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Lead-Lag Relationships between World Crude Oil Benchmarks: Evidence from West Texas Intermediate, Brent, Dubai and Oman

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Abstract

In this paper, we examine whether world's crude oil benchmarks (West Texas Intermediate in North America, Brent crude in Europe, and Dubai and Oman crude oil prices in Asia) are stationary as well as whether there exist a long-run equilibrium relationship between the three major oil markets in the three enclaves. The study period is from January 1st, 1990 through November 19, 2010, totally 5450 daily samples. We find that the prices of the four main crude oil benchmarks are cointegrated; indicating that in the long run the world oil market is unified rather than regionalized. We also find that Western oil markets (WTI and Brent) lead East-of-Suez (EOS) markets (Dubai and Oman). Specifically, this study found that WTI significantly leads Brent, Dubai and Oman crude oil prices; Brent significantly leads Dubai and Oman crude oil prices; and Oman moderately leads Dubai crude oil prices. This also paper concludes that in the long-term the prices of the four (WTI, Brent, Dubai and Oman) crude oil main markers will reach equilibrium. Our cointegration and VECM results are consistent with the one-great-pool concept advocated by Adelman.

Keywords: WTI, Oman, Dubai and Brent Crude Oil prices; VECM; lead-lag relationship; Cointegration;

1. Introduction

The price of crude oil is undoubtedly the most important commodity price in the world. The world market of crude oil has four major international benchmarks used for pricing of other crudes: two in the West - West Texas Intermediate (WTI) in the US and Dated Brent in Europe, and two in Asia - Dubai and Oman. These benchmarks play a major role in the oil price discovery process for most of the crude oil sold in both the spot and term markets. Crude oil benchmark grades are also critical in defining spot values of related crude oils and represent key price variables in many term contract price formulae. Term sellers use these benchmarks to price their crude oil exports after making adjustments related to differences in qualities and locations. In addition, they are the basis for most hedging and risk management efforts, and attract the bulk of speculative trading interest. They serve as the chief reference levels for crude oils of similar quality and in similar locations, providing a focus for increased trading and a rise in market liquidity. These benchmarks also provide the main marginal pricing signals for the world oil industry as they are among the last barrels sold to refiners, reflecting the immediate supply pressure facing buyers. Crude sellers use marginal pricing – as in theory, the last barrel that comes to the markets determines the price of all barrels during that day -as an integral part of their crude oil pricing methodologies. These international crude oil pricing benchmarks have a significant impact on everything from oil's company's share price to its investment plans. Crude oil benchmarks are also one of the main barometers for measuring OPEC's success at balancing global supply and demand. While it's true that OPEC has already abandoned its "price band" target, preferred prices are routinely mentioned by OPEC's oil ministers as a gauge for the tightness of world oil supply demand fundamentals.

Moreover, crude oil, and mainly because of its direct consequences on everyone's personal life, can be a much important as food. Petroleum products, notably gasoline and diesel and jet fuel, is required for transport. Various developing country governments have made a decision to subsidize these transportation fuels below world prices because of less than favorable economic consequences for its citizens. From consumers' perspective, high oil prices make industrial productions more expensive and result in higher inflation. Fluctuations in oil prices, not necessarily higher prices, result in lower profitability in the refining and airline industries, and the population and the economy at large will face cost pressures. Consumers as well, will have to change their behavior when faced with higher transportation cost. From producers' perspective though, weaker prices result in lower investments in additional production capacity and will eventually result in higher oil prices, as the market will not be immune from sudden spikes in oil prices due to dwindling production capacity.

Economically, volatility in crude oil prices can have important ramifications on the global economy. In a buyers' market, it has a profound effect on the economies of most producing countries, where low prices frequently require a rapid reduction in national governments' budgets. In a sellers' market, usually a strong market, economic consequences, such as inflationary pressures can be unbearable for some countries. Especially during these times of higher oil prices, consultants and researchers alike are asked to provide explanation not only for high oil prices but also relationships between prices in the main three continents, i.e., America Europe and Asia.

In this article, we investigate the interaction between the four international crude oil benchmarks, and utilize the prices of WTI, Brent, Dubai and Oman oil to discuss whether the prices series are stable, and discover whether there exists a long-run equilibrium relationship in the oil markets. If these international oil benchmarks are found to be cointegrated, then we can conclude that in the long run the world market is unified and homogenous. If these prices deviate from each other however, then the market is fragmented and regionalized. Furthermore, through the impulse response function, we explore the dynamic process for current and future phases on the oil price and its endogenous variables.

2. Literature Review

The question of whether crude oil produced in different countries or locations constitutes a unified (or homogeneous) world oil market is one interesting academic topic. The hypothesis is presented in Weiner (1991) who, based on empirical tests of oil price adjustments across regions, concludes that the world crude oil market is far from unified, that is, crude oil prices do not move together around the world. Contrary to these empirical findings, Adelman (1984, 1992) rejects the Weiner regionalization hypothesis and argue that if the price differential between crude oil from two different regions is less than the transaction cost among the same regions – and hence no needs for shipping of oil –the oil market will be unified.

