Price Leadership on the World Crude Oil Market

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Abstract: The paper investigates the role of Saudi Arabia in the dynamic behavior of world crude oil prices over recent decades. The analysis tests the hypothesis that Saudi Arabian crude oil prices lead crude oil prices on the world market. If Saudi Arabian crude oil price has led the prices of other countries on the world crude oil market, there would be a long-run equilibrium relationship between each country's crude oil price and Saudi Arabian price. Comparable geographic data were assembled for six OPEC (Iran, Indonesia, Libya, Nigeria, Saudi Arabia and Venezuela) and six non-OPEC (Canada, China, Mexico, Norway, United Kingdom and United States) countries, covering the period 1970 through 2007. Three widely used econometric techniques (dynamic correlation analysis, cointegration analysis and VAR analysis) are employed. The results support a long-run equilibrium relationship between Saudi Arabian crude oil price and prices in other OPEC and non-OPEC countries.

1. INTRODUCTION

The world oil market, as a result of a wide variety of cyclic and short term factors, has experienced significant tightness since the end of 2003 in such a way that the growth of demand has been unexpectedly high causing upward pressure on oil prices. Fundamentally, oil prices remain an important determinant of global economic performance; and given their importance, economists over the years have devoted considerable energy to trying to understand both the factors that play a role in oil price movements and their time series properties [1-11]. Most of the research, however, has focused on how oil price shocks affect macroeconomic performance. For example, several applied research and policy studies have examined the role played by oil prices in determining economic growth or inflation rates. Mork [12] surveys the literature on the impact of oil price shocks on the macro economy and financial markets. Jones and Kaul [13] examine whether oil price shocks are rationally absorbed by stock markets. Rogoff [7] considers the impact of oil prices on the global economy, while Cavalo and Wu [14] develop two measures of exogenous oil price shocks based on market commentaries on daily oil price fluctuations.

The purpose of this paper is to investigate the role of Saudi Arabia in the dynamic behavior of world crude oil prices. The analysis tests the hypothesis that Saudi Arabian crude oil prices lead crude oil prices on the world market. Particularly, we examine the relative behavior of prices between crude oil from Saudi Arabia and oils from other Organization of the Petroleum Exporting Countries (OPEC) and non-OPEC countries. If the price of crude oil from Saudi Arabia leads the price of crude oils from other countries, then one would not expect other countries' individual prices and Saudi Arabian price to move away from each other, at least in the long-run. This, in turn, would imply a long-term equilibrium relationship between Saudi Arabian crude oil prices and prices in other individual countries or between Saudi Arabia and other countries' group average price.

The rest of the paper is organized as follows. The next section presents a brief background on the Kingdom of Saudi Arabia. Section 3 presents a description of crude oil price series, while Section 4 discusses the methodological approaches for examining the time series properties of the price series. We look at patterns and trends in the data and test for stationarity and the order of integration. Next, we form a Vector Autoregressive Regression (VAR) system. This step involves testing for the appropriate lag length of the system, including residual diagnostic tests. Issues of impulse responses, and forecast error decomposition are addressed. The results and conclusion are presented in Sections 5 and 6, respectively.

2. BACKGROUND

The Kingdom of Saudi Arabia is the most prominent member of the Organization of the Petroleum Exporting Countries (OPEC)[1] and has played an important role in OPEC that cannot be duplicated by any other country. Particularly, Saudi Arabia is the biggest oil producer in OPEC. With one-fifth of the world's proven oil reserves, some of the lowest production costs, and an aggressive energy sector investment initiative, Saudi Arabia is likely to remain the world's largest net oil exporter [15]. By far, its export volume per day (Fig. **1**) is higher than any other OPEC member (roughly 66% in 2006) and the value of its crude oil export has steadly increased since 2003 (Fig. **2**). Having the world's largest oil reserve (estimated at about 60% of OPEC's spare capacity) has enabled the Kingdom of

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[1] On September 14, 1960, OPEC an intergovernmental organization whose stated objective is to coordinate and unify petroleum policies among member countries was formed. The founding members were Saudi Arabia, Iraq, Iran, Kuwait and Venezuela. The five founding members were later joined by nine other members including Algeria, Indonesia, Libya, Qatar, Ecuador, Gabon, United Arab Emirates, Angola and Nigeria.

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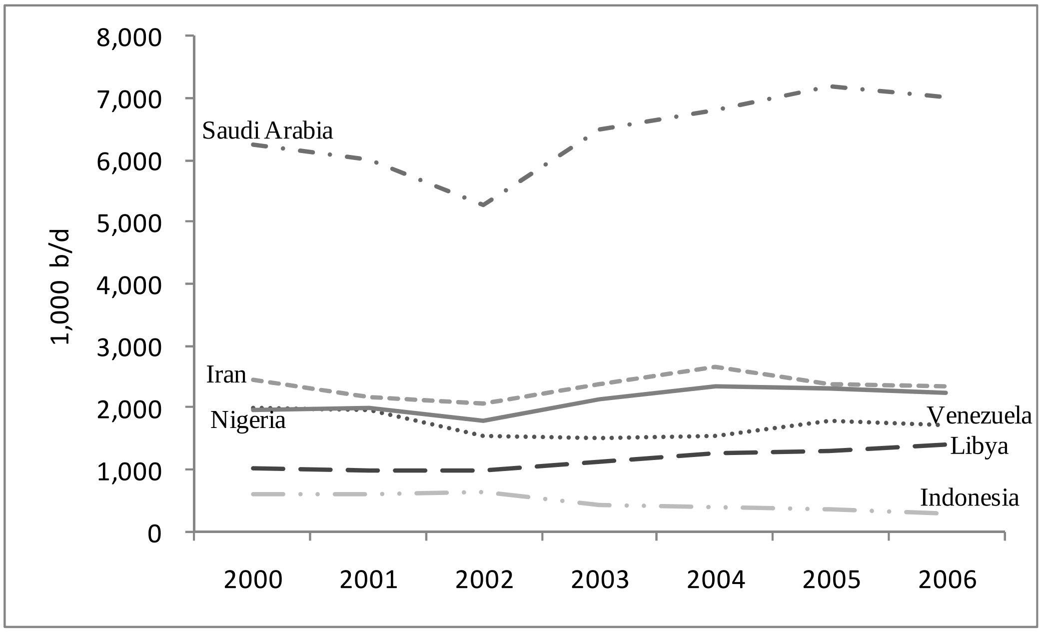

