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Abstract

This paper analyzes the relationship between international and Da Qing crude oil prices in China using threshold cointegration methods. Evidence of a long-run equilibrium relationship between international and Da Qing oil prices is found. We also estimate asymmetric adjustments under the M-TAR specification. The results show that adjustments to eliminate disequilibrium are quicker when oil price spread widens than when it narrows. The Granger causality tests support the fact that China has impacts on the international oil prices.

Keywords: Crude oil prices, M-TAR model, GLS

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I. Introduction

Due to its rapid economic growth after introducing market economic reform in 1978, crude oil consumption in China has increased drastically over the past 30 years. The China's crude oil consumption rose to 483.7 million tonnes in 2012, equaling 11.7% of the total world consumption, which is the second largest after the United States (British Petroleum, 2013) and is expected to become the largest consumer of oil by 2030 (IEA, 2013b). To meet its rising demand, the country has to rely increasingly on the international crude oil markets. According to IEA (2013a), China imported 251 million tonnes of oil in 2011, which accounted for 12.07% of the world oil imports, making it the second largest importer after the United States. Against this background, we propose to study the dynamic relationship between international and domestic crude oil prices in China.

There are several reasons why there is a need to carry out this study. First, as China is the second largest oil importer and oil consumer in the world, it will be of our interest to examine the market integration hypothesis or the "one great pool" hypothesis (Adelman, 1984) between international and China's oil markets. If these oil markets in the world are integrated as if they are in a great pool, the oil prices in these markets will move together and a long-run pricing relationship can be maintained. Hence, the shocks of oil prices in one market resulting from changes in economic conditions or government policy will be transmitted to other markets effectively. Second, any deviations of the price spread from the long-run pricing relationship will lead to adjustment process through arbitrage activities. The analysis of changes in price spread can provide useful information on how to formulate arbitrage strategies to exploit the mispricing opportunities. The effectiveness of the arbitrage activities therefore affects the degree of market integration. Third, since China is one of the main drivers of increasing oil demand in international markets, our study can help identify the directions of causality between international and China's oil prices. This may shed some light on clarifying the controversial question of whether the oil price shocks in China have exerted influence on the international markets. For example, if oil price shocks in China are driven by outside markets but not vice versa, China is then just a price taker of the international markets (Chen, et al., 2009; Liu et al., 2013). However, when shocks from China can drive the oil prices in the international markets, it indicates that China has an oil pricing power in the world oil markets and can therefore use the bargaining power to negotiate with international oil suppliers for more favorable payment terms on the oil supplies. Also, when China has become a source of oil price volatility, oil price risk would be larger than before and it leads to an increasing demand for the establishment of a crude oil futures market in China for hedging activities.

The dynamic relations between the China's and international oil prices are significantly determined by the price-setting mechanism adopted by the government, which has undergone a prolonged process of reform. Before the launch of the economic reforms in 1978, China used state planning to allocate resources between competing users. In the absence of a well-functioning market mechanism, domestic crude prices were strictly controlled under the central planning system. As a result, there was little domestic price adjustment in response to fluctuating supply and demand in the international and China's oil markets. However, since 1978, the regulation of domestic oil prices in China has become less restrictive. In 1981, the State Council of China launched a "double-track" pricing system whereby domestic oil explorers could sell their products at a higher price after they had met output targets laid down by the government. The oil explored from the largest oil field, Da Qing, for example, was allowed to be sold to its users at international prices in the late 1980s once its yearly output target of 50 million tons had been fulfilled (Wang et al. 1991). Although this double-track pricing policy encouraged explorers to produce more than they had under strict planning, it also led to rampant corruption. Therefore, the deregulation of oil pricing entered the next stage in 1994. Over the subsequent four years, the dual track system was phased out and the setting of domestic oil prices in China was increasingly influenced by market conditions. Since 1998, China's domestic oil prices have been set by the National Development and Reform Commission by benchmarking against the prices of international oil benchmarks with similar quality. This policy was introduced as China has become increasingly dependent on imports to meet domestic demand (Hang and Tu, 2007). Resulting from a series of price deregulation reforms, domestic crude oil prices in China have been staying in a close range to international oil prices since this period (Li and Leung, 2011). Nevertheless, the oil industry in China is not operated in a free competition market structure. The businesses of oil production, distribution and refinery have been monopolized in hands of large state-owned oil enterprises and only a few large oil enterprises with import rights are allowed to import oil. Such monopolized management structure may cause asymmetric adjustment paths of oil price spread that have policy implications for oil development policy in China.