There are many studies support the point of view of Adelman (1984, 1992). Gülen (1997, 1999) reported evidence consistent with globalization, as oil prices in different markets were co-integrated and moved together even in the short run. Ewing and Harter (2000) find that the crude oil prices of Alaska North Slope and Brent share a long-run common trend and that the markets are unified, which is also generally supported by Kleit (2001), who concludes the oil markets becoming more integrated. Sauer (1994) examined the extent of regionalization in the world market for crude oil imports and concluded that empirical results lend support to Adelman's characterization of the world oil market as "one great pool'. Adelman's view is also held by Hogan (1983) who noted that the essential international character of an oil stockpile derives from inherent fungibility of oil in the world markets. Rodriguez and Williams (1993) provided strong evidence in support of Adelman's conjecture of homogeneous world oil markets. He argues that the oil markets act as "one great pool" and this result does not depend on the choice of empirical methodology. The findings of Reboredo (2011) suggest that crude oil prices are linked with the same intensity during the bull and bear markets, thus supporting the hypothesis that the oil market is 'one great pool' – in contrast with the hypothesis that states that the oil market is regionalized. Hammoudeh et al. (2008) also found a long-run equilibrium relationship between different oil benchmark prices. Fattouh (2010) argues that the different oil markets are linked and his findings support the 'one great pool' or the 'globalization' hypothesis.

Mossavar-Rahmani (1988) concludes from his research that world's oil markets are "regionalized" and therefore changes in supply or demand amongst the participants in a limited geographic area do not fully "register" in other geographic markets. Milonas and Henker (2001) concluded that oil markets were not totally integrated. More recently, Fattouh (2010) considered crude oil price differentials for different grades in terms of a two-regime threshold autoregressive process, finding strong evidence of threshold effects in adjustments to long-run equilibrium, which implies that markets are not necessarily integrated in every time period. Spiller and Huang (1986) argued that crude oil markets are regional in character.

3. Methodology

The basic relationship to be investigated when analyzing relationships between each of the two different crude oil benchmark prices (CP*1*) and (*CP2*) observed at time *(t)* is

$$\ln CP_{1t} = \alpha + \beta \ln CP_{2t} \tag{1}$$

where α is a constant term to capture differences in the levels of the prices and β gives the relationship between these prices. If β=0, there is no relationship between the prices and if β=1, the spreads are constant and therefore the two are perfect substitutes. If $\beta\neq 0$ and $\beta\neq 1$, then there exists a relationship between the prices, but the spread or the relative price is not constant.

Undoubtedly, the cointegration analysis is the appropriate tool to infer causal long-run relationships between nonstationary time series. If each of the two crude oil prices is nonstationary, then they are required to be differenced once to produce a stationary series. In general, a linear combination of nonstationary data series will be nonstationary. In this case there is no long-run relationship between the data series. However, when the data series form a long-run relationship, the data series will move together over time and a linear combination of the data series,

$$CP_{1t} - \psi\, CP_{2t} = \varepsilon_t \, , \tag{2}$$

will produce a residual series ε_t which is stationary. In this case, the first crude oil benchmark, for example WTI, and the second crude oil marker, for example Brent are said to be cointegrated, with the vector [1,ψ] as the cointegration vector (Engle and Granger, 1987).

We first examine first the stationarity properties of the univariate time series using the Augmented Dickey-Fuller (ADF) (1981) unit root test and the Phillips-Perron (PP) (1988) test to examine the stationarity of the data series. The ADF test consists of running a regression of the first difference of the series against the series lagged once, lagged difference terms, and optionally, a constant and a time trend, and it can be expressed as follows:

$$\Delta_{yt} = \beta_{1yt\text{-}1} + \beta_2\Delta_{yt\text{-}1} + \beta_3\Delta_{yt\text{-}2} + \beta_4 + \beta_{5t} \tag{3}$$

If the coefficient yt-1 is significantly different from zero then the hypothesis that y contains a unit root is rejected and rejection of the null hypothesis implies stationarity. The PP root test is also based on Equation (1), but without the lagged differences. Banerjee et al. (1993) suggests that the PP unit root test is generally has greater power than the ADF test.

Then, we examine the time series for cointegration. If a cointegration relationship is identified, the model should include residuals from the vectors (lagged one period) in the dynamic Vector Error Correcting Mechanism (VECM) system. Johansen (1988, 1992) cointegration test is used to identify a cointegrating relationship among the variables. The Johansen multivariate cointegrating system is estimates the following equation:

$$\Delta_{z_t} = \Gamma_1 \Delta_{z_{t-1}} + \ldots + \Gamma_{k-1} \Delta_{z_{t-k-1}} + \Pi_{z_{t-1}} + \mu + \varepsilon_t : t = 1, \ldots T \tag{3}$$

where Δ is the first difference operator, z denotes a vector of variables, εt ~ niid (0, Σ), μ is a drift parameter, and Π is a (p x p) matrix of the form Π = α β', where α and β are both (p x r) matrices of full rank, with β containing the r cointegrating relationships and α carrying the corresponding adjustment coefficients in each of the r vectors.

We then carry out Granger causality tests; the trace statistic and the maximum Eigenvalue test. The null hypothesis is that there are r cointegrating vectors, against the alternative of r + 1 cointegrating vectors. Johansen and Juselius (1990) indicated that the trace test might lack power relative to the maximum Eigenvalue test. Based on the power of the test, the maximum Eigenvalue test statistic is often preferred. According to Granger (1969, 1980, 1988), Y is said to "Granger-cause" X if and only if X is better predicted by using the past values of Y than by not doing so with the past values of X being used in either case. In short, if a scalar Y can help to forecast another scalar X, then we say that Y Granger-causes X. If Y causes X and X does not cause Y, it is said that unidirectional causality exists from Y to X. If Y does not cause X and X does not cause Y, then X and Y are statistically independent. If Y causes X and X causes Y, it is said that feedback exists between X and Y.