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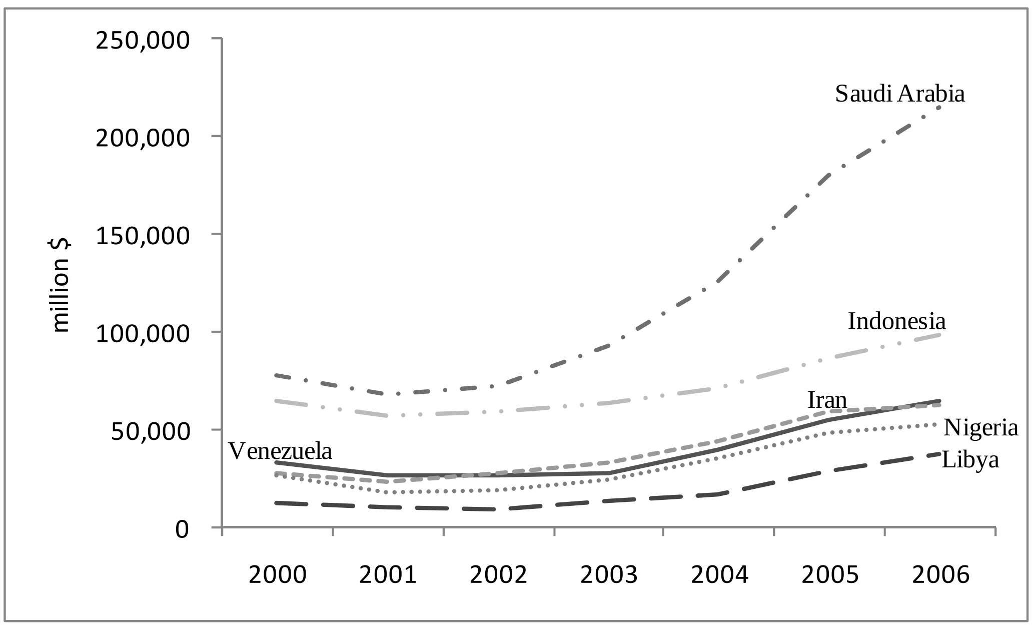
Fig. (1). OPEC's crude oil export volumes, 2000-2006.



Source: Created by authors using data from the OPEC Annual Statistical Bulletin [53]

Fig. (2). OPEC's values of crude oil exports, 2000-2006.

Saudi Arabia to boost output quickly in times of crisis [15-17], thus giving the Saudis the potential to influence activities on the global oil market.

In its role as the leader of OPEC, Saudi Arabia has been recognized as the swing producer of the world [18]. Over the years, the swing production status resulted in Saudi Arabia, having a lot of idle capacity which has helped OPEC in general and Saudi Arabia in particular, gain control over oil prices. As Kaul and Subramanian [18] have noted, whenever the inventory level of oil stocks in industrialized nations, particularly the members of Organization of Economic Cooperation and Development (OECD) goes up, Saudi Arabia (as the swing producer) reduces output; and this artificial scarcity does not allow oil prices to fall. The same idle capacity has been used to pump extra oil into the market to prevent dramatic price rises during times of unexpected supply interventions [15-17]. For instance, Saudi Arabia has effectively used its idle capacity in the past to prevent any price increase during the Iran-Iraq war, the Gulf War and the recent Venezuelan crisis; hence, calming markets in times of turmoil [18-19].

Economically, the Kingdom of Saudi Arabia is the largest economy in the Middle East and remains heavily dependent on oil and petroleum-related industries, including petrochemicals and petroleum refining [15]. The IMF reported that in 2006, oil export revenues accounted for around 90 percent of total Saudi export earnings, 80 to 90 percent of state revenues, and 46 percent of the country's gross domestic product [20]. While Saudi Arabia has indicated increasing its oil production capacity to 12.5 million barrels per day by 2009 and to reach 15 million b/d by 2025 [15], recent developments show a renewed desire for diversification away from oil revenue in the long term and a desire to meet short-term fluctuations in domestic and foreign expenditures [21].

The Kingdom has never been such a vital partner in securing regional and global security, and has played pivotal roles in recent global summits, notably bringing an all-important Saudi presence to the recent Annapolis peace conference (Council on Foreign Relations, 2007). On the geopolitical landscape, the Kingdom is located in a politically unstable region of the world, thus, its actions, as well as other developments in the region, are followed very closely by concerned parties, including traders in the spot market [23].

3. DATA

Data for spot crude oil prices (in nominal U.S. dollar per barrel) were collected from the U.S. Department of Energy's Energy Information Administration. All annual price series are found on the Energy Information Administration's website under the Petroleum Prices section [24]. The data stem from six OPEC (Iran, Indonesia, Libya, Nigeria, Saudi Arabia and Venezuela) and six non-OPEC countries (Canada, China, Mexico, Norway, United Kingdom and United States). OPEC price series have been collected for the period 1970 to 2007, while non-OPEC prices are mainly from 1980 to 2007. Table **1** presents the descriptive statistics, while the evolutions of the series are presented in Figs. (**3**, **4**). The table shows all price indices are distributed asymmetrically as the skewness coefficients are different from zero. The kurtoses of all series are greater than zero indicating that the tails of their distribution are fatter than the normal distribution. The sample variance suggests that Libyan and Norwegian crude oil prices are the most volatile among OPEC and non-OPEC countries, respectively.

Figs. (**3**, **4**) shows the annual spot price of a barrel of crude oil in the respective countries, measured in U.S. dollars. The long series depicted in Fig. (**3**) shows for instance, how a long spell of stability came to an end in 1973, triggering a new era characterized by large and persistent fluctuations in the price of crude oil, punctuated with occasional sharp run-ups and spikes, and ending with the prolonged rise of the past few years. Similar patterns are evident in Fig. (**4**) among the non-OPEC series. Overall, the data shows roughly similar trends and closeness among OPEC than in non-OPEC series.

4. METHODOLOGY

Various economists have attempted to empirically analyze the behavior of commodity prices using different econometric techniques. Earlier studies, such as Reinhart and Wickham [25] and Borensztein and Reinhart [26] adopt a structural model to identify the key fundamentals behind commodity prices, and more importantly to quantify the relative contributions of demand and supply shocks. Cashin, Liang and McDermott [27] and Labys [28] examine the persistence of shocks to commodity prices. They use a median-unbiased estimation procedure proposed by Andrews [29] instead of a unit root test to check the persistence of shocks. Weiner [30] employs correlation analysis and switching regression technique to test whether the oil market is unified or regionalized while Gülen [23] reexamines Weiner's hypothesis using cointegration analysis. Labys [31] and Kyrtsou and Labys [32] employ chaotic tests of the

Table 1. Descriptive Statistics and Characteristics of the Price Series

Country	Crude Type	Min	Max	Mean	SD	Variance	Skewness	Kurtosis
OPEC Countries: 1970-2007								
Indonesian	Minas-34° API	2.05	55.57	20.86	12.29	151.16	0.81	1.11
Iranian	Light-34° API	2.09	59.22	22.15	13.16	173.19	0.90	1.11
Libyan	Es Sider-37° API	2.10	63.28	22.23	13.40	179.46	1.08	1.88
Nigerian	Bonny Light-37° API	1.67	63.87	21.79	13.14	172.75	1.08	2.08
Saudi Arabian	Light-34° API	1.35	55.94	20.06	12.07	145.69	0.92	1.53
Venezuelan	Tia Juana Light	1.35	55.94	20.06	12.07	145.69	0.92	1.53
Non-OPEC Countries: 1980-2007								
Canada	Lloyd blend 22º	6.01	40.39	19.47	8.29	68.73	0.61	0.01
China	Daqing 33º	9.85	61.09	25.95	11.62	134.99	1.37	2.42
Mexico	Maya-22° API	9.37	55.46	25.29	11.16	124.62	1.12	1.35
Norway	Ekofisk Blend 42º	10.60	60.26	26.68	11.98	143.57	1.33	1.93
UK	Brent Blend-38° API	10.44	60.50	26.50	11.91	141.80	1.44	2.29
US	Domestic Acquisition	13.18	69.63	26.89	14.04	120.65	1.77	5.53