According to Weiner (1991), oil prices in spatially separated regions will move together in an integrated market. Based on this idea, cointegration analysis is often used to investigate the long run co-movement of the data series in question and hence it has become a common methodology for testing market integration in the existing literatures (see, for example, Gulen, 1997 and 1999; Lanza et al., 2005; Bachmeir and Griffin, 2006; Bentzen, 2007). On the other hand, evidence of cointegration guarantees the existence of error-correction adjustment process in the system according to the Granger representation theorem. The analysis of both cointegration relationship and the adjustment dynamics can help determine the degree of market integration (Warell, 2006). A few previous studies, such as Jiao et al. (2004), Chen et al. (2009), Guo and Zhang (2009), and Li and Leung (2011), found evidence of cointegration between China's and international crude oil prices by using linear cointegration tests which assume symmetric adjustments. However, asymmetric adjustments can usually be found in crude oil markets (for example, Chen et al., 2005; Ewing et al., 2006; Hammoudeh, et al., 2010; Lin and Liang, 2010). Further, Hammoudeh et al. (2008) and Ghoshray and Trifonova (2014) show that the price spreads between pairs of international oil benchmarks and non-benchmarks exhibit momentum threshold autoregressive (M-TAR) adjustment process. In this paper, we study dynamic relationship between the international and China's crude oil prices by exploring the possibility of cointegration with asymmetric adjustments. Hence, in line with Hammoudeh et al. (2008) and Ghoshray and Trifonova (2014), we adopt the

M-TAR cointegration method of Enders and Siklos (2001), together with the more powerful version introduced by Cook (2007), who has combined M-TAR process and local-to-unity detrending via generalized least squares (GLS), as an empirical framework for our analysis. We also examine whether oil price shocks from China can exert impacts on the international markets by using nonlinear Granger causality tests that operate in a threshold vector error-correction model (TVECM).

The rest of this paper is organized as follows. The methodology is outlined in Section 2, the data description is provided in Section 3, the empirical results are reported in Section 4, and then the main conclusions are summarized in Section 5.

Ⅱ. Methodology

The residual-based threshold cointegration methodology developed by Enders and Siklos (2001) begins with the OLS estimation of a cointegrating relationship. In this study, the linear relationship between the international and China's oil benchmark prices can be modeled as:

$$P_t^Y = \alpha + \beta P_t^X + e_t, \tag{1}$$

where P_t^Y and P_t^X are the logarithmic prices of the international and the China's crude oil prices, respectively, at time t. The intercept and the slope coefficient are denoted by α and β, respectively. The residual e_t is the oil price spread between

P_t^Y and P_t^X. Enders and Siklos (2001) propose an M-TAR model for specifying e_t in the following way:

$$\Phi(L)\Delta e_t = \rho_1 e_{t-1} M_t + \rho_2 e_{t-1}(1-M_t) + \sum_i^n \gamma_i \Delta e_{t-i} + \varepsilon_t \qquad (2)$$

where M_t is the Heaviside indicator function such that

$$M_t = \begin{cases} 1 & \text{if } \Delta e_{t\text{-}1} \geq \tau \\ 0 & \text{if } \Delta e_{t\text{-}1} < \tau \end{cases}. \qquad (3)$$

Asymmetric adjustment is observed if the values of ρ_1 and ρ_2 are not equal. In the first (second) regime where Δe_{t-1} is greater (smaller) than the threshold τ, the price spread is widening (narrowing). The adjustments are modeled by $\rho_1 e_{t-1}$ and $\rho_2 e_{t-1}$ in the regimes of oil price spread widening and narrowing, respectively. The value of τ is not known and can be consistently estimated together with the values of ρ_1 and ρ_2 through minimizing the sum of squared errors (Chan, 1993).

Conventional cointegration methods will suffer from low testing power when the adjustment dynamics are actually nonlinear (Pippenger and Goering, 2000). Therefore, Enders and Siklos (2001) suggest using the M-TAR threshold cointegration test to overcome this problem. The first step of this test involves a linear cointegration test of equation (2), which requires the point estimates of ρ_1 and ρ_2 to be negative, and the null hypothesis of no cointegration, namely $\rho_1 = \rho_2 = 0$, to be rejected by the F statistics. Since this F statistics, denoted Ψ_{OLS}, is non-standard under the null, their critical values have to be obtained from simulation. Once the null of non-cointegration is rejected, we can then proceed to the second step to examine the null hypothesis of symmetric adjustment, i.e., $\rho_1 = \rho_2$, by using the standard F-statistic. If the null hypothesis of $\rho_1 = \rho_2$ is rejected, then it implies the existence of M-TAR adjustments. In particular, if $|\rho_1| > |\rho_2|$, it implies that the M-TAR model exhibits quicker error-correcting adjustment when $\Delta e_{t-1} \geq \tau$ than otherwise. On the contrary, the speed of adjustments would be reversed if $|\rho_1| < |\rho_2|$.

To increase the power of Enders-Skilos's (2001) M-TAR cointegration test, Cook (2007) proposes employing local-to-unity detrending via GLS procedure developed by Elliott et al. (1996) to modify the data. There are two possible ways to implement the GLS detrending procedure. The first one is to demean the price series by use of a constant term with $z_t = 1$, and the second is to detrend via use of a constant and a trend term t, with $z_t = (1, t)'$. Both of the demeaned and detrended series will be used in our study. The quasi-differenced data are generated as:

$$\bar{P}_{\alpha}^{Y} = [P_1^Y, P_2^Y - \bar{\alpha}P_1^Y, \ldots, P_T^Y - \bar{\alpha}P_{T-1}^Y]', \quad \bar{P}_{\alpha}^{X} = [P_1^X, P_2^X - \bar{\alpha}P_1^X, \ldots, P_T^X - \bar{\alpha}P_{T-1}^X]',$$

$$\bar{z}_{\alpha} = [z_1, z_2 - \bar{\alpha}z_1, \ldots, z_T - \bar{\alpha}z_{T-1}]', \tag{4}$$

where $\bar{\alpha} = 1 + \bar{c}/T$ with $\bar{c} =$ -7 if $z_t = 1$, and $\bar{c} =$ -13.5 if $z_t = (1, t)'$ and T is the sample size. The GLS detrended series $\bar{P}_t^Y$ is then derived as $\bar{P}_t^Y = P_t^Y - \phi_0$, for

