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Testing the International Crude Oil Market Integration with Structural Breaks

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Abstract

As spread between the WTI and Brent crude oil price is widening after early 2011, it could be that the price relationship between these crude oil is changing. To see if such change affected the price linkages among the international crude oil markets, this study investigates if the world's major benchmark crude oil markets are integrated using the latest data and test the globalization hypothesis when effects from structural breaks are reflected in the test model. The study reveals that while the Brent and Dubai crude oil markets continue to have a long-run relationship, the WTI no longer have a long-run relationship with the international crude oil market.

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1. Introduction

Before 2011, the world's major benchmark crude oil prices, the Brent and the WTI prices tracked closely or the Brent price was traded at a slightly lower price with the WTI price. However, the recent surge in shale oil production in the U.S. put downward pressure on the price of the West Texas Intermediate (WTI) crude oil and the WTI market started to diverge from the international crude oil market. The increased shale oil production in the US is related to the Bakken oil boom in Montana, North Dakota, Saskatchewan, and Manitoba after mid-2000 and this rise in the unconventional oil production is recently keeping the WTI crude oil price to be lower than the Brent crude oil price. Another important factor for the WTI crude oil price to stay at a lower level is that the U.S. has restricted the crude oil export since the Energy Policy and Conservation Act of 1975 (Alquist and Guénette, 2014). Because of this legal restriction, the increased crude oil production in the U.S. cannot be exported outside of the U.S., and hence, the supply glut has pushed the WTI crude oil price to decline.