4. Empirical Results

In this paper, we apply the US marker grade West Texas Intermediate, the European and African crude oil marker grade (Brent), the Middle East and high sulfur benchmark Dubai crude oil and Oman crude oil marker grade daily prices. The study period extends from January 1st, 1990 through November 19, 2010, totally 5450 daily samples. From Figure 1 we observe that there's rising trend since 2000 in oil prices, and a steep rise in 2007. However, in July 2008 the prices fell sharply, implying that the series may be non-stationary. Thus, we apply the unit root tests to examine whether the series are stationary. Furthermore, we apply the co-integration tests and the vector error correction model (VECM) to discuss whether there exists a long-run equilibrium relationship and the lead-lag relationship in WTI, Brent, Dubai and Oman oil prices.

Figure 1: WTI, Brent, Dubai and Oman Daily Oil Pries

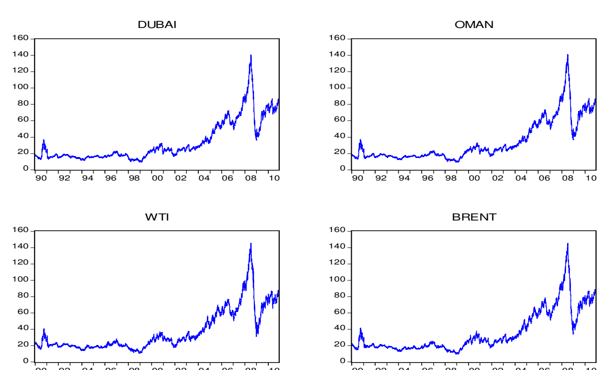

Figure 1: WTI, Brent, Dubai and Oman Daily Oil Pries - continued

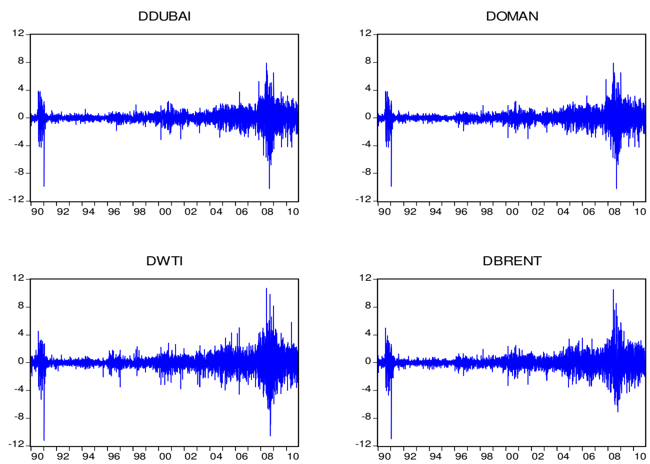

Table 1 shows the descriptive statistics of the four series. The mean, median, max and minimum and standard deviation values of the Eastern oil benchmarks (Dubai and Oman) are all larger than Western crude oil benchmarks (WTI and Brent). Furthermore, the skewness is larger than zero for all four oil benchmarks series representing skewed to the right. Kurtosis values for all four benchmarks are larger than 3 meaning that the series are leptokurtic and fat-tail distributions. Significant Jarque-Bera statistics shows that series of WTI, Brent, Dubai and Oman are all not normally distributed.

Table 1: Descriptive statistic is of Oil Benchmarks

	WTI	Brent	Dubai	Oman
Mean	33.60708	34.04823	37.23548	36.05330
Median	23.29500	23.52000	26.40500	24.98000
Maximum	140.7700	141.3000	145.3100	145.5100
Minimum	9.380000	9.390000	10.70000	9.640000
Std. Dev.	24.75898	24.86345	25.27978	25.46882
Skewness	1.519315	1.510809	1.493522	1.472984
Kurtosis	4.827725	4.799576	4.817782	4.683708
Jarque-Bera	2855.313	2808.714	2776.493	2614.547
Observations	5450	5450	5450	5450

The order of integration of each series in question is determined by performing augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests in order to determine if the variables can be entered into a cointegration system. The lag length for the augmenting term is selected according to Schwarz information criterion (SIC) in a way to make the error term as much white noise as possible. From Table 2, it is clear that we cannot reject the null hypotheses that there exists unit root in Dubai and Brent oil prices series. That is, they are non-stationary series. We also find that the two series are I (1) from the difference item. Thus, they are non-stationary series with the same interegrating order. So we may apply the co-integration tests to examine whether there exists a long run relationship between the two oil markets.

Table 2: Unit Root Test

Variable	ADF		PP	
	level	1st difference	level	1st difference
Brent	-0.905231	-70.90392**	-0.877939	-70.87632**
Dubai	-0.690038	-76.40546**	-0.737035	-76.37520**
Oman	-0.673029	-75.94462**	-0.735453	-75.96470**
WTI	-1.170171	-76.34054**	-1.092942	-76.37232**

**means reject the null hypothesis (the data has a unit root) at 1% significance level

Next, the Johansen test for cointegration is applied to the multivariate system to check on whether there exist any linear combinations of the variables that have a stochastic common trend. Since the Johansen test is quite sensitive to the lag length selected, the most commonly used criteria such as AIC, SIC, sequential likelihood ratio (LR) are utilized to determine the proper lag length. According to the SC information selection criteria, the most suitable lag is 5 for WTI and Brent, the most suitable lag is 6 for WTI and Dubai, the most suitable lag is 6 for WTI and Oman, the most suitable lag is 5 for Brent and Dubai, the most suitable lag is 5 for Brent and Oman, the most suitable lag is 4 for Dubai and Oman. Results of maximal Eigen value test and the trace test of Johansen are shown in Table 3. Under 1 % significant level, the trace test and maximal Eigen value test for all series show that we can reject the null hypothesis that r=0, however, cannot reject the null hypothesis that r≤1. Such results show that there is a cointegration vector, representing a long-run equilibrium relationship exists between these prices.

