LEX_{it}	The share of oil revenues to total exports revenues (%)	WDI

Source: Research finding.

Empirical Results

Unit Root Test Results

Regarding the purpose of the paper, the results of the two-panel data models (linear and nonlinear by considering the threshold variable) are presented. In the first step, the unit root test was used to check the stationarity of the variables in panel data. In this paper, the Levin-Lin-Chu (LLC) test can be used to examine the unit root hypothesis in variables. As shown in Table 3, results from the LLC test (adjusted t and relevant p-value) indicate that all variables are stationary at the level or all variables are I(0).

Table 3. Results of Levin-Lin-Chu Unit-Root Test

Variable	Adjusted t	p-value	Result
$\mathbf{LQV_{it}}$	-2.503	0.006	Stationary at level
$\mathbf{LQVT_{it}}$	-6.904	0.000	Stationary at level
$\mathbf{LEX_{it}}$	-1.818	0.034	Stationary in level

Source: Research finding.

Diagnostic Tests Results

Table 4 presents the results of some of the essential diagnostic tests for determining the properties of the final model.

Table 4. Diagnostic Tests Results

Test	Value	P-value	Result
F-Limer	F(8,222)=1.77	0.084	Panel Data model
Hausman	7.79	0.028	Fixed Effects model
Pesaran	-3.027	0.034	cross-sectional dependence
Wooldridge	F(1,8)=38.741	0.000	serial correlation
Likelihood-ratio	LR chi2(8)=181.43	0.000	Heteroskedasticity

Source: Research finding.

The F-limer test is used to choose the panel data model against the estimated model of pooled data. According to the obtained value for the F-Limer test (1.77) in Table 2, the null hypothesis cannot be rejected at a 95 percent confidence level, and, we can use the panel data method to estimate the model.

Hausman Test (1978) is used for selecting between the random effects (null hypothesis) against the fixed effects model (alternative hypothesis). As shown in table 2, the Hausman test's value and prob is 7.79 and 0.028, respectively, and, the null hypothesis can be rejected in 95 percent confidence level, so the fixed effect model is selected.

The Pesaran test has been used to test the cross-sectional dependence (CD) in our panel-data model. The CD test results show that the null hypothesis of no cross-sectional dependence has been rejected and the cross-sectional units are independent.

Because the Wooldridge (2010) test to serial correlation in the presence of random and fixed effects is based on fewer assumptions, it should be more robust (Baltagi, 2008). Likelihood-ratio used to test the heteroskedasticity. The null hypothesis is the existence of homoskedasticity (or constant variance). Results indicate that the null hypothesis can be

rejected in all confidence levels (90, 95, and 99 percent) and in hence there is heteroskedasticity in the model.

According to the results of Table 2, the model should be estimated based on the panel data. Also, according to the results of the Hausman test, the use of the fixed effects method is proposed. Due to the existence of heterogeneity of variance and serial correlation in the model, the Feasible Generalized Least Squares (FGLS) should be used to estimate the final model.

To estimate nonlinear threshold effects, a two-stage ordinary least squares (OLS) approach is proposed by Hansen (1999). In the first stage, threshold value g, which is the corresponding sum of squared errors (SSR), is calculated by the OLS method; then threshold value is obtained using the minimum SSR based on presumed threshold values. In the second stage, coefficients are estimated for different regimes that are separated by the threshold values in the model.

Panel Data Regression Estimation (Linear Model)

The results of the linear panel regression estimation presented in table 5. Based on the z-statistic and the probability of the $LQVT_{it}$ variable, it can be said that the effect of violations by other OPEC members is positive and statistically significant. In other words, there is a co-movement between OPEC member's behaviors in a quota violation. Also, according to the z-statistic and the probability of the LEX_{it} variable, the effect of the dependence of oil revenues on each member of the OPEC is positive and statistically significant. Wald's statistics and probability verify the significance of estimated regression. In the next section, to clarify the obtained results, we explore the Non-Linearity relationship between model variables.

Table 5. FGLS Panel Regression Estimation (Linear Model)

variable	Coef	Std.Err	Z test	p-value	Conf. Interval 95%	
constant	150.642	51.273	2.94	0.003	50.148	251.136
$LQVT_{it}$	0.065	0.006	9.43	0.000	0.051	0.079
LEX_{it}	196.799	86.919	2.26	0.024	26.441	367.157
Wald chi2(2)=89.01				Prob > chi2=0.0000		

Source: Research finding.

Determining the Number of Thresholds

To determine the number of thresholds, the model was estimated by least square (LS), allowing for sequentially zero, two and two thresholds. The F test statistics along with their bootstrap p-values are presented in table 6. Results show that the test for a single threshold is significant with a bootstrap p-value of 0.021, and the test for a double threshold is not close to being statistically significant with a bootstrap p-value of 0.480. Moreover, there is robust evidence that there is a single threshold in the regression relationship, therefore, we reject the linear model and fit a single threshold model.