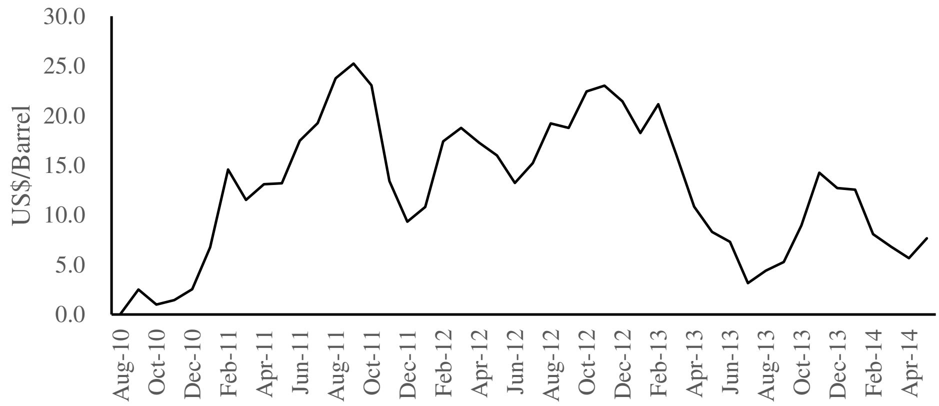

Figure 1 WTI-Brent Spread

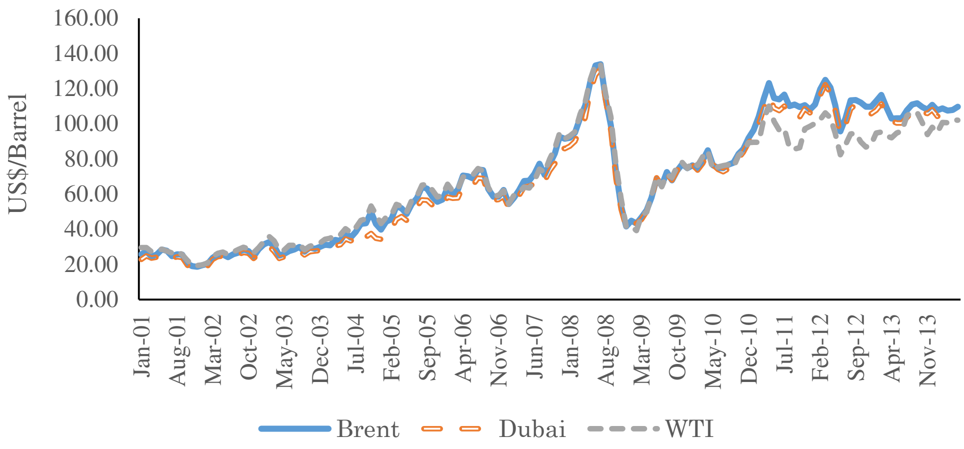

Figure 2 Crude oil price series

Figure 1 illustrates the price difference between the Brent and WTI crude oil prices since late 2010. As seen in the figure, the price of WTI crude oil remains at a lower price compared to the Brent crude oil price since late 2010. The WTI and Brent crude oil markets are historically well connected and considered as integrated. Kim et al. (2013) have tested the long-run relationships among the WTI, Brent, and Dubai crude oil prices and they reveal that these benchmark crude oil markets are integrated during the 1997:1 to 2012:7 period. However, it is only after late 2010 where the WTI-Brent spread started to widen, and if this spread continues to exist in the future, it can be expected that the inter-relationships between these two markets are becoming weaker or disappearing.

Figure 2 illustrates the price movements of the world's three major benchmark crude oil markets for the 2001:1 to 2014:5 period. This figure too reveals that the WTI price series started to move apart from the Brent and Dubai price series after late 2010 and it could be that the global crude oil market is on the verge of structural change.

Evidence from previous studies testing the international crude oil linkages to find out if the international crude oil market is integrated is mixed. As Adelman (1984) suggested in his paper, the "world oil market, like the world ocean, is one great pool," studies such as Gülen (1999), Hammoudeh et al. (2008), and Wilmot (2013) supports the idea of the globalization hypothesis. On the other hand, Weiner (1991) uses the correlation and regression analysis to find out that "the world oil market is far from completely united." Milonas and Henker (2001) also provide evidence that the U.K. Brent and the U.S. WTI crude oil markets are not fully integrated. Thus, the results of empirical studies testing the globalization hypothesis are contradicting, and recently, the shale oil revolution in the U.S. is causing the WTI market to move independently from the global oil market. Furthermore, after 2001, the global crude oil market has become extremely volatile (Gironés and Guerra, 2013), and not just because of the shale oil revolution but factors such as the world financial crisis of 2008 and the increased oil demand from the emerging economies are likely affecting the global crude oil market. Hence, the importance of testing the globalization hypothesis is once again becoming stronger especially with consideration of structural breaks in the crude oil markets.

To shed light on this issue, this study will investigate if the world's major benchmark crude oil markets are integrated using the latest data and test the globalization hypothesis when effects from structural breaks are reflected in the test model.

The results of this study will provide useful information for hedgers and arbitrageurs investing in crude oil futures market and for buyers importing crude oil from the international oil market. Furthermore, since crude oil is used as a production source in various commodities, crude oil price is one of the important price indicators for various commodities. Thus, whether the WTI price can be used as a global benchmark is a crucial matter for various market participants. If the results reveal that the WTI price remains to move closely with the Brent and Dubai prices, it will imply that the WTI price is still a suitable benchmark for the global crude oil price. However, if the test results of the study show that the WTI price is no longer moving together with the Brent and Dubai prices, we should no longer use this price as a global benchmark.

There are quite a few studies examining the oil price differentials (Fattouh, 2010; Borenstein and Kellogg, 2012; and Buyuksahin et al., 2013) but not many have focused on how the long-run international oil price linkages change when structural breaks in the price series are considered. Recently, Kim et al. (2013) and Wilmot (2013) have tested the cointegration relationships among the world's benchmark crude oil markets with structural breaks and these studies find that long-run relationships hold even when the effects of the breaks are considered. However, these studies only endogenize one break in the model and they do not test the relationships when more than one breaks are considered in the model. This study will cover this gap and investigate the international crude oil market integration with two breaks.

In the next section, the methods used in the study are explained. In the third section, the empirical results of the tests performed in this study are shown. Finally, the last section summarizes the findings of the study and concludes.

2. Methods

First, all the crude oil price series used in this study are tested for their stationarity. For this purpose, the study conducts the Phillips-Perron (PP), KPSS and Lee-Strazicich (LS) (2003) unit root tests with two endogenous breaks. The PP and LS unit root tests test the null hypothesis of non-stationarity of the series while the KPSS tests the null of stationarity of the series. For the LS test with two structural breaks, the model C, which allows for a change in both the level and trend is used. The model C of the LS test is performed under the following data generating process:

$$p_t = \alpha' z_t + e_t, \quad e_t = \beta e_{t-1} + \varepsilon_t \tag{1}$$

where p is the crude oil price series, $z_t = [1,\ t,\ D_1,\ D_2,\ DT_1,\ DT_2]'$, and $\varepsilon_t \backsim iid(N, \sigma^2)$. $D_{jt} = 1$ for $t \geq T_{B_j} + 1$ $(j = 1,2)$ and zero otherwise, and $DT_{jt} = t$ for $t \geq T_{B_j} + 1$ $(j = 1,2)$ and zero otherwise where T_{B_j} represents the time period when the break occurs.