As mentioned above, there is a long-run equilibrium between the four crude benchmarks. Based on the results from the maximal Eigen value test and trace test, the specifications for the individual variables in the error-correction VAR model and the relevant diagnostic statistics are shown in Table 4A, table 4B, table 4C, table 4D, table 4E and table 4F in the appendix. As shown in Table 4A, WTI leads Brent from the estimated results of VECM. We also carry out an impulse response analysis of error-correction system to examine the responses of Brent to random shocks from WTI. Figures in the appendix show the Impulse Responses of Brent to one standard deviation shock in both Brent and WTI for up to 10 periods. We conclude that one standard deviation random shock in WTI will cause the change of Brent price. In contrast, , one standard deviation random shock in Brent will not cause violate change in the WTI price and the influence is moderate.

Table 3: Johansen Cointegration Tests (Trace test & Max-Eigen test)

Commodity	Test statistics	HO: No cointegration relation	HO: At most one cointegration relation
WTI/Brent	Trace Statistics	130.4083**(0.0001)	0.775765 (0.3784)
	Max-Eigen Statistics	129.6325**(0.0001)	0.775765 (0.3784)
WTI /Dubai	Trace Statistics	52.98818**(0.0000)	0.486778 (0.4854)
	Max-Eigen Statistics	52.50140**(0.0000)	0.486778 (0.4854)
WTI /Oman	Trace Statistics	62.27693**(0.0000)	0.481154 (0.4879)
	Max-Eigen Statistics	61.79578**(0.0000)	0.481154 (0.4879)
Brent/Dubai	Trace Statistics	45.82469**(0.0000)	0.477064 (0.4898)
	Max-Eigen Statistics	45.34763**(0.0000)	0.477064 (0.4898)
Brent/OmanBrent/Oman	Trace Statistics	65.03726**(0.0000)	0.500560 (0.4793)
	Max-Eigen Statistics	64.53670**(0.0000)	0.500560 (0.4793)
Dubai/ Oman	Trace Statistics	125.7402**(0.0001)	0.442924 (0.5057)
	Max-Eigen Statistics	125.2973**(0.0001)	0.442924 (0.5057)

** denotes rejection of null hypothesis at 1% significance level. Numbers in the parentheses are the p-values of the testing result.

As for WTI and Dubai, and as shown Table 4B in the appendix, we conclude that WTI leads Dubai from the estimated results of VECM. Also shown in the appendix, the Impulse Responses of Dubai to one standard deviation shock in both Dubai and WTI show that one standard deviation random shock in WTI will cause significant changes to Dubai. However, one standard deviation random shock in Dubai WTI will not cause violate change in the WTI price and the influence is moderate. For WTI and Oman, we conclude that WTI leads Oman. From the Impulse Responses relationship, shown in the appendix, one standard deviation random shock in WTI will cause significant changes to Oman price. In contrast, as we can see from the above figure, one standard deviation random shock in Dubai will cause moderate changes in the WTI price.

As for Brent and Dubai, and according to the t-statistics of the VECM model shown in the appendix, we can conclude that Brent leads Dubai from the estimated results of VECM. The Impulse

Responses of Dubai and Brent shows that one standard deviation random shock in Brent will cause significant changes to Dubai. In contrast, as we can see from the above figure, one standard deviation random shock in Brent will only cause moderate change in Brent price. We also find that Brent leads Oman and one standard deviation random shock in Brent will cause very significant changes to Oman price while one standard deviation random shock in Oman will cause moderate change in Brent price. Finally, our analysis concludes that Oman moderately leads Dubai. As per the Impulse Responses relationship shown in the appendix, one standard deviation random shock in Oman will cause moderate change to Dubai while one standard deviation random shock in Dubai will cause only moderate change in the Oman price.

5. Policy Implications

If world oil markets behave as “one great pool”, where changes in market conditions in one area quickly affect other geographical areas, policy implications with regards to the effectiveness of national oil policies, such as crude oil and refined products strategic storages, security of supply, diversification of sources of supply and changes in regional supply/demand fundamentals will be far reaching. How policy makers perceive world oil markets, whether homogenous or heterogeneous, and the policies they pursue to attain “secure sources of supply” and “import diversification”, in addition to other various energy policies, such as tariffs on imported oil, China’s increasing efforts with regards to buying energy assets abroad as well as middle east producers’ regional crude oil pricing, are all issues of interest to market analysts and participants. Generally speaking, suppliers assume world oil markets are mostly regionalized and consumers contend those markets are more or else unified.

This debate of whether world oil markets are unified or regionalized has commercial and strategic ramifications with regards to the energy security concerns, import vulnerability and the desire among some consuming countries to achieve "energy independence”. A unified market makes the self-reliance in energy seems a simplistic view which not only fails to recognize the realities of energy markets and the fungiblity of oil and gas as commodities, but also ignores basic economic fundamentals, the mutual benefits that come with cross-border trade, and the highly integrated nature of today's global economy. The fact is that the full range of essential commodities and necessary resources are simply not available in sufficient economic quantities in the various regions of the world. Also, the notion of self-sufficiency defies the principles of market economics, which dictate that we should produce things where it is most economical to do so, and that larger markets offer a greater number of opportunities and choices for producers, consumers and investors. In a nutshell, a homogenous market is in favor of replacing independence with interdependence.