$z_t = 1$ and $\bar{P}_t^Y = P_t^Y - \phi_0 - \phi_1 t$ for $z_t = (1, t)'$, where ϕ_i is obtained from the regression of $\bar{P}_\alpha^Y$ upon $\bar{z}_\alpha$. The GLS detrended series $\bar{P}_t^X$ is obtained in the identical way.

Following equation (1), we can use the GLS detrended series to estimate their cointegrating relationship as below:

$$\bar{P}_t^Y = \gamma \bar{P}_t^X + \eta_t \quad . \tag{5}$$

The resulting residuals η_t can be used to estimate the following GLS M-TAR model:

$$\Phi(L)\Delta\eta_t = \rho_1 \eta_{t-1} M_t + \rho_2 \eta_{t-1}(1 - M_t) + \sum_i^n \varphi_i \Delta\eta_{t-i} + \zeta_t \,, \tag{6}$$

where $M_t = \begin{cases} 1 & \text{if } \Delta\eta_{t\text{-}1} \geq \tau \\ 0 & \text{if } \Delta\eta_{t\text{-}1} < \tau \end{cases}.$ (7)

The null hypothesis of no cointegration, i.e., $\rho_1 = \rho_2 = 0$, can be examined by comparing the non-standard F statistics, denoted Ψ_{GLS}, with their simulated critical values.[1] The test of threshold adjustment is implemented, as mentioned above, in the same manner as in Enders and Siklos (2001).

The existence of threshold cointegration justifies the estimation of the following 2-regime TVECM in order to examine the asymmetric adjustments and the directions of Granger causality:

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[1] Cook (2007) restricts τ to be zero but we follow Ghoshray and Trifonova (2014) to estimate τ using the grid search method of Chan (1993). Hence, our simulated critical values of the GLS M-TAR tests are different from those of Cook (2007).

$$\Phi(L)\Delta Z_t = \kappa_1\theta' Z_{t-1}M_t + \kappa_2\theta' Z_{t-1}(1-M_t) + \mu + u_t, \tag{8}$$

where $Z_t = (P_t^Y, P_t^X)'$, $\Phi(L)$ is a 2×2 matrix comprising of four p-th polynomials, which can be specified as $\Phi(L) = (\Phi_1(L), \Phi_2(L))'$ where $\Phi_1(L) = (\Phi_{1y}(L), \Phi_{1x}(L))$ and $\Phi_2(L) = (\Phi_{2y}(L), \Phi_{2x}(L))$; $\kappa_1 = (\kappa_{11}, \kappa_{21})'$ and $\kappa_2 = (\kappa_{12}, \kappa_{22})'$ are the 2×1 vectors of adjustment coefficients when $M_t = 1$ and 0, respectively; μ is a 2×1 vector of constants; $\theta = (1, -\alpha, -\beta)'$ denotes the cointegrating vector; and $u_t = (u_t^Y, u_t^X)'$ is a 2×1 vector of uncorrelated error terms. The adjustment coefficients in κ_1 and κ_2 measure the proportion of the lagged disequilibrium e_{t-1}, namely $\theta' Z_{t-1} = P_{t-1}^Y - \alpha - \beta P_{t-1}^X$, that has been eliminated in time period t with the speeds of the M-TAR adjustment, measured by κ_1 and κ_2, differing over the two regimes of widening and narrowing oil price spreads.

The information about the long-run form of the Granger causality between international and China's crude oil prices can be obtained by testing the null hypotheses of the zero adjustment coefficients (Granger, 1988; Toda and Phillips, 1993) using the standard Wald statistics (Seo, 2011). Evidence of nonlinear long-run Granger causality can be established if at least one of the adjustment coefficients in κ_1 or κ_2 in equation (8) is significantly different from zero. Moreover, the existence of short-run Granger causality is tested by examining the null hypothesis of whether all the short-run coefficients in $\Phi_{1x}(L)$ and $\Phi_{2y}(L)$ are equal to zero by using the standard Wald statistics. Short-run causality may occur when an oil price exerts a temporary influence on another due to transitory factors, such as speculative capital flows in oil markets, irrational expectations, and waves of excessively pessimistic or optimistic views that are unrelated to long-run relations.

Ⅲ. Data

To carry out this analysis, we choose the spot closing prices of West Texas Intermediate (WTI), Brent and Dubai crudes as proxies for international crude oil prices, since they are widely used as the crude oil benchmarks in the international markets. Also, the spot closing price of Da Qing crude from the Da Qing field, the largest oil field in China is employed as a proxy for China's crude oil benchmark price. The daily data for the international oil prices (WTI, Brent and Dubai) are obtained from the US Energy Information Administration (EIA),[2] while the Da Qing oil price series are downloaded from the website of the International Oil Network (in Chinese).[3] Prices of crude oil are expressed in US dollars per barrel. The sample periods span from 3rd January, 2003 to 26th November, 2012. The total number of observations is 2,504.