Second, the Bai and Perron (BP) (1998) multiple structural break test is conducted on the price series to see if structural breaks persist in these markets. This test is useful when identifying unknown breaks in the price series. The three price ratios, WTI/Brent, WTI/Dubai, and Brent/Dubai are used for the BP test. The test is conducted using the following model:

$$P_t = R_t'\beta_j + u_t \quad (t = T_{j-1}+1, \ldots, T_j,\ j = 1, \ldots, m+1) \tag{2}$$

where P_t is the price ratio between the three crude oil price series at time t $(t = 1, \ldots, T)$, R_t is the vector of regressors, which include the intercept and the first order lag of P_t, β_j is the corresponding vector of regression coefficients, and by convention, $T_0 = 0$ and $T_{m+1} = T$. *m* is the maximum number of breaks used for the test, and in this study, *m* is set to five. The unweighted (UDmax) and weighted (WDmax) double maximum tests are performed to find out if at least one break exists in the price series. Then, the statistically optimum number of breaks are identified by the $supF(l+1|l)$ test. The null hypothesis of this test is that the optimum number of breaks is l while the alternative hypothesis states that the optimum number of breaks is $l+1$.

Finally, the Hatemi-J (2008) cointegration test with two structural breaks is applied to see if price linkages sustain among the WTI, Brent, and Dubai crude oil markets. The Hatemi-J cointegration model has the following form:

$$p_t^1 = c + \alpha_1 D_{1t} + \alpha_2 D_{2t} + \beta_0' p_t^2 + \beta_1' D_{1t} p_t^2 + \beta_2' D_{2t} p_t^2 + \mu_t \tag{3}$$

where p_t^1 and p_t^2 are the mix of two crude oil price series to be tested, c is the intercept, α_i $(i = 1,2)$ is the change in the intercept due to the breaks, β_0 is the coefficient of the price series p_t^2 which captures the effect of p_t^2 on p_t^1, and β_i $(i = 1,2)$ denotes the change in the coefficient due to the breaks. D_{it} $(i = 1,2)$ is a dummy variable defined as $D_{it} = 0$ for $t \leq n\tau_i$, and $D_{it} = 1$ for $t > n\tau_i$ where *n* is the number of observations. $\tau_i \in (0,1)$ represents the relative timing of the regime change point. Equation (3) is the model used in this study and this model is based on Model 4 of Gregory and Hansen (1996). The main difference of the Hatemi-J model from the Gregory-Hansen model is that this model considers two breaks instead of one break in the model. The cointegration test is conducted by testing the stationarity of μ_t using the modified ADF, z_t, and z_α test statistics (see Gregory and Hansen (1996), and Hatemi-J (2008) for details). These test statistics are defined as follows:

$$\mathrm{ADF}^* = \inf_{(\tau_1,\tau_2)\in T} ADF(\tau_1,\tau_2), \tag{4}$$

$$z_t^* = \inf_{(\tau_1,\tau_2)\in T} z_t(\tau_1,\tau_2), \tag{5}$$

$$z_\alpha^* = \inf_{(\tau_1,\tau_2)\in T} z_\alpha(\tau_1,\tau_2), \tag{6}$$

where $\mathrm{T} \in (0.15\mathrm{n}, 0.85\mathrm{n})$. The null hypothesis of no cointegration with structural breaks is tested by using the smallest values of these test statistics across all values for τ_1 and τ_2, with $\tau_1 \in T_1 = (0.15, 0.70)$ and $\tau_2 \in T_2 = (0.15 + \tau_1, 085)$. As seen in this setting of the test statistics, the distance between the two break points is at least set to shift for 15%. This assumption is based on the foot-steps of Gregory and Hansen (1996).