WTI’s leadership of the world crude oil prices, even though it remains an isolated marker from the rest of the global market, is of great interest to other regions, especially those in Asia accounting for the majority of oil demand growth now and in the future. This paper’s conclusion that WTI leads and influences Brent price and therefore influences all of those who price their crude oil based on Brent, as well as leads Dubai and Oman both directly and indirectly through Brent, shows that influence may be advantageous to some while costly to others. Since WTI price can be affected by a small pipeline ruptures, refinery outages, trading squeezes or stock levels, the consequences of this leadership –due to inclusion in term contract price formulas- are both financial and strategic. While WTI is the most visible, highly-traded crude oil in the world, it remains a landlocked US domestic grade that never appears on the world market and only competes with internationally traded crude oils when they are imported into the US. Middle East producers, upon complaints from refiners in the America, have recognized these limitations and switched from WTI to linkage to the new ASCI for their US sales in January 2010.

That however still leaves consumers in Asia under the influence of WTI’s leadership and volatility. As this study proved, Asian refiners will pay more for their international oil purchases, including African Brent-based barrels and Middle East barrels, because of WTI’s influence and leadership of other oil benchmarks. Asian consumers, and instead current oil benchmarks such as Dubai and Oman that are located in the producing center of the Middle East and influenced by market developments in the US and Europe, should develop their own regional benchmarks in the consumer center, may be China or Japan, similar to western benchmarks (WTI and Brent). The newly developed benchmark(s) in the Far East should delink themselves from short term developments either related to WTI or Brent and reduce as much as possible the influence of the Brent-Dubai spread and may even be advantageous to consumers in terms of better freight economics.

The conclusion of unified oil markets is not consistent with Middle East producers' "regional pricing". Regional pricing is based on the premise that regional markets have their own supply/demand balance and fundamentals and therefore crude oil pricing should be reflective of those regional forces. Asian refiners believe the current "regional pricing", which is based on geographic destination, regional benchmarks and marginal economics, may not be in their favor. In a globalized efficient market, a consumer away from the demand center would be required to shoulder transporting the said commodity to his location. The shorter the distance from the consuming center, the lower the freight cost and the more competitive the market is. As far as Asia is concerned, the introduction of a new marker through participation of Asian refiners will surely minimize, if not eliminate, the influence Western benchmarks and make oil pricing truly reflective of Asian market forces.

Within Asia, the conclusion that Dubai is moderately led by Oman confirms that Dubai crude oil, with its dwindling volumes, has been undermined as a reliable benchmark and the neighboring Oman grade is starting to dominate the market Adding to Oman's appeal is the launch of an Oman futures contract on the Dubai Mercantile Exchange (DME), which is working hard to elevate Oman to benchmark status, although the market has seemed reluctant so far to fully embrace Oman. This paper confirms that Oman crude is East of Suez marker in the making. The acceptance of Oman futures, as a benchmark for sour crude trade in the Middle East and Asia, has been lately growing across the industry, although concerns still remain about liquidity.

In a homogenous world market, the construction of national strategic petroleum reserve (SPR) would be regarded as an effective policy since these markets will be immune from the vagaries of disruptions in regional as well as international markets. In integrated markets, consuming countries will be able to use their crude and refined products stockpiles to offset higher prices resulting from supply distributions. The release of crude and products from OECD's stockpiles during the Libyan crisis is a good example of the effectiveness of SPR release in a "one great pool" market. As most of the Libyan crude production is sweet type, unlike OPEC's additional capacity, which is sour crude, the release of SPR was instrumental in tempering peaks in oil prices. Most probably, in a regionalized market, these efforts would have been less effective.

Also, crude supply diversification policies in a unified market make a lot of sense. Consumers with huge appetite for oil, such as China, see a huge value in diversifying crude oil sources not only to reduce the risk of costly supplier behavior, but also to ensure availability in case of supply disruption. In energy guzzling economy like China, diversification of supply sources ensures minimizing the price risk associated with dependence on a single supplier. In a homogenous market, efforts such as China's diversifying its energy sources through the construction of pipelines to transport oil from Kazakhstan and Russia makes a lot of sense as it competes with Europe on sourcing energy from these areas. Driven by the assumption that world oil markets are homogeneous, and the corresponding competition for energy resources, the Chinese believe that cross-border pipelines are much safer than the transportation routes of seaborne oil, especially as the west controls most of the check points along the strategic waterways.

Undoubtedly, China's overall dependence on imports will continue to grow as demand grows and production plateaus. This explains the increased energy ties between China and major oil producers. The former will most probably account for the majority of future oil demand growth, while the latter will account for the majority of future production growth. The assumption that these energy ties between China and oil producing countries will result in above market prices is at least problematic. Oil is fungible commodity, where total demand and supply will be much more important than relationships, and will eventually compete only on the basis of price and/or availability

6. Conclusion

This study investigates the interaction between the four international crude oil benchmarks - WTI, Brent, Dubai and Oman. These four crude oil markers play a major role in determining the final price of this important commodity. The importance and cost of this commodity has direct consequences on everyone's personal life. This study found a long-run equilibrium relationship between these markers located in different oil markets. As these international oil benchmarks were found to be cointegrated, then we can conclude that in the long run the world market is unified and homogenous. Furthermore, through the impulse response function, we conclude that WTI significantly leads Brent, Dubai and Oman; Brent significantly leads Dubai and Oman; and Oman moderately leads Dubai.