Figure 1 depicts the movements of the data series under study during the sample

[2] Source: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=rbrte&f=d
[3] Source: http://oil.in-en.com/quote/spot-oil-info.asp?cpname=Daqing

period. As shown, the oil prices started to surge upward from about $30 per barrel in the beginning of 2003 to about $70 in August of 2006. Following a slight retreat between August of 2006 and March of 2007, there was a rapid run-up in the oil prices again and reached to the peak of around $145 in July of 2008. Because of the financial tsunami in September of 2008, the prices slumped dramatically to about $40 in the first quarter of 2009, and then rebounded quickly to around $110 toward the end of 2012. Also, all the price series exhibit positive skewness reflecting their rising trend over the sample period. As can be seen in Figure 1 and Table 2, the price series exhibit the strong observed co-movement and each price is closely correlated with each other, signifying that all the oil benchmarks in our sample are likely to be in "one great pool".

Figure 1. The spot prices of WTI, Brent, Dubai and Da Qing crude oil

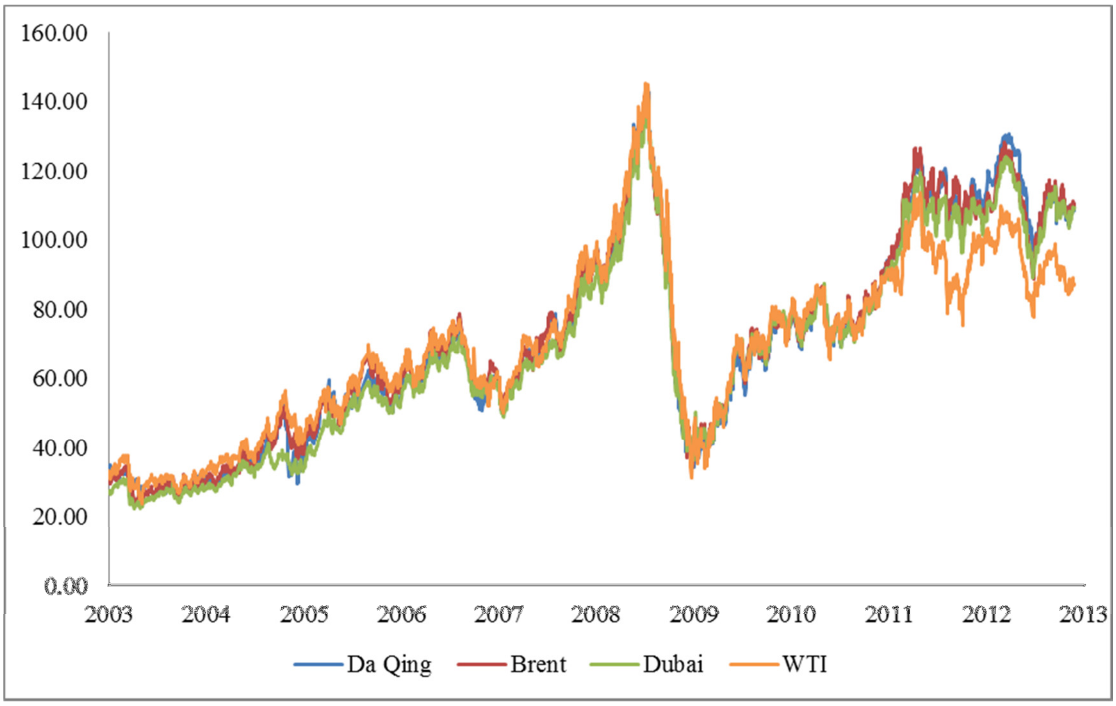

Table 1 Summary statistics of oil price series

	WTI	Brent	Dubai	Da Qing
Mean	69.808	71.950	68.782	71.138
Median	70.305	69.355	66.705	67.655
Maximum	145.310	144.220	140.770	143.750
Minimum	23.700	22.880	22.360	25.400
Standard Deviation	25.032	29.463	29.120	29.874
Skewness	0.220	0.256	0.247	0.331
Kurtosis	2.522	2.035	2.011	2.044

Table 2 Correlation analysis of price series

	WTI	Brent	Dubai	Da Qing
WTI	1.000			
Brent	0.984*** (282.589)	1.000		
Dubai	0.981*** (258.377)	0.994*** (491.480)	1.000	
Da Qing	0.982*** (266.743)	0.995*** (509.653)	0.994*** (477.2401)	1.000

Notes:

Correlation is calculated using the Spearman rank-order method.

The figures in the parentheses are the t-statistics.