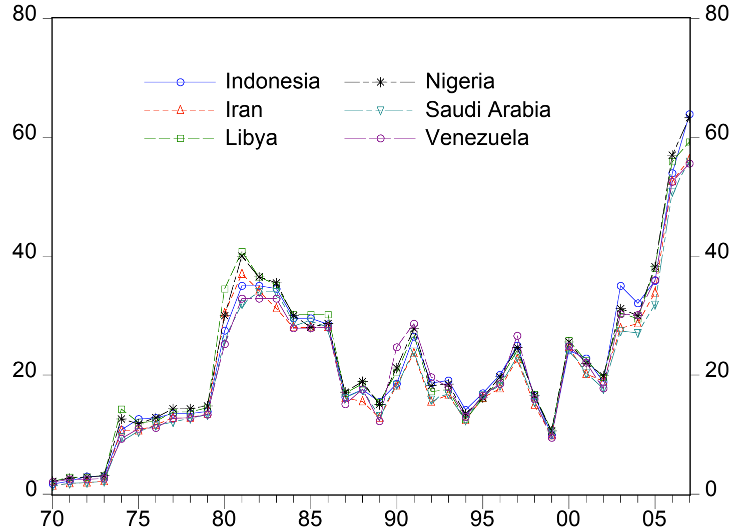


Fig. (3). Crude Oil Prices (OPEC).

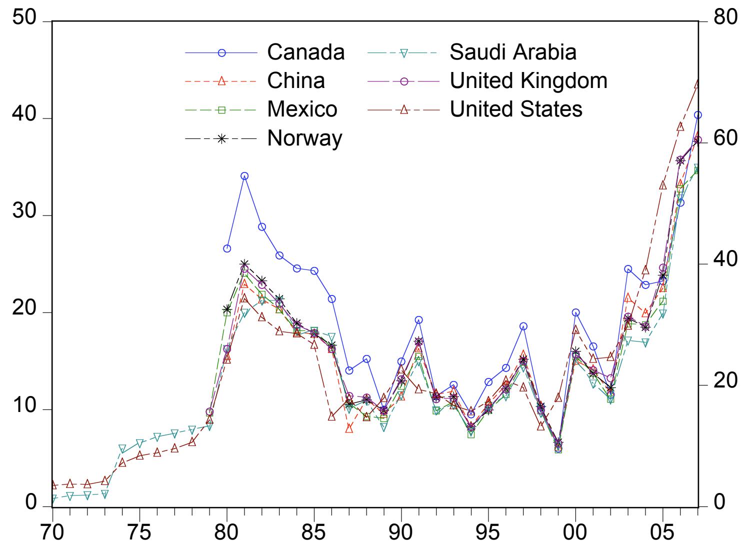


Fig. (4). Crude Oil Prices (Non-OPEC with Saudi Arabia).

relation between oil prices and inflation. Dibooglu and Aleisa [17] investigate the sources of macroeconomic fluctuations in Saudi Arabia using Structural Vector Autoregression method. Most recently, Fattouh [33] model crude oil price differentials as a two-regime threshold autoregressive process using Caner and Hansen's [34] method. These studies provide insights in the methods to analyze crude oil prices. In the present context, we employ three tests: (1) Dynamic correlation analysis to study the short-run responses; (2) Cointegration analysis to study the equilibrium relationship between the different price series; and (3) Vector Autoregression (VAR) analysis of price leads and lags. A brief discussion on each of these techniques follows.

A. Dynamic Correlation Analysis

The computation of simple correlation coefficients within different sub-periods of a total sample period can be employed to study the dynamics of the linkages between variables separated by space [30]. However, since correlation analysis is static rather than dynamic, it is also important to examine cross-correlations with a lag structure between the variables of interest [35]. To accomplish this, simple correlation coefficients (r_i^2) within different sub-periods of the total sample are calculated on the level series. Following Bukenya and Labys [35], the estimated r_i^2 coefficients are then used to estimate the dynamic correlation indexes, C_{ij} and C_{iT} as:

$$C_{ij} = \frac{r_{12}^2 + r_{13}^2 + r_{14}^2 + \ldots + r_{56}^2}{n_{c2}} \tag{1}$$

$$C_{iT} = \frac{C_{ij}}{C_{11}} \tag{2}$$

where $i = 1, 2, \ldots, 6$; $j = 1$; $T = 1, 2, \ldots, 8$; and C_{11} is the C_{ij} for the first sub-period. Here, i represent a country; j represents a commodity (crude oil) and T represents sub-periods in each case. In the above equations a coefficient of C equal to one, would be interpreted as a perfect transmission of price shock, while a coefficient of zero would represent a short-run invariance to changes in price elsewhere. Since the short-run effect is in principle unrestricted, a value of C_{iT} greater than unity, for example, would suggest an over-reaction to changes in price in the current period.

B. Cointegration Analysis

A growing body of empirical literature has used cointegration techniques in measuring equilibrium relationships between variables. Previous applications to commodity prices include Bukenya and Labys [35], Asche *et al.* [36], Gülen [37], Bernard and Durlauf [38], Alexander and Wyeth [39], Zanias [40], and Goodwin [41]. Since only non-stationary series can be subject to cointegration analysis, the first step is to confirm that the variables are nonstationary and integrated of the same order. To this end, several different tests are available. In the present context, we employ the Dickey-Fuller and Augmented Dickey-Fuller tests using the following regression:

$$\Delta y_t = a + g y_{t-1} + \sum_{i=1}^{k} b_i \Delta y_{t-i} + e_t \tag{3}$$

The lag length k is chosen to generate a white noise error term e_t. To determine whether y_t is nonstationary, the null hypothesis of nonstationarity is evaluated by testing whether $g = 0$ against the alternative of stationarity $g < 0$. Following stationarity tests, we proceed with cointegration tests using two approaches: the Johansen [42], Johansen and Juselius [43] and the Bernard and Darlauf [38] methods. Since these methodologies have been extensively discussed in the literature, we only offer brief descriptions starting with Johansen's method.

Johansen's methodology takes its starting point in the vector autoregression (VAR) of order p given by

$$y_t = \mu + A_1 y_{t-1} + \cdots + A_p y_{t-p} + \varepsilon_t, \tag{4}$$

where y_t is an n x 1 vector of variables that are integrated of order one, commonly denoted I(1), and ε_t is an n x 1 vector of innovations. This VAR can be re-written as

$$\Delta y_t = \mu + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-1} + \varepsilon_t \tag{5}$$

where

$$\Pi = \sum_{i=1}^{p} A_i - \mathrm{I} \quad \Gamma_i = -\sum_{j=i+1}^{p} A_j \tag{6}$$

If the coefficient matrix Π has reduced rank $r < n$, then there exist n x r matrices α and β each with rank r such that $\Pi = \alpha\beta'$ and $\beta' y_t$ is stationary. r is the number of cointegrating relationships, the elements of α are known as the adjustment parameters in the vector error correction model and each column of β is a cointegrating vector. It can be shown that for a given r, the maximum likelihood estimator of β defines the combination of y_{t-1} that yields the r largest canonical correlations of Δy_t with y_{t-1} after correcting for lagged differences and deterministic variables when present.