Table 6. Test for Threshold Effects

Threshold	F stat	Prob	Crit 10	Crit 5	Crit 1
Single	15.37	0.021	11.12	13.06	17.44
Double	5.51	0.480	10.23	11.85	17.77

Source: Research finding.

As stated in the methodology section, a threshold is chosen for the minimum level of variance for the residuals. Table 7 present the threshold estimator at the 95% level.

Considering the higher and lower values of the threshold, it can be said that at a significant level of 95%, the threshold value calculated is statistically valid.

Also, the anti-logarithm of the obtained threshold is 0.54. In other words, countries in which the share of oil revenues to their total export revenues is less than 0.54 are in regime 1, and countries in which the share of oil revenues to their total export revenues is more than 0.54 are in the regime 2.

Table 7. Threshold Estimator (level = 95)

model	Threshold	Lower	Upper
Th-1	-0.608	-0.614	-0.608

Source: Research finding.

Threshold Panel (Non-Linear) Model Estimation

Table 8 shows the results of the estimation of the threshold panel model. Given the threshold value, the effect of the coefficients obtained in the model is affected by the threshold. Based on these results, the effect of dependency variables on oil revenues in both regimes and the quota violation of other OPEC's members on violations of the quota for a country at a significant level of 99% are statistically significant.

It can be stated that taking into account the effect of coefficients on the calculated threshold level, on average, a unit of violation of other OPEC members from the allocated quota would result in 0.07 violation of one member. This results in a violation of the quota that can confirm the existence of herding behavior among OPEC members.

In countries where the level of dependence on oil export revenues is higher than the threshold, the violation of allocated quotas is 1.5 times higher than countries with less dependency on oil export revenues. Therefore, it can be said that there is a nonlinear relationship between the behavior of OPEC members in violation of the quota and their degree of dependence on oil revenues. The higher the dependency on oil revenues, the greater the possibility of a quota breach among OPEC members.

Table 8. Non-Linear (Threshold) Regression Estimation

Variable	Coef	Std.Error	t test	p-value	95% Conf. Interval	
Constant	378.207	103.304	3.66	0.000	174.624	581.791
$LQVT_{it}$	0.077	0.016	4.57	0.000	0.043	0.110
$LEX_{it} \leq -0.608$	489.307	157.901	3.10	0.002	178.130	800.484
$LEX_{it} > -0.608$	703.989	217.191	3.24	0.003	275.968	1132.01
F(8,222)=1.75				Prob > F=0.087		

Source: Research finding.

Conclusion and Discussion

Quota allocation is one of the OPEC mechanisms to manage oil supply in the global oil market. However, a violation of the allocated quota will occur repeatedly in OPEC members, which will reduce the efficiency of the production cut mechanism. In this study, considering the share of oil revenues to total exports as a threshold variable and by a modification in Griffin (1985) model as a base model, the OPEC members' violation of the established quota for the years 1982-2015 for 9 selected countries was modeled.

The main contributions of this study are the Modeling the Co-movement (Herding behavior) and quota violation in the OPEC members in a non-linear model in the panel data,

and consideration of the level of dependence on oil revenues (considering as threshold variable) as a country-specific characteristic are the main contributions of this paper.

The results of our linear model show that a violating form established quota in other OPEC members would result in an average of 0.06 units of non-compliance by the other country. Also, further increasing the dependence on oil, as well as increasing the incentive to violate the established quota. In countries where the level of dependence on oil export revenues is higher than the threshold, the violation of allocated quotas is 1.5 times higher than countries with less dependency on oil export revenues.

Our results also show that there is a positive and significant relationship between the violation of other members and the violation of one country. There is a co-movement between the violations of the quota among OPEC members so that the violation of other OPEC members can have a direct and significant impact on the violation of each OPEC member. Confirmation of the co-movement between the behaviors of members of OPEC is in line with the results of Griffin (1985). However, in Griffin's (1985) study, the movement has also been confirmed in the production of OPEC members, and in this study, a co-movement has been verified in violation of established quota.

Also, while all OPEC member countries rely on oil production and exports, their dependence on oil export revenues is different, which affects their rate of violation of established quotas. Based on the findings of this study, the higher the dependency on oil revenues is, the higher the rate of violation would. Results showed if the dependence on oil revenues is higher than the threshold level measured (54 %), the impact of oil revenues to the total export ratio on quota violations is about 1.5 times that of the mentioned ratio below the threshold level.

As the results show, the dependence of OPEC member countries on oil revenues increases the incentive to violate the quotas, which means that there will be a violation of the quota among OPEC members, then more oil supply to the global market will lead to a further decline in global oil prices which can worsen the budget situation of these countries.

In addition to budgetary constraints in OPEC members which intensify them to violating the established quota, by limiting below-capacity production, OPEC countries see their market share diminished, and production control benefits can reach to the non-OPEC countries. This could be one of the triggers for the violation of the quota. Therefore, in terms of policy implications, it seems that OPEC's cooperation with non-OPEC countries, or the term OPEC Plus, could reduce the incentive to violate the quotas in OPEC members and in hence, production cuts policy can be more affected.

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