*** denotes significance at the 1% level

In general, the light and sweet crude oil that has higher American Petroleum Institute (API) gravity and lower sulfur content is of better quality and can be sold at higher prices than heavy and sour oil.[4] The WTI and Brent crudes are classified as light and sweet, while the Dubai crude is heavy and sour and Da Qing crude is sweet but heavy.[5] Hence, as shown in Figure 1 and Table 1, the price of heavy and sour Dubai is on average the lowest among the four oil benchmarks. The sweet but heavy Da Qing is usually priced higher than Dubai but is lower than the light and sweet WTI and Brent. The WTI, with the higher API and lower sulfur content than Brent, was usually priced above Brent until 2007. As from 2007, lack of storage and the rapid build-up of WTI-priced stockpiles resulting from reduction in the refining capacity around the area of Cushing, Oklahoma in the United States, which is the delivery

[4] The New York Mercantile Exchange defines light crude oil as having API gravity between 37 degrees and 42 degrees, and sweet oil with less than 0.42% sulfur content.

[5] WTI has an API gravity of 39.6 degrees on average with a sulfur content of 0.24%. Brent crude has the average API gravity of 38.3 degrees and a sulfur content of 0.4%. Dubai crude has an average API gravity of 31 degrees with a sulfur content of 2%. Da Qing has an API gravity averaging 32.2 degrees, and a sulfur content of 0.11%.

point of the WTI contract, caused the price of WTI to drop (Shenk, 2007; Fattouh, 2010). Starting from early 2011, the price of WTI further deviated from Brent crude, and the price differential between WTI and Brent rose to over $25 in late 2011 when Brent began to move up in reaction to political tensions in Egypt and across the Middle East, and also with increased crude oil production in the United States, but because of the limited pipeline capacity, the WTI-priced stockpiles at Cushing could not effectively be transported to the Gulf Coast of the United States for arbitrage (EIA, 2013). The price of WTI continued to stay depressed in 2012. Hence, the actual crude price differentials depend on the market locations, transaction costs and market conditions as well as quality differences.

IV. Empirical results

Before conducting the cointegration tests, we apply four standard unit root tests and one stationarity test to check for the existence of a unit root in the oil price series of the dataset. All price series for empirical testing are taken in natural logarithms. A constant and a linear time trend are included in the test regressions. The four unit root tests we use include the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP) test, the Elliott-Rothenberg-Stock (ERS) Dickey-Fuller with GLS de-trending (DF-GLS) method, and the ERS point optimal (PO) test. The stationarity test we use is the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test, which examines the null hypothesis of trend stationarity against the alternative of a unit root process. As can be seen from the results in Table 3, none of the unit root tests can reject the null of a unit root process for the level oil prices. However, they can significantly reject the null of a unit root process when the oil prices are expressed in the first difference. Similarly, the KPSS test significantly rejects the null of stationarity for the price variables in level, but not for their first difference. As a result, these oil prices in level are all integrated of order one.

Table 3 Results of unit root and stationarity tests

Variables	ADF	PP	DF-GLS	PO	KPSS
WTI	-2.444	-2.376	-2.388	7.944	0.323***
Brent	-2.268	-2.330	-2.172	9.401	0.472***
Dubai	-2.164	-2.165	-2.009	11.218	0.508***
Da Qing	-2.221	-2.307	-2.232	9.134	0.407***
Δ WTI	-51.592***	-51.628***	-43.295***	0.064***	0.040
Δ Brent	-48.895***	-48.886***	-6.492***	0.073***	0.041
Δ Dubai	-52.181***	-52.139***	-9.904***	0.173***	0.045
Δ Da Qing	-51.340***	-51.348***	-4.861***	0.135***	0.044

Notes:

The bandwidth or truncation lag for PP and KPSS was chosen based on the Newey-West automatic selection method using the Bartlett kernel. For the PO test, the lag length was chosen using the AR spectral OLS method based on the Bayesian Information Criterion (BIC). For the ADF and DF-GLS tests, automatic lag selection was based on the BIC.

The 5% and 1% critical values for ADF and PP are -3.411 and -3.961; for DF-GLS are -2.890 and -3.480; for PO are 5.620 and 3.960; and for KPSS are 0.146 and 0.216, respectively.

*** denote statistical significance at the 1% level.

After the unit root tests, we proceed to the detection of threshold cointegration using both the OLS and GLS based M-TAR tests. To begin with, we estimate the equation (1) using the OLS for each pair of international and Da Qing crude oil prices.

The residuals or oil price spreads, e_t from equation (1) are then used to estimate the values of threshold τ and other parameters of the M-TAR model given by equations (2) and (3). The results presented in Table 4 indicate that the point estimates of ρ_1 and ρ_2 are all negative. We further test the null hypothesis of $\rho_1 = \rho_2 = 0$ using the Ψ_{OLS} statistics, which exceed their simulated critical values at the 1% significance level for all the cases, leading us to conclude that there exists a cointegration relationship between each pair of crude oil prices under study. These findings support the market integration or the 'one great pool' hypothesis, implying that under the prevailing China's partially deregulated oil pricing policy, the prices of China's and international oil benchmarks are unified together. Further, the values of the intercept α represents the equilibrium price spread between each pair of prices under study in the long run, which results from the presence of transaction costs and quality difference. The positive (negative) sign of α reported in Table 4 indicates that the international oil price is higher (lower) than that of Da Qing in the long run, which is consistent with their quality differences. On the other hand, since the values of the slope coefficient β which measures the relative long-run movements between the international and China's oil benchmark prices are approximately equal to unity, enhancing evidence of market integration.[6] Moreover, Tables 5 and 6 report the results of GLS M-TAR cointegration tests given by the Ψ_{GLS} statistics using demeaned and detrended series, respectively. These results, obtained from the estimation of equations (4) to (7), provide the qualitatively same evidence of cointegration as those obtained from the OLS M-TAR tests.