On the other hand, the Bernard and Durlauf [38] approach defines long-run convergence between countries i and j if the long-term forecasts of the price variable for both countries are equal at a fixed time t:

$$\lim_{k\to\infty} E\left(p_{i,1+k} - p_{j,t+k} \,|\xi_t\right) = 0 \tag{7}$$

where ξ_t stands for the information available at time t. This definition is satisfied if $p_{i,1+k} - p_{j,t+k}$ is a mean zero stationary process. This implies that variables for countries i and j to converge, the two series must be cointegrated with cointegrating vector [1, -1]. In addition, if the variables are trend-stationary, then the definitions imply that the trends for each country must be the same. Recent empirical application of this approach to gasoline prices is Bentzen [44] who estimates a cointegrating equation of the form:

$$\Delta\left(p_{i,t} - \bar{p}_t\right) = \alpha + \beta_t + \mu\left(p_{i,t-1}\right) + \text{lags of } \Delta\left(p_{i,t} - \bar{p}_t\right) + \varepsilon_t \tag{8}$$

Following Bentzen [44], we estimate equation 8, where the test relies on a Dickey-Fuller type of test for a unit root in the difference of the (log) values of crude oil prices, with t indicating a time trend. In the presence of a unit root, Saudi Arabian crude oil price and the group average price will be driven by separate stochastic trend and, hence, diverge over time. On the other hand, the absence of a unit root in equation (8) implies that the intercept term and the deterministic trend parameter may be insignificant and thus indicate long-run convergence. Finally, when the deterministic trend parameter differs significantly from zero, a catching-up process is likely to take place assuming that the initial values of crude oil prices differ in levels [44].

C. VAR Analysis

In addition to measuring the broad correlation in the variables of a system, Vector Autoregression (VAR) helps us to measure the lead-lag relationships. VAR is commonly used for forecasting systems of interrelated time series and for analyzing the dynamic impact of random disturbances on the system of variables [45]. The VAR approach sidesteps the need for structural modeling by modeling every endogenous variable in the system as a function of the lagged values of all of the endogenous variables in the system. The estimated VARs are used to calculate the percentages of each endogenous variable that can be explained by innovations in each of the explanatory variables and provides information about the relative importance of each random innovation to the variable in the VAR. The mathematical form of a VAR is

$$Y_t = A_1 Y_{t-1} + \ldots + A_p Y_{t-p} + \beta X_t + \varepsilon_t \tag{9}$$

where Y_t is a k vector of endogenous variables, X_t is a d vector of exogenous variables, $A_1, \ldots, A_p$ and β are matrices of coefficients to be estimated, and ε_t is a vector of innovations that may vary contemporaneously.

Table 2. Dynamic Correlation Index

Period	OPEC (1970-2007)				Non-OPEC (1980-2007)			
	Without Saudi Arabia		With Saudi Arabia		Without Saudi Arabia		With Saudi Arabia	
	c_{ij}	c_{iT}	c_{ij}	c_{iT}	c_{ij}	c_{iT}	c_{ij}	c_{iT}
1970-74	1.00	1.00	1.00	1.00	---	---	---	---
1975-79	0.97	0.97	0.98	0.98	---	---	---	---
1980-84	0.79	0.80	0.83	0.83	1.00	1.00	0.77	1.00
1985-89	0.99	0.99	0.99	0.99	1.09	1.09	0.93	1.21
1990-94	0.97	0.97	0.97	0.97	1.09	1.09	0.92	1.21
1995-99	0.99	0.99	0.99	0.99	1.11	1.11	0.94	1.23
2000-04	0.97	0.98	0.98	0.98	1.09	1.09	0.92	1.2
2005-07	0.99	0.99	0.99	0.99	1.03	1.03	0.89	1.16

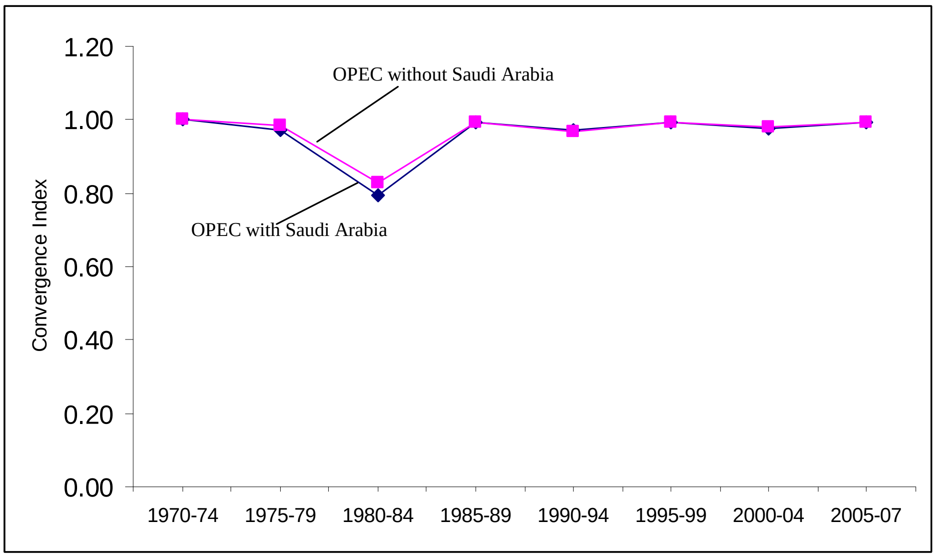


Fig. (5). Dynamic Correlation Index (c_{iT}) for OPEC.

In this paper the VAR model is used to highlight the impact of changes in Saudi Arabia crude oil price on prices of crude oils from other OPEC and non-OPEC countries in two ways: decomposition of the variance in forecast errors and the analysis of impulse shocks. Variance decomposition involves decomposing the variance of the forecasts error into components that can be attributed to each of the endogenous variables. Impulse shocks involve tracing the response of each variable to a shock, or innovation, in one variable in the system.

5. RESULTS

Dynamic Correlation Index

The estimated dynamic correlation indexes (C_{ij} and C_{iT}) are reported in Table **2**, and the graphical representations of the C_{iT} indexes are depicted in Figs. (**5**, **6**). As noted earlier, a coefficient of 1 in Table **2** represents a perfect transmission of price shocks, while a coefficient of 0 represents a short-run invariance to changes in prices elsewhere. Since the short-run effect is in principle unrestricted, C_{iT} greater than unity suggests an over-reaction to changes in prices in the current period. The results for OPEC countries with and without Saudi Arabia show a movement towards perfect transmission of price shocks (Fig. **5**). To the contrary, while the results for non-OPEC countries with Saudi Arabia omitted in the sample suggests a movement close to a perfect transmission of price shocks, the results when Saudi Arabia is included in the analysis suggest an over-reaction to changes in prices (Fig. **6**). The general conclusion here is a case of a perfect transmission of price shock among OPEC and an over-reaction to changes in Saudi Arabian crude oil prices among non-OPEC countries in the short-run[2].

[2] The estimates of individual country's correlation with Saudi Arabia are reported in the Appendix. The results show stronger correlation with Iran (OPEC) and Norway (non-OPEC) crude oil prices, respectively and weaker correlation with Venezuela (OPEC) and the US (non-OPEC), respectively.

Cointegration Analysis

To perform the cointegration analysis of the crude oil price variables, unit root tests are first conducted using the Augmented Dickey-Fuller method; hereafter ADF [46-47]. Whether or not to include the linear trend in conducting unit root tests is still contentious. For instance, McCoskey and Selden [48] indicated that the ADF regressions should not include any linear trend, because the intercept itself already acts as a trend and power is lost in the case of a limited sample. To the contrary, Hansen and King [49] argued that the time trend is evident and must be included to apply the ADF test in its general form. In this paper, unit root tests are performed using equations that incorporate a constant with and without a trend. The non-rejection of the null hypothesis for the unit root indicates that the series is characterized by a random walk representation ([46, 50]).