All the crude oil price series used in this study are obtained from the International Monetary Fund (IMF) Primary Commodity Prices. The WTI price series represent the monthly prices of US$ per barrel of West Texas Intermediate light crude oil with an API gravity of around 40, the Brent prices are the US$ per barrel of Brent light blend crude oil with an API gravity of around 38, and the Dubai prices are the US$ per barrel of Fateh medium sour crude oil with an API gravity of around 32. The monthly price series for the 2001:1 to 2014:5 period are used in the study.

3. Results

To find out if the crude oil price series are stationary, the PP, KPSS, and Lee-Strazicich (LS) tests are performed on the price series. WTI(1), Brent(1), and Dubai(1) in Tables 1 and 2 denote the first differences of the price series. As seen in Tables 1 and 2, the results of the PP, KPSS, and LS unit root tests with only a constant suggested that all variables are integrated of the first order. The LS test with a constant and trend indicated that all three crude oil price series are trend stationary. Thus, the results of the stationarity tests imply that all price series are integrated of the same order.

Table 1 Phillips-Perron and KPSS unit root tests

	With only a constant		With constant and trend	
Prices	PP	KPSS	PP	KPSS
WTI	-1.72	1.32 ***	-3.44 *	0.12 *
Brent	-1.47	1.37 ***	-3.35 *	0.06
Dubai	-1.45	1.40 ***	-3.37 *	0.06
WTI(1)	-8.39 ***	0.02	-8.37 ***	0.02
Brent(1)	-8.14 ***	0.03	-8.12 ***	0.03
Dubai(1)	-7.25 ***	0.03	-7.22 ***	0.03

Note: ***, **, and * denote significance at 1%, 5%, and 10%.

Table 2 Two-break Lee-Strazicich unit root test with linear trend

	With only a constant				With constant and trend			
Prices	Test statistic	TB1	TB2	k	Test statistic	TB1	TB2	k
WTI	-4.89	Jun-09	May-12	2	-6.37 **	Jan-08	Nov-08	4
Brent	-4.19	Feb-11	May-12	2	-5.33 *	Aug-08	May-11	2
Dubai	-4.68	Jun-09	Apr-12	2	-5.93 **	Jan-08	Apr-09	2
WTI(1)	-10.94 ***	Jun-08	Dec-08	0	-11.14 ***	Jun-08	Dec-08	0
Brent(1)	-9.41 ***	Jun-08	Nov-08	0	-11.07 ***	Jun-08	Dec-08	0
Dubai(1)	-8.08 ***	Apr-08	Apr-09	2	-9.50 ***	Jun-08	Jan-09	2

Note: ***, **, and * denote significance at the 1%, 5%, 10% levels. Critical values used are in Strazicich, Lee and Day (2004). TB1 and TB2 are the estimated break points and k is the optimal lag length.

Table 3 Bai-Perron test results and the break dates identified for the crude oil price ratio

Price ratio	WTI/Brent	WTI/Dubai	Brent/Dubai	
Test	Scaled F-statistic	Scaled F-statistic	Scaled F-statistic	Critical Value
sup-F(1|0)	16.11**	16.11**	45.48**	11.47
sup-F(2|1)	14.57**	14.57**	31.13**	9.75
sup-F(3|2)	16.38**	16.38**	22.67**	8.36
sup-F(4|3)	16.12**	16.12**	17.68**	7.19
sup-F(5|4)	7.50**	7.50**	5.25	5.85
Break date	Jan. 2003, Jan. 2005, Jan. 2007, Feb. 2009, Feb. 2011	Jan. 2003, Jan. 2005, Jul. 2007, Feb. 2009, Feb. 2011	Oct. 2004, Nov. 2006, Jan. 2009, Oct. 2011	

Note: ** denotes significance at the 5% level.

Table 4 Hatemi-J cointegration test

	Modified ADF	Z_t	Z_α
WTI vs. Brent	-6.13**	-5.620	-57.02*
Break dates	Apr. 2006, Mar. 2009	Apr. 2006, Feb. 2009	Apr. 2006, Feb. 2009
WTI vs. Dubai	-6.15**	-5.520	-55.05*
Break dates	Mar. 2006, Oct. 2008	Feb. 2006, Feb. 2009	Apr. 2006, Feb. 2009
Brent vs. Dubai	-7.23***	-7.16***	-80.50**
Break dates	Mar. 2005, Feb. 2006	Feb. 2005, Mar. 2006	Feb. 2005, Mar. 2006

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels based on the critical values taken from Hatemi-J (2008).