The empirical results reported here lend support to Adelman's characterization of the world oil market as "one great pool". Policy implications from this conclusion include the preference for interdependence over independence between producers and consumers, inconsistency of the producers' regional pricing, the legitimacy of strategic petroleum reserves (SPRs) as well as supply diversification policies. The conclusion that WTI and Brent lead Asian benchmarks (Dubai and Oman) means Asian refiners will pay more for their international oil purchases. The need therefore for an Asian oil benchmark, preferably in close proximity to the largest consuming centers in the Far East, is of high importance. Clearly as influence from West of Suez benchmarks would directionally result in lower prices of imported oil for Asian countries. Finally a unified market confirms the fungibitly of the oil commodity (price and availability), highlighting the importance of supply/demand over relationships. All energy agreements and ties between producers and consumers will have to pass the litmus test of any fungible commodity and eventually compete on the basis of price and availability.

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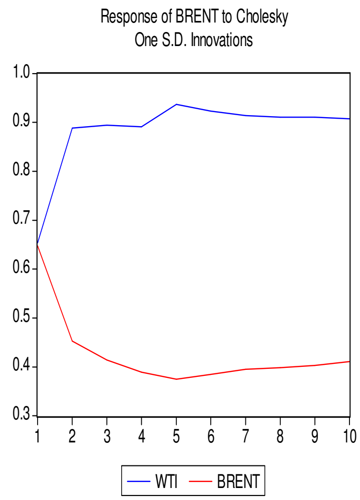
Appendix

Table 4A: Error-Correction Models for WTI and Brent

	D(WTI)		D(BRENT)	
	Coefficients	t-value	Coefficients	t-value
ECM	0.060100*	[-5.91673]	0.022930*	[2.68212]
D(WTI(-1))	-0.004468	[-0.21864]	0.370968*	[21.5694]
D(WTI(-2))	-0.015223	[-0.69186]	0.162159*	[8.75658]
D(WTI(-3))	0.064609*	[2.96172]	0.108118*	[5.88878]
D(WTI(-4))	0.115422*	[5.70235]	0.099933*	[5.86605]
D(BRENT(-1))	-0.018072	[-0.76235]	-0.277326*	[-13.9001]
D(BRENT(-2))	-0.000480	[-0.01978]	-0.143218*	[-7.01223]
D(BRENT(-3))	-0.104173*	[-4.37637]	-0.108096*	[-5.39564]
D(BRENT(-4))	-0.074612*	[-3.52186]	-0.046147*	[-2.58811]
Intercept	-0.011300	[0.76258]	0.009938*	[0.79687]
R-squared	0.014602		0.103705	
Adj. R-squared	0.012970		0.102221	
F-statistic	8.948796		69.87263	
Log likelihood	-8206.075		-7267.342	



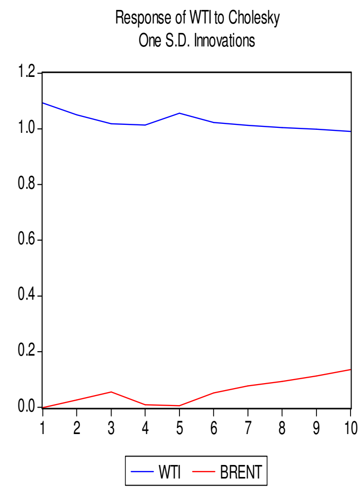
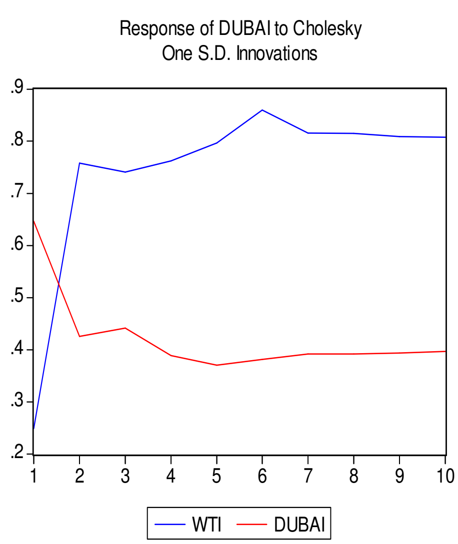


Table 4B: Error-Correction Models for WTI and Dubai

	D(WTI)		D(Dubai)	
	Coefficients	t-value	Coefficients	t-value
ECM	-0.027771*	[-4.49016]	0.014487*	[3.70197]
D(WTI(-1))	-0.023479	[-1.53660]	0.528089*	[54.6206]
D(WTI(-2))	-0.028671	[-1.46759]	0.176966*	[14.3160]
D(WTI(-3))	0.042374	[2.13218]	0.105169*	[8.36343]
D(WTI(-4))	0.087490*	[4.44317]	0.096539*	[7.74831]
D(WTI(-5))	-0.005645	[-0.30300]	0.077280*	[6.55609]
D(Dubai(-1))	0.037890	[1.63490]	-0.326571*	[-22.2698]
D(Dubai(-2))	-0.051441	[-2.12153]	-0.112343*	[-7.32249]
D(Dubai(-3))	-0.060335	[-2.49666]	-0.087886*	[-5.74755]
D(Dubai(-4))	-0.057487	[-2.43997]	-0.059596*	[-3.99759]
D(Dubai(-5))	0.009788	[0.55132]	0.002783	[0.24774]
Intercept	0.011725	[0.78996]	0.008185	[0.87152]
R-squared	0.012249		0.399759	
Adj. R-squared	0.010249		0.398543	
F-statistic	6.123841		328.8812	
Log likelihood	-8210.703		-5719.049	