The findings suggest that the null hypothesis of a random walk in the levels series, when a time trend is included, cannot be rejected in all series (Table **3**). Critical values at the 5 percent level of significance require t-statistics in excess of 3.54 in absolute value for rejection of the null hypothesis ([51] p. 373); here the estimated t-statistics are

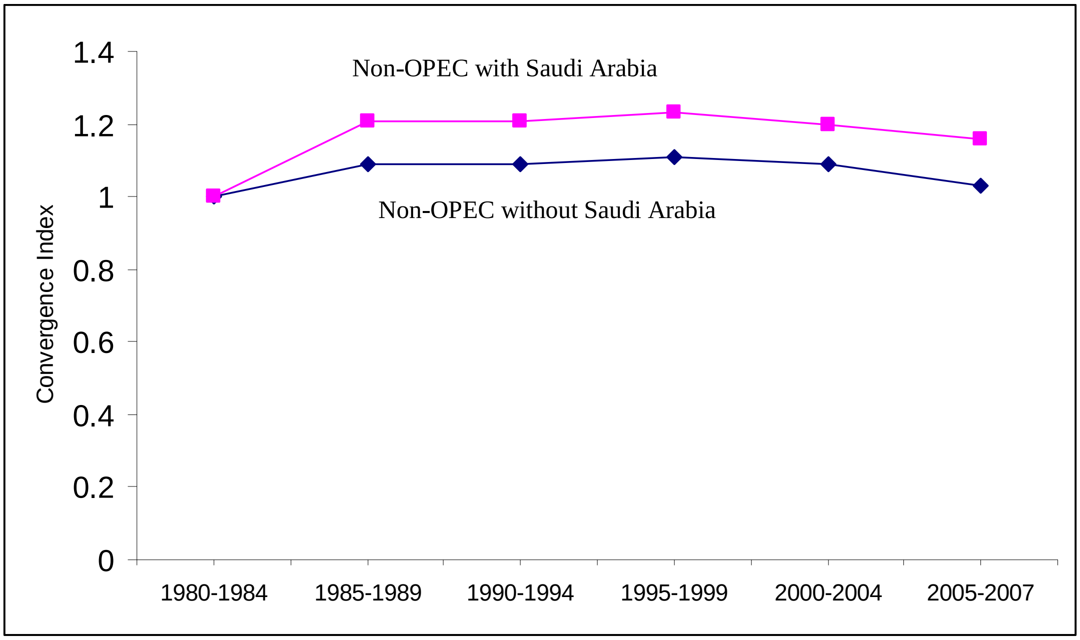


Fig. (6). Dynamic Correlation Index (c_{iT}) for Non-OPEC.

Table 3. Augmented Dickey-Fuller (ADF) Test Results

Series	ADF (Trend)		ADF (No Trend)	
	Levels	1ST Differences	Levels	1ST Differences
OPEC				
Indonesia	-1.03	-4.20*	1.11	-3.83**
Iran	-1.36	-4.25**	0.77	-3.97**
Libya	-1.41	-4.37**	0.70	-4.11**
Nigeria	-1.20	-4.08*	0.90	-3.77**
Saudi Arabia	-1.21	-3.98*	0.93	-3.68**
Venezuela	-1.54	-4.71**	0.78	-4.42**
Non-OPEC				
Canada	-0.45	-6.96**	-0.19	-4.74**
China	0.20	-5.16**	0.66	-3.53**
Mexico	-0.04	-5.56**	0.26	-3.75**
Norway	0.19	-5.08**	0.36	-3.33**
UK	0.14	-5.01**	0.43	-3.38**
US	-0.46	-6.32**	0.06	-4.30**

*(**) denotes rejection of the hypothesis at 5% (1%) significance level, respectively.

below 3.48 in absolute values. To the contrary, the null hypothesis of a random walk in the *first differences* is rejected for all series. That is, the ADF t-statistics on the *first difference* series with a trend for all commodities are all in excess of 5.0 in absolute value. These findings suggest that the *first differences* of all series are stationary.

Turning to the *no time-trend* specification, the results for the *level series* are consistent with the earlier findings for the time trend specification (Table **3**). Under the *no time-trend* specification, an approximate 5 percent critical value of –2.95 is used and the null hypothesis of a random walk in the *levels series* is not rejected since the test statistics are not greater than the critical values for all series. On the contrary, however, the null hypothesis of a random walk in the *first difference* series is rejected for all series. Similar to the trend specification, the *first differences* of each series under the *no time-trend* specification are stationary for all series.

On the basis of the above unit root tests, we conduct cointegration analysis using two alternative techniques: the maximum likelihood method developed by Johansen [42] and Johansen and Juselius [43] and the approach proposed by Bernard and Durlauf [38]. First, we apply the Johansen cointegration test in order to identify the presence of any possible long-run relationships among the variables. As quoted in Gülen [37], Granger [52] notes that at the least sophisticated level of economic theory lies the belief that certain pairs of economic variables should not diverge from each other by too great an extent, at least in the long-run. In our case, one such pair consists of Saudi Arabian crude oil prices and individual OPEC and non-OPEC crude oil prices. If the prices of crude oil from Saudi Arabia lead the prices of crude oils from other countries, then one would not expect other countries' individual prices and Saudi Arabian price to move away from each other, at least in the long-run. This, in turn, would imply a long-term equilibrium relationship between Saudi Arabian crude oil price and prices in other individual countries; implying that these pair of price series should be cointegrated.

The estimated Likelihood Ratio (LR) test statistics and 5 percent critical values are reported in Tables **4** and **5** for OPEC and non-OPEC countries, respectively, with and without a linear trend in the regression. As shown in Table **4**, the results for OPEC, when a linear trend is included in the regression, suggest cointegrating relationship only between Saudi Arabia and Iran crude oil prices. The null hypothesis cannot be rejected for the other country series at the 5 percent level of significance. To the contrary, the null hypothesis of no cointegration can be rejected at the 5 percent level of significance or higher, in all cases, when a linear trend is removed from the regression. This implies the existence of a long-run relationship between Saudi Arabian crude oil price and prices of crude oil in the other OPEC countries under the no-trend specification.

Turning to the non-OPEC countries (Table **5**), the results suggest that when a trend is included, the null hypothesis of no cointegration can be rejected for Mexico and Norway at the 5 percent level of significance and for the US at the 1 percent level of significance. In line with OPEC results, the null hypothesis of no cointegration is rejected, at the 5 percent level of significance or higher, for all series when the linear trend is removed from the regression. In summary, the existence of a long-run relationship between Saudi Arabian crude oil price and prices of crude oils from other OPEC and non-OPEC countries (with no trend) indicates that Saudi Arabia leads crude oil price in the other countries. However, the results when a trend is included in the regression are

Table 4. Johansen Cointegration Test for OPEC

Pairs	Intercept and Trend			No Intercept and No Trend		
	Eigenvalue	LR	Hypothesized No. of CE(s)	Eigenvalue	LR	Hypothesized No. of CE(s)
Saudi Arabia - Indonesia						
	0.428	22.300	None	0.402	19.067	None **
	0.075	2.747	At most 1	0.029	1.047	At most 1
Saudi Arabia - Iran						
	0.472	26.770	None *	0.454	21.499	None **
	0.118	4.409	At most 1	0.009	0.300	At most 1
Saudi Arabia - Libya						
	0.454	24.232	None	0.335	14.734	None *
	0.084	3.068	At most 1	0.013	0.458	At most 1
Saudi Arabia - Nigeria						
	0.434	22.982	None	0.423	19.817	None **
	0.083	3.043	At most 1	0.016	0.550	At most 1
Saudi Arabia - Venezuela						
	0.429	22.153	None	0.316	13.940	None *
	0.069	2.512	At most 1	0.019	0.656	At most 1

*(**) denotes rejection of the hypothesis at 5% (1%) significance level.