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[6] The OLS estimate of β for the WTI-Da Qing system increases to 0.944, which is closer to unity when the sample periods from 2007 onward are truncated.

Table 4 Results of OLS based M-TAR cointegration tests

	WTI–Da Qing	Brent–Da Qing	Dubai–Da Qing
OLS τ threshold	0.0327	-0.0108	0.0071
OLS ρ_1	-0.116	-0.089	-0.049
OLS ρ_2	-0.025	-0.034	-0.019
Ψ_{OLS} $(\rho_1 = \rho_2 = 0)$	28.501***	30.888***	26.161***
α	0.637	0.067	-0.148
β	0.848	0.987	1.026
$F(\rho_1 = \rho_2)$	24.217***	7.499***	10.013***
Lags	2	3	3
BIC	-7.232	-7.670	-9.152

Notes:

τ represents the consistently estimated value of the threshold.

In the case of OLS M-TAR adjustment, the simulated critical values for the statistics with two, and three lagged changes are 6.427 (6.428), 7.611 (7.610) and 10.408 (10.407) for the 10%, 5% and 1% significance level, respectively. The simulation is based on 50,000 replications for a sample size of 2500.

Lags refer to the number of lagged differences in the OLS M-TAR model based on the BIC.

** and *** denote statistical significance at the 5%, and 1% level, respectively.

On the other hand, as presented in Tables (4) to (6), the F statistics calculated from the OLS and GLS based M-TAR models significantly reject the null hypothesis of $\rho_1 = \rho_2$ at the 1% level, favoring the existence of the M-TAR adjustments. Also, we find $|\rho_1| > |\rho_2|$ for all cases, implying faster convergence when the price spread is widening than narrowing. In other words, the increases in the oil price spreads tend to revert more quickly than the decreases in the spread.[7]

Table 5 Results of GLS based M-TAR cointegration tests under demeaning

	WTI–Da Qing	Brent–Da Qing	Dubai–Da Qing
GLS τ threshold	0.0327	-0.0108	0.0046
GLS ρ_1	-0.101	-0.086	-0.041
GLS ρ_2	-0.022	-0.028	-0.016
Ψ_{GLS} $(\rho_1=\rho_2=0)$	25.012***	29.794***	23.759***
γ	0.849	0.987	1.026
F $(\rho_1=\rho_2)$	20.521***	7.950***	8.686***
Lags	2	3	3
BIC	-7.228	-7.669	-9.150

Notes:

In the case of GLS M-TAR adjustment under demeaning, the simulated critical values for the Ψ_{GLS} statistics with two (three) lagged changes are.5.714 (5.724), 6.674 (6.666) and 8.787 (8.782) for the 10%, 5% and 1% level, respectively. The simulation was based on 50,000 replications for a sample size of 2500.

Lags refer to the number of lagged differences in the GLS M-TAR model under demeaning based on the BIC.

** and *** denote statistical significance at the 5%, and 1% level, respectively.

Table 6 Results of GLS based M-TAR cointegration tests under detrending

	WTI–Da Qing	Brent–Da Qing	Dubai–Da Qing
GLS τ threshold	0.0336	-0.0108	0.0065

[7] Unlike the M-TAR tests in our study, Liu, et al. (2013) does not support the integration between China's and international oil markets using TVECM with TAR adjustment proposed by Hansen and Seo (2002).

GLS ρ_1	-0.100	-0.079	-0.050
GLS ρ_2	-0.031	-0.036	-0.016
Ψ_{GLS} $(\rho_1=\rho_2=0)$	25.155***	27.153***	22.140***
γ	0.954	0.974	0.937
$F(\rho_1=\rho_2)$	13.816***	4.626**	10.727***
Lags	2	3	3
BIC	-7.152	-7.767	-9.290

Notes:

In the case of GLS M-TAR adjustment under detrending, the simulated critical values for the Ψ_{GLS} statistics with two (three) lagged changes are.7.155, (7.158), 8.223 (8.217) and 10.467 (10.491) for the 10%, 5% and 1% level, respectively. The simulation was based on 50,000 replications for a sample size of 2500.

Lags refer to the number of lagged differences in the GLS M-TAR model under detrending based on the BIC.