*denotes rejection of null hypothesis at 10% significance level



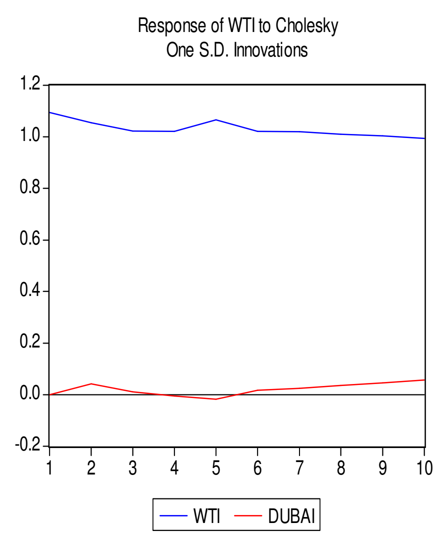
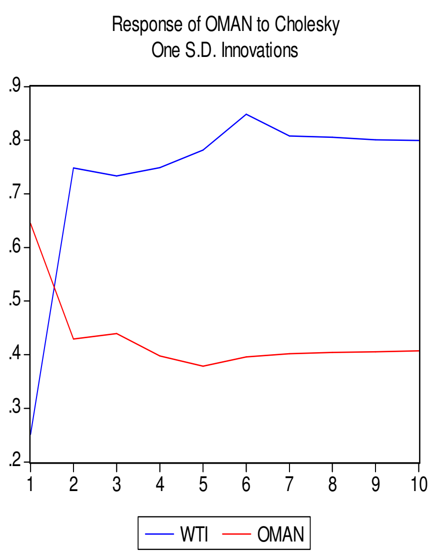


Table 4C: Error-Correction Models for WTI and Oman

	D(WTI)		D(Oman)	
	Coefficients	**t-value**	**Coefficients**	**t-value**
ECM	-0.031677*	[-4.74180]	0.017419*	[4.12741]
D(WTI(-1))	-0.018777	[-1.21754]	0.512414*	[52.5910]
D(WTI(-2))	-0.026554	[-1.36714]	0.168636*	[13.7427]
D(WTI(-3))	0.029266	[1.48451]	0.095295*	[7.65134]
D(WTI(-4))	0.080221*	[4.10671]	0.089913*	[7.28575]
D(WTI(-5))	-0.010006	[-0.54119]	0.077047*	[6.59591]
D(Oman(-1))	0.026505	[1.13899]	-0.315727*	[-21.4758]
D(Oman(-2))	-0.029867	[-1.23156]	-0.108566*	[-7.08600]
D(Oman(-3))	-0.047322	[-1.95752]	-0.083872*	[-5.49167]
D(Oman(-4))	-0.047346	[-2.00713]	-0.059361*	[-3.98325]
D(Oman(-5))	0.007002	[0.39003]	0.007857	[0.69277]
Intercept	0.011550	[0.77770]	0.008283	[0.88285]
R-squared	0.011108		0.387524	
Adj. R-squared	0.009105		0.386283	
F-statistic	5.546925		312.4466	
Log likelihood	-8213.846		-5713.781	

*denotes rejection of null hypothesis at 10% significance level



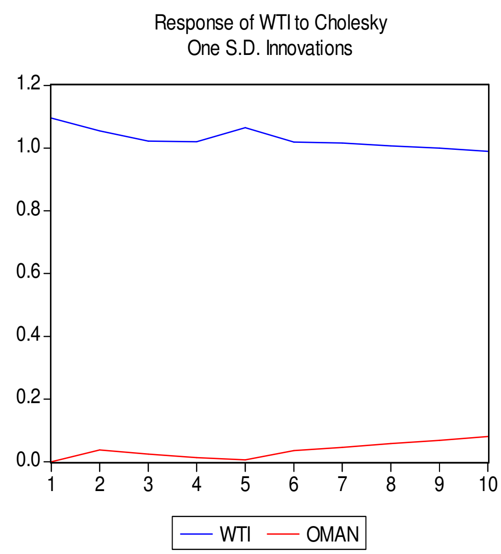
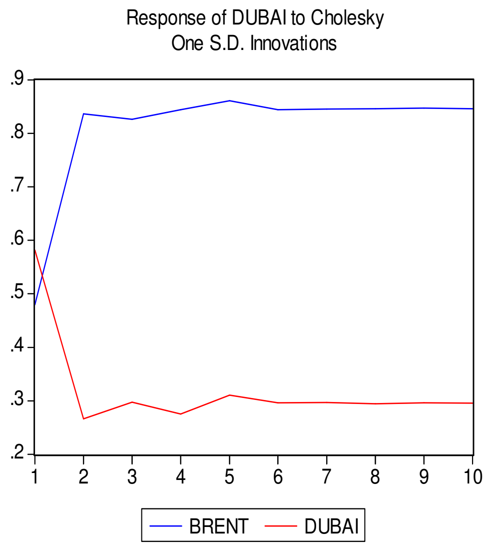


Table 4D: Error-Correction Models for Brent and Dubai

	D(Brent)		D(Dubai)	
	Coefficients	**t-value**	**Coefficients**	**t-value**
ECM	-0.015953*	[-2.11603]	0.021060*	[3.59049]
D(Brent(-1))	0.022779	[1.22971]	0.614915*	[42.6673]
D(Brent(-2))	-0.047628	[-2.10456]	0.282692*	[16.0557]
D(Brent(-3))	-0.016393	[-0.72059]	0.188096*	[10.6276]
D(Brent(-4))	0.024649	[1.19304]	0.105348*	[6.55387]
D(Dubai (-1))	0.051496	[2.23471]	-0.520331*	[-29.0233]
D(Dubai(-2))	0.025976	[1.01687]	-0.262066*	[-13.1863]
D(Dubai (-3))	0.011964	[0.48041]	-0.165988*	[-8.56705]
D(Dubai(-4))	-0.025693	[-1.31588]	-0.043941*	[-2.89262]
Intercept	0.010803	[0.82209]	0.009892	[0.96750]
R-squared	0.005091		0.288157	
Adj. R-squared	0.003443		0.286978	
F-statistic	3.090046		244.4568	
Log likelihood	-7551.522		-6184.702	