Table 5. Johansen Cointegration Test for Non-OPEC

Pairs	Intercept and Trend			No Intercept and No Trend		
	Eigenvalue	LR	Hypothesized No. of CE(s)	Eigenvalue	LR	Hypothesized No. of CE(s)
Saudi Arabia - Canada						
	0.424	24.957	None	0.394	12.886	None *
	0.361	11.186	At most 1	0.014	0.362	At most 1
Saudi Arabia - China						
	0.445	24.192	None	0.426	14.145	None *
	0.315	9.453	At most 1	0.011	0.276	At most 1
Saudi Arabia - Mexico						
	0.528	29.390	None *	0.505	17.559	None **
	0.346	10.609	At most 1	0.000	0.003	At most 1
Saudi Arabia - Norway						
	0.533	27.100	None *	0.505	17.810	None **
	0.275	8.039	At most 1	0.010	0.244	At most 1
Saudi Arabia - UK						
	0.432	21.546	None	0.402	12.959	None *
	0.256	7.399	At most 1	0.004	0.109	At most 1
Saudi Arabia - US						
	0.651	35.729	None **	0.632	25.167	None **
	0.315	9.446	At most 1	0.008	0.207	At most 1

*(**) Denotes rejection of the hypothesis at 5% (1%) significance level.

difficult to interpret; since we find some, but not all of the pairs to be cointegrated.

To conclude whether Saudi Arabian prices lead crude oil prices of other countries, it is probably more appropriate to conduct cointegration test among the group average price and Saudi Arabian price. For that purpose, we use a procedure introduced by Benard and Durlauf [38] and recently used by Bentzen [44] which provides estimation of the relationship between Saudi Arabian crude oil price and the group average price. The results are reported in Table **6**. First, among OPEC countries, the unit root hypothesis is rejected for Saudi Arabia and in all other countries; and in all countries the intercept term is not statistically different from zero, indicating that price differences between Saudi Arabia and all other OPEC will likely vanish over time as the time trend is most likely zero. Similarly, the unit root hypothesis is rejected among the non-OPEC countries. Although the results based on the Johansen's method, when a trend was included, were mixed, the findings in Table **6** show evidence of long-run relationships among OPEC and non-OPEC countries. Next, we present the VAR results.

VAR Measures

The estimated VARs are used to calculate the percentage of the total variation in each endogenous variable that can be explained by innovations in each of the variables. This measure, accordingly, can illustrate the economic significance and the dynamic pattern of the international transmission of Saudi Arabian crude oil prices by providing the percentage of crude oil price variations in each country at time t+k that are due to unexpected changes in crude oil prices in Saudi Arabia at time t. By focusing only on the impact of Saudi Arabian price shocks, we discuss the dynamic property of the price series using variance decomposition and impulse response functions.

Variance Decomposition

The variance decomposition of a vector autoregressive model gives information about the relative importance of the random innovations. It gives information on the percentage of variation in the forecast error of a variable explained by its own innovation and the proportion explained by innovations in other variables. Tables **7** and **8** summarize the results of the variance decomposition of the effects of Saudi Arabian crude oil prices on the prices of crude oils from other OPEC and non-OPEC countries, respectively.

Starting with OPEC countries, Table **7** shows that in addition to explaining 69.2% (on average) of the variation in forecast error by its own innovation (or other factors outside this model), Saudi Arabia explains, on average, 6.1%, 17.0%, 3.1%, 4.0% and 0.6% of the variations in forecast error of Indonesia, Iran, Libya, Nigeria and Venezuela, respectively. This evidence shows that the effect of Saudi Arabian crude oil price, although small (especially in Venezuela), is important in explaining the dynamic behavior of crude oil prices among OPEC countries. The variance

Table 6. Test Statistics for the Convergence (Catching up) Hypothesis

	ADF Test	$\hat{\alpha}$	$\hat{\beta}$	R^2	D-W stat
OPEC					
Indonesia	-5.690**(1)	-0.260	0.021	0.656	2.113
		(-0.391)	(0.703)		
Iran	-4.752**(1)	0.078	-0.008	0.680	1.993
		(0.169)	(-0.400)		
Libya	-6.140**(1)	0.140	-0.005	0.627	2.068
		(0.236)	(-0.199)		
Nigeria	-4.682**(1)	-0.206	0.019	0.632	1.952
		(-0.502)	(1.013)		
Saudi Arabia	-5.339**(1)	0.105	-0.011	0.565	2.083
		(0.226)	(-0.549)		
Venezuela	-4.538**(1)	0.201	-0.017	0.673	1.954
		(0.273)	(-0.514)		
Non-OPEC					
Canada	-7.409**(1)	-0.400*	0.027**	0.78	2.18
		(0.1634)	(0.0098)		
China	-5.638**(1)	0.035	-0.0005	0.71	2.05
		(0.088)	(0.0052)		
Mexico	-6.721**(0)	0.043	-0.0016	0.67	2.24
		(0.063)	(0.0038)		
Norway	-5.724**(1)	0.206	0.0002	0.71	2.21
		(0.502)	(1.0048)		
UK	-7.541**(1)	-0.362**	0.0248**	0.78	2.16
		(0.152)	(0.0092)		
US	-7.833**(1)	-0.404**	0.027**	0.80	2.20
		(0.153)	(0.0093)		
Saudi Arabia	-6.995**(0)	0.026	-0.0013	0.68	1.78
		(0.0249)	(0.0015)		

*(**) denotes rejection of the hypothesis at 5% (1%) significance level, respectively.

decomposition results also illustrate that current movement of crude oil price in Saudi Arabia depends largely upon past performance. Another interesting observation is that the percentage of the variation in the forecast error of crude oil prices in OPEC countries that can be explained by Saudi Arabia innovation increases over time, while the percentages of the variation in the forecast error explained by its own innovation declines.

Turning to non-OPEC countries, Table **8** suggests that in addition to explaining 40.4% (on average) of the variation in forecast error by its own innovation (or other factors outside this model), Saudi Arabia explains, 1.1%, 8.0%, 0.5%, 21.7%, 6.0% and 22.4% of the variations in forecast error of Canada, China, Mexico, Norway, UK and US, respectively. As expected, the effect of Saudi Arabian crude oil price is more important in explaining the dynamic behavior of crude oil prices in the US, Norway, China and the UK than in Canada and Mexico. Again, the percentage of the variation in the forecast errors in non-OPEC countries that can be explained by Saudi Arabia innovation are generally increasing over time, while the percentages of the variation in the forecast error explained by its own innovation declines.