** and *** denote statistical significance at the 5%, and 1% level, respectively.

In order to better understand the threshold adjustments of the price spreads to equilibrium and the directions of Granger causality in the bivariate TVECM with M-TAR adjustments, we estimate equation (8) using the full information maximum likelihood method. Table 7 reports the empirical results. For the system of WTI and Da Qing, all the regime-specific adjustment coefficients of the lagged disequilibrium e_{t-1} are significant, thereby implying that both WTI and Da Qing will initiate adjustments to correct any disequilibrium of the system that appears in both regimes. In particular, WTI responds to widening (narrowing) of oil price spread by adjusting in the current period to eliminate 8% (1%) per day of the deviations from equilibrium in the preceding period. Similarly, Da Qing will respond to widening (narrowing) of spread by eliminating 5% (0.8%) per day of the equilibrium errors. From the estimated values of adjustment coefficients, the adjustments made by WTI and Da

Qing are faster for widening of oil price spread (i.e. $\Delta e_{t-1} \geq 0.0327$) than for narrowing. On the other hand, WTI has short-run impacts on Da Qing but not vice versa. Hence, we observe a bidirectional long-run Granger causality between WTI and Da Qing in both regimes, while the short run Granger causality is unidirectional running from WTI to Da Qing only.

As for the system of Brent and Da Qing, a deviation from the equilibrium in Da Qing in the preceding period will cause an error-correcting adjustment made by Brent to eliminate 3% of disequilibrium in the following day when oil spread is widening (i.e. $\Delta e_{t-1} \geq -0.0108$). On the other hand, Da Qing will adjust to eliminate 5.3% (3.2%) of deviations from equilibrium in Brent in response to widening (narrowing) of the spread. Therefore, the long-run Granger causality between Brent and Da Qing runs in both directions only when the oil spread is widening. When the spread is narrowing, Brent unidirectionally Granger causes Da Qing to move in the long run. In the short-run, there exists a two-way short-run Granger causality between Brent and Da Qing.

The error-correcting adjustments between Dubai and Da Qing are made by Da Qing only, which responds to widening of the spread (i.e., $\Delta e_{t-1} \geq 0.0071$) and corrects the deviations from equilibrium by about 6.8% per day. Dubai does not respond to disequilibrium. Because of this, we can refer to Dubai as weakly exogenous to the system and the evidence of weak exogeneity for Dubai is consistent with those results of Hamoudeh, et al. (2008) and Ghoshray and Trifonova (2014). Also, the long-run Granger causality is unidirectional running from Dubai to Da Qing when oil price spread is widening only. As is the previous case of Brent and Da Qing, the movements of Dubai and Da Qing have short-run impacts on each other.

As is well known, arbitrage transactions, which involve buying and selling the oil contracts at a price deviating from the equilibrium level, can bring the oil price spread back to an equilibrium level.[8] In case if the oil spread is widening, say, because the international oil price increases more than the China's oil price, it will induce the oil arbitrageurs in China to long the domestic oil spot contracts and to short the international oil spot or futures contracts in international exchanges in order to exploit profit opportunities. The opposite is also true for the narrowing of price spread. By observing changes in oil price spread and asymmetric adjustments, it is possible to predict how the oil prices would change. The availability of this kind of information may be helpful for oil traders to formulate their long-short arbitrage and hedging strategies.

Our empirical results of asymmetric adjustments show that the market traders respond faster to the widening of oil spreads than narrowing. Two institutional factors may explain this result. First, in China, there are only a small number of dominant state-owned oil companies that wield a high level of domestic market power (Ishida, 2007).[9] When the price spread is increasing, the estimates of adjustment coefficients in the TVECM suggest that these domestic oil giants respond relatively quick in raising their selling prices of domestic oil to catch up with the increase in international oil price, but are relatively sluggish in adjusting domestic price downward if the oil

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[8] Taking the coal market as an example, Morse and He (2010) found out that because of the arbitrage, the domestic prices of coal in China have more or less aligned with the international import prices.

[9] The dominant state-owned oil companies in China include, for example, China National Offshore Oil Corporation, China National Petroleum Corporation, and China Petroleum & Chemical Corporation, which are listed in Shanghai, Hong Kong, and New York.

spread is decreasing. This outcome may be caused by the oil producers to maintain their profit margin.[10]

Second, when oil spread is decreasing, say, due to decreases in international oil prices, arbitrageurs will normally respond by importing oil of relatively lower international prices and selling short domestic oil of relatively higher prices. However, the import oil market is monopolized in China, and not all oil enterprises and arbitrageurs can freely import oil. Only a few large oil companies and refineries are granted with the import rights to purchase oil from overseas markets for their own use and the refineries and arbitrageurs that do not have the import rights have to buy imported oil from them at a markup.[11] Further, there is no crude oil futures market in China, which means that oil arbitrageurs cannot sell short domestic crude oil in the local futures market as they can do in international markets. Because of the above, arbitrage trades would be more costly and less effectively with slower adjustment to equilibrium when price spread is decreasing than when it is increasing. Therefore, the policy implications from the empirical results of asymmetric adjustments point to the need of opening up the domestic crude oil market which allow more enterprises, including non-state owned ones, to participate into the businesses of oil production, refinery and distribution of oil products. Moreover, it is necessary to break the monopolized oil import market in China, and allow more oil companies and refineries to import oils for the sake of enhancing competition and efficiency in the oil industry. Further, the establishment of a well-functioning crude oil futures market is important

[10] The state-owned oil companies in China have become increasingly profit-oriented after economic reform in the late 1970s and being listed in stock markets in the early 2000s (Leung, 2011).