*denotes rejection of null hypothesis at 10% significance level



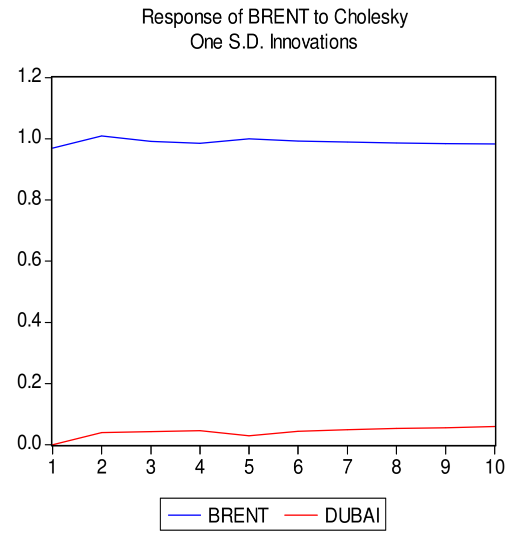
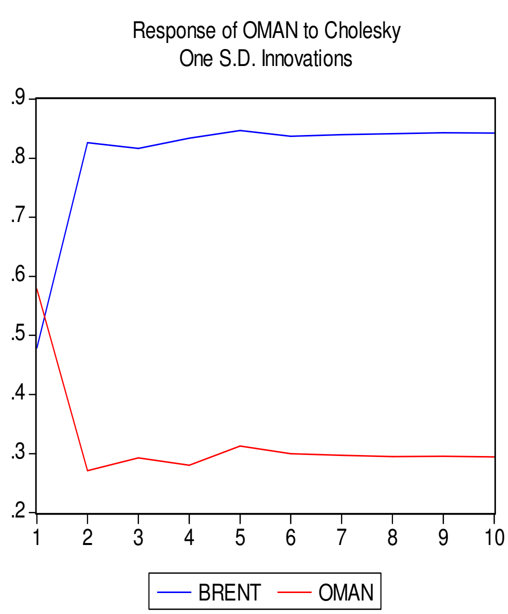


Table 4E: Error-Correction Models for Brent and Oman

	D(Brent)		D(Oman)	
	Coefficients	t-value	Coefficients	t-value
ECM	-0.019087*	[-2.21139]	0.030404*	[4.54760]
D(Brent(-1))	0.025506	[1.35363]	0.590515*	[40.4576]
D(Brent(-2))	-0.043836	[-1.93815]	0.266360*	[15.2036]
D(Brent(-3))	-0.019148	[-0.84485]	0.172048*	[9.79985]
D(Brent(-4))	0.014629	[0.71042]	0.086522*	[5.42414]
D(Oman(-1))	0.049055	[2.10202]	-0.500163*	[-27.6682]
D(Oman(-2))	0.021661	[0.84488]	-0.256300*	[-12.9059]
D(Oman(-4))	0.021957	[0.87827]	-0.146836*	[-7.58240]
D(Oman(-4))	-0.010666	[-0.54044]	-0.033770*	[-2.20888]
Intercept	0.010660	[0.81105]	0.010031	[0.98526]
R-squared	0.004844		0.278404	
Adj. R-squared	0.003197		0.277209	
F-statistic	2.939764		232.9903	
Log likelihood	-7552.197		-6161.564	

*denotes rejection of null hypothesis at 10% significance level



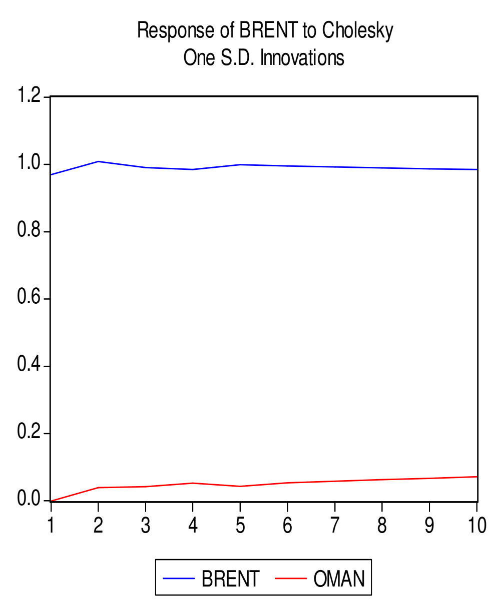


Table 4F Error-Correction Models for Oman and Dubai

	D(Dubai)		D(Oman)	
	Coefficients	**t-value**	**Coefficients**	**t-value**
ECM	-0.017486	[-0.64905]	0.035843	[1.34197]
D(Dubai(-1))	-0.200571*	[-2.61960]	-0.122218	[-1.61012]
D(Dubai(-2))	0.198712*	[2.58788]	0.121960	[1.60212]
D(Dubai(-3))	-0.361132*	[-4.72736]	-0.253121*	[-3.34224]
D(Oman(-1))	0.176503*	[2.28448]	0.095602	[1.24813]
D(Oman (-2))	-0.172502*	[-2.22578]	-0.100069	[-1.30240]
D(Oman (-3))	0.362431*	[4.69924]	0.247162*	[3.23251]
Intercept	0.011600	[0.96244]	0.011729	[0.98156]
R-squared	0.009847		0.005074	
Adj. R-squared	0.008572		0.003794	
F-statistic	7.725629		3.962047	
Log likelihood	-7084.020		-7036.918