Impulse Responses

Next we present the results for the dynamic property of crude oil price series using impulse response functions. Our interest is in discovering the lags and the signs of these lags, as they measure the impacts of Saudi Arabian crude oil price changes on prices of crude oils from other OPEC and non-OPEC countries. This is best accomplished through impulse response functions that simulate the impacts of a shock of

Table 7. Variance Decomposition for OPEC (1970-2007)

Period	S.E.	Saudi Arabia	Indonesia	Iran	Libya	Nigeria	Venezuela
1	0.247	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.299	89.0%	0.1%	6.7%	2.5%	1.5%	0.3%
3	0.338	77.0%	5.3%	11.4%	4.2%	1.2%	0.8%
4	0.367	75.8%	7.0%	11.2%	3.6%	1.6%	0.7%
5	0.408	66.5%	8.4%	18.6%	3.1%	2.7%	0.7%
6	0.437	63.2%	8.1%	22.5%	2.7%	2.9%	0.6%
7	0.453	60.1%	8.3%	24.4%	3.2%	3.5%	0.6%
8	0.471	55.9%	8.2%	24.8%	3.5%	6.8%	0.7%
9	0.485	53.1%	7.9%	25.4%	3.8%	9.1%	0.7%
10	0.493	51.6%	7.9%	25.6%	3.9%	10.3%	0.7%
Average		**69.2%**	**6.1%**	**17.0%**	**3.1%**	**4.0%**	**0.6%**

Ordering: Saudi Arabia Indonesia Iran Libya Nigeria Venezuela.

Saudi Arabian prices (leaving all variables endogenous) and then compute the predicted dynamic responses of each of the included countries.

Figs. (**7**, **8**) show the response of crude oil prices in OPEC and non-OPEC countries, respectively to a one standard deviation shock to Saudi Arabia crude oil price. The x-axis gives the time horizon or the duration of the shock whilst the y-axis gives the direction and intensity of the impulse or the percent variation in the dependent variable (since we are using logs) away from its base line level. Monte Carlo simulations (with one hundred draws) from the unrestricted VAR were used to generate the standard errors for the impulse response coefficients. The confidence bands for the response function are 90% intervals generated by normal approximation.

Summarizing these results, the OPEC impulses suggest that a positive shock to Saudi Arabia crude oil prices positively leads crude oil prices in the other OPEC countries, persisting for eight periods after which the impact modestly approaches zero. This result implies that crude oil price difference between Saudi Arabia and the other OPEC countries will likely vanish over time and as such, the underlying price series are stationary. In comparison, the impulse results for the non-OPEC countries show that a positive shock to Saudi Arabia crude oil price positively lead crude oil prices for the first four periods, but tapers off afterwards. The negative effect of the shock are most felt in the sixth period, but gradually moves towards zero as we approach the last period. Therefore, the conclusion from the impulse function results is that, though the effect of a one standard deviation shock to Saudi Arabia's innovations is more felt in non-OPEC than in OPEC countries, in the long-run crude oil prices in both OPEC and non-OPEC countries move towards their pre-shock levels; implying a long-term equilibrium relationship between individual country's crude oil price series and Saudi Arabian crude oil prices.

Table 8. Variance Decomposition for Non-OPEC (1980-2007)

Period	S.E.	Saudi Arabia	Canada	China	Mexico	Norway	UK	US
1	0.187	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.266	56.1%	0.2%	0.9%	0.1%	25.3%	4.6%	12.8%
3	0.327	40.6%	1.5%	4.1%	0.5%	24.8%	4.3%	24.2%
4	0.358	36.5%	1.3%	7.3%	0.4%	24.9%	5.4%	24.2%
5	0.383	32.2%	1.3%	9.6%	0.4%	25.1%	6.7%	24.7%
6	0.404	29.7%	1.2%	10.8%	0.5%	24.1%	7.3%	26.3%
7	0.421	28.0%	1.3%	11.4%	0.6%	23.9%	7.7%	27.1%
8	0.432	27.3%	1.3%	11.6%	0.8%	23.3%	8.0%	27.8%
9	0.436	26.9%	1.3%	11.8%	0.8%	22.9%	8.1%	28.2%
10	0.438	27.0%	1.2%	11.9%	0.8%	22.7%	8.2%	28.2%
Average		**40.4%**	**1.1%**	**8.0%**	**0.5%**	**21.7%**	**6.0%**	**22.4%**

Ordering: Saudi Arabia Canada China Mexico Norway UK US.

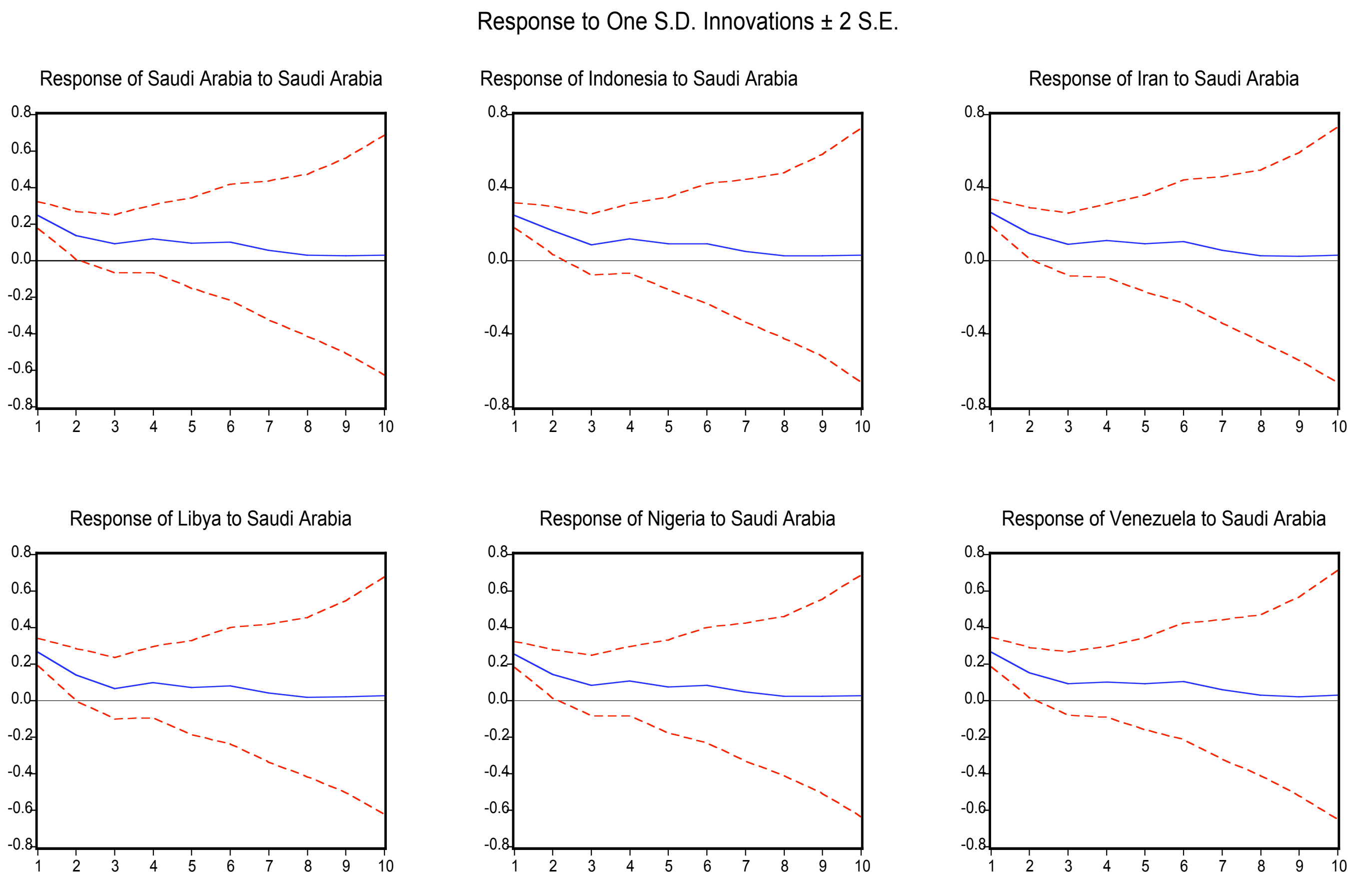


Fig. (7). Impulse response functions for OPEC .