[11] The enterprises that are granted with import rights include, for example, China National Petroleum Corporation, China Petrochemical Corporation, China National Offshore Oil Corporation, Zhuhai Zhen Rong Company and Sinochem Corporation.

as it will help facilitate arbitrage activities.

Furthermore, in the literature, it is often found that the Chinese oil market does not affect the volatility to other markets (for example, Chen et. al., 2009; Liu et al., 2013). However, based on our findings of nonlinear Granger causality tests, oil price shocks in China would generally have causal impacts on the international markets. Also, as the world oil prices have become increasingly volatile, partly due to the influence of price shocks from China, it is important oil enterprises to know how to manage their exposures to oil price risk. Although some Chinese state-owned enterprises are granted with the 'Overseas Futures Business Operation Permits' to undertake futures trading for hedging in overseas futures exchanges, they are subject to strict regulations such as the types of hedging business they are allowed to do.[12] Hence, the establishment of a domestic crude oil futures market is vitally important for the improvement of its oil price discovery mechanism and the implementation of hedging activities. With no doubt, this should be one of the top objectives for the Chinese government to develop its energy industry.

Table 7 Results of TVECM with M-TAR adjustment

	WTI–Da Qing		Brent–Da Qing		Dubai–Da Qing	
	ΔP_t^Y	ΔP_t^X	ΔP_t^Y	ΔP_t^X	ΔP_t^Y	ΔP_t^X
$M_t\, e_{t-1}$	-0.080*** (0.011)	0.050*** (0.006)	-0.030*** (0.011)	0.053*** (0.008)	0.021 (0.013)	0.068*** (0.013)
$(1-M_t)\, e_{t-1}$	-0.010* (0.005)	0.008** (0.0042)	0.013 (0.015)	0.032*** (0.011)	-0.005 (0.007)	0.014 (0.008)
ΔP_{t-1}^Y	-0.030** (0.015)	0.518*** (0.007)	0.014 (0.017)	0.529*** (0.012)	-0.047 (0.032)	-0.054 (0.034)
ΔP_{t-2}^Y	0.033** (0.014)	0.080*** (0.011)	-0.020 (0.021)	0.115*** (0.016)	0.035 (0.033)	-0.122*** (0.034)

12 See SAFE (2013) and Linklaters (2013) for details.

ΔP^{Y}_{t-3}			-0.019 (0.019)	0.053*** (0.013)	-0.085** (0.036)	-0.164*** (0.036)
ΔP^{X}_{t-1}	-0.028 (0.020)	-0.143*** (0.013)	0.032 (0.020)	-0.283*** (0.015)	0.009 (0.032)	0.020 (0.032)
ΔP^{X}_{t-2}	0.006 (0.016)	0.035*** (0.012)	0.046** (0.020)	-0.043*** (0.015)	0.016 (0.033)	0.153*** (0.032)
ΔP^{X}_{t-3}			0.053*** (0.018)	0.006 (0.013)	0.103** *(0.032)	0.171*** (0.032)
Wald	2.218	5068.061***	10.047**	1753.69***	10.732**	39.751***
Log	12333.39		12716.82		14216.95	
BIC	-9.815		-10.109		-11.308	
Q(p+1)	1.437 [0.999]		3.201[0.999]		4.478 [0.997]	
Q(p+3)	22.238 [0.327]		22.548 [0.546]		13.364 [0.959]	

Notes:
Standard errors are shown in parentheses.
Wald refers to the standard Wald statistics for the short-run Granger causality tests.
Log refers to the value of the log likelihood function.
Q(p+1) and Q(p+3) are the Q statistics with lags of p+1 and p+3 respectively where p is the system lag order.
P-values for the Q statistics are shown in squared brackets.
***, ** and * denote statistical significance at the 10%, 5%, and 1% level, respectively.

V. Concluding remarks

This paper investigates the long-run relationships between the crude oil prices of Da Qing and the other three international crude oil benchmarks - WTI, Brent and Dubai. Our study indicates that there is a close linkage between the Chinese oil prices and its international counterparts under the current oil pricing policy of China, which renders support to the ‘one great pool’ hypothesis. This implies that China has become a part of the integrated world oil market and could rely on the international markets to meet its oil demand. Despite this, Leung (2011) and Li and Leung (2011) observed that China is actively taking actions in diversifying the sources of its oil imports in order to assure its oil supply security.[13] Also, the error-correcting dynamics under the M-TAR specification are asymmetric such that discrepancies from equilibrium resulting from increases in oil spread are eliminated at a quicker pace than from decreases. It provides useful information for developing better arbitrage strategies in China's oil market. The asymmetric responses may result from oligopolistic market structure in China's oil industry, absence of Chinese oil futures market and the restrictive management system of oil import. The policy implications are that the Chinese government should open up its domestic and imported oil industry and establish a well-functioning crude oil futures market. Moreover, the long-run and short-run causality directions show that any energy shock in China will be transmitted to the world oil markets and vice versa. With its rapid economic growth, China's influence on the world energy market will continue to grow over time.

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[13] Unlike Weiner (1991), Gulen (1997) argued that long-term contracts between oil buyers and sellers or supplier diversification policy implemented by oil importers which can safeguard long-term supply of crude oil are therefore not necessarily inconsistent in an integrated world oil market.

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Important Note

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