Before conducting the cointegration test, the Bai-Perron test is performed on the price ratios between the pairs of the three crude oil price series. The double maximum tests of BP test suggested that at least one break exists in the price ratio series so the sup-F test is used to identify the statistically appropriate number of breaks in the series. As seen in Table 3, the results indicate that at least four to five structural breaks persist in the price series. The Jan. 2003 breaks for the WTI/Brent and WTI/Dubai are likely related to the increased domestic oil demand in the U.S. after the 9/11 attacks in 2001. The Jan. 2005 breaks are perhaps the effect from the OPEC to abandon its price band due to the limited spare production capacity in 2005. Finally, it is noticeable that in all the crude oil price ratios, a break point is found for 2009 and 2011. I believe the 2009 breaks are related to the World financial crisis which occurred in late 2008 and the 2011 breaks reflect the influence from the shale revolution in the U.S. Thus the result of BP test reveals that structural breaks do hold in the benchmark crude oil price series and that it is important to consider the effects of structural breaks when conducting cointegration tests between the three crude oil price series.

Finally, the Hatemi-J cointegration is performed on the three benchmark crude oil prices. As seen in Table 4, the modified ADF statistic suggests that the null of no cointegration is rejected for all the tests performed in this study. This implies that long-run price relationships hold between the WTI and Brent, WTI and Dubai, and Brent and Dubai crude oil prices. However, the result from the z_t test statistic indicates that while the Brent and Dubai crude oil have a cointegration relationship, the WTI crude oil is not cointegrated with the Brent and Dubai crude oil prices. The z_α test statistic also suggests that WTI crude oil is only linked at the 10% significance level with the Brent and Dubai crude oil prices. Gregory and Hansen (1996) suggest that the z_t test statistic is the most powerful of the three test statistics presented in Table 4, so our cointegration tests with structural breaks likely suggest that the long-run relationships between the WTI and the international crude oil market are on the verge of change. This result is likely reflecting the deviation of the WTI price series from the Brent and Dubai price series after late 2010 as shown in Figure 2. It could be that this rise in the WTI-Brent and WTI-Dubai price spread after late 2010 is affecting the price linkages among the major benchmark crude oil markets. It is likely that the U.S. crude oil market is now under structural change in its long-run relationship with the international crude oil market.

4. Conclusions

In early 2011, the WTI-Brent spread became apparent and the longstanding relationship between the WTI and Brent crude oil prices began to change (EIA, 2013), and hence, it was expected that the long-run relationships among the WTI, Brent, and Dubai crude oil markets to alter or disappear. Our cointegration test performed among the three benchmark crude oil prices show that this change in the long-run relationship is not fully occurring at the moment but the relationships between the WTI crude oil and international crude oil market are changing. The Hatemi-J cointegration test indicated that while the Brent and Dubai price series continue to have a cointegration relationship, the WTI and Brent and the WTI and Dubai prices no longer have such a relationship. This results imply that the price relationships between the WTI and the international crude oil market are becoming weaker and it could be that the recent surge in the shale oil production in the U.S. is affecting the WTI market to move apart from the international crude oil market. If so, the WTI-Brent spread might not narrow down anytime soon and the spread might continue to hold between the WTI and Brent crude oil markets.

The price of the WTI crude oil being lower than the international crude oil price might sound good news for the U.S. consumers but this does not reflect market reality (IHS, 2014). The reality is that it is the global gasoline market that determines the U.S. gasoline price so the U.S. consumer will not fully benefit from the lower gasoline price unless the global gasoline price starts to decline through the increased U.S. crude oil export. A report by IHS (2014) reveals that lifting the oil export ban in the U.S. will drop the U.S. gasoline price for about 8 cents a gallon, and according to this report, this fall in the gasoline price will create a savings for consumer of $265 billion between 2016 and 2030. The report also claims that the free trade in crude oil will have positive impacts on job growth, trade, government revenues, and economic output. Hence, the results of our study, which revealed that the WTI crude oil price is starting to move apart from the international oil market, might be telling us that it is time the U.S. government to restructure its crude oil export policy.

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