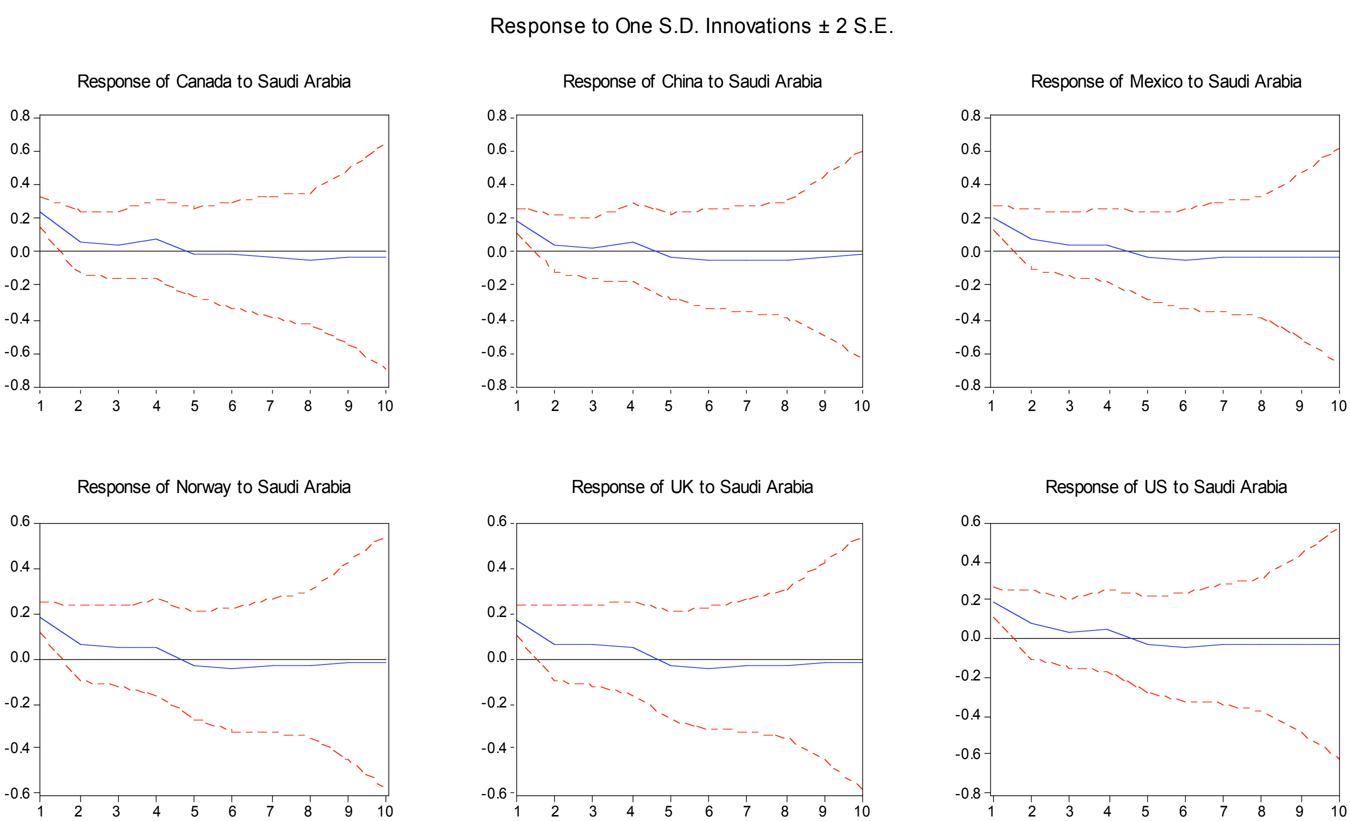


Fig. (8). Impulse response functions for non-OPEC countries.

6. CONCLUSION

If the price of Saudi Arabian crude oil has led the prices of other countries in the world oil market, there would be a long-run equilibrium relationship between each country's crude oil price and Saudi Arabian price. This hypothesis is tested among OPEC and non-OPEC countries using dynamic correlation analysis, cointegration analysis and VAR analysis. Dynamic correlation results showed a case of a perfect transmission of Saudi Arabian crude oil price shock among OPEC and a reaction to changes in Saudi Arabian crude oil price among non-OPEC countries in the short-run. The cointegration results found all country price series to be moving together with Saudi Arabian crude oil price in the long-run. As for the VAR analysis, evidence from the variance decomposition results shows that the effect of Saudi Arabian crude oil prices, although small in some countries, is important in explaining the dynamic behavior of crude oil prices among OPEC and non-OPEC countries. Also, that the percentage of the variation in the forecast errors in OPEC and non-OPEC countries that can be explained by Saudi Arabia innovation are generally increasing over time.

Finally, the impulse function results suggest that, although the effect of a one standard deviation shock to Saudi Arabia's innovations is more felt in non-OPEC than in OPEC countries, in the long-run crude oil prices in both OPEC and non-OPEC countries move towards their pre-shock levels; implying a long-term equilibrium relationship between individual country's crude oil prices and Saudi Arabian crude oil prices. Thus, the overall finding is evidence of a long-run equilibrium between Saudi Arabian crude oil price and prices in other OPEC and non-OPEC countries, over the studied period.

APPENDIX

Table 9. Correlation Coefficient Estimates: Saudi Arabia versus OPEC and non-OPEC Countries

Period	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-07	1970-2007
OPEC (1970-2007)									
Indonesia	0.997	0.950	0.957	0.992	0.973	0.996	0.921	0.988	0.988
Iran	1.000	0.971	0.523	0.993	0.999	1.000	0.984	0.999	0.990
Libya	1.000	0.943	0.429	0.996	0.998	0.989	0.989	0.998	0.986
Nigeria	1.000	0.957	0.764	0.996	0.998	0.989	0.977	0.999	0.990
Venezuela	1.000	0.928	0.970	0.997	0.953	0.991	0.979	0.998	0.982
Non-OPEC (1980-2007)									
Canada	---	---	0.314	0.983	0.988	0.992	0.986	0.937	0.934
China	---	---	0.852	0.957	0.968	0.996	0.925	0.994	0.981
Mexico	---	---	0.466	0.971	0.993	0.997	0.979	0.998	0.984
Norway	---	---	0.590	0.991	0.998	0.988	0.981	0.998	0.986
UK	---	---	0.818	0.989	0.996	0.993	0.948	0.998	0.985
US	---	---	0.503	0.963	0.950	0.993	0.941	0.852	0.885

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