Testing Persistence of WTI and Brent Long-run Relationship after Shale oil Supply Shock

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Outline

- Does WTI and Brent crude oil prices still integrated?
- We investigate the existence and strength of long-run relationships among WTI and Brent prices before and after shale oil supply shock

Introduction

- Crude oil is not a homogenous product
- American Petroleum Institute (API) gravity formula measures:
  - oil's density, light to heavy
  - oil's acidity and sulfur content, sweet (low-sulfur) to sour (high-sulfur) Figure 1
- Two dominant oil reference prices:
  - West Texas Intermediate (WTI): American crude oil benchmark, extracted from wells in US and sent via pipeline to Cushing, Oklahoma
  - Brent-blend (Brent): European crude oil benchmark, extracted from North Sea. Brent (BFOE) is composed of:
    - Brent (started from November 1976), United Kingdom
    - Forties (added from July 2002), United Kingdom
    - Oseberg (added from July 2002), Norway
    - Ekofisk (added from June 2007), Norway

Brent vs WTI

- Brent and WTI crude are classified as sweet light crude oil, however, Brent crude is not as sweet and light as WTI
- Brent has been used to price 60% of the world's internationally traded crude oil supplies
- Historically, Brent and WTI crude oil prices tracked closely, with a price-difference per barrel between +-3 USD/bbl, with WTI usually priced higher than Brent
- Since changes in the spread could bring arbitrage opportunities, these benchmark prices form a long-run relationship leading to an equilibrium position.
- In beginning of 2011, this longstanding relationship began to change, and Brent crude oil starts to priced much higher than WTI Figure 2

Why is Brent taking over?

Many reasons can be cause of this widening such as:

- capacity constraint due to oversupply of crude oil production in North America
- US crude oil export ban
- dollar currency movements
- variation in regional demand
- slow economic rebound in North America
- Brent moved up in reaction to Libyan civil war
- Brent moved up in reaction to civil unrest in Egypt and across the Middle East
- gradual depletion of Brent in the North Sea

Shale Oil

- The application of two technological innovations, horizontal drilling and hydraulic fracturing or fracking have enabled the US to grow dramatically the production of abundant shale oil resources
- Shale oil (tight oil or light tight oil, LTO) is petroleum that contains of light crude oil with low sulfur, found in some rock formation deep below the earth's surface
- Rapid production growth in shale oil in the US has become a significant part of the total oil production. such a significant change might have affected the long-run relationship between WTI and Brent prices Figure 3

Literature Review

- Evidence from previous studies testing whether WTI and Brent crude oil market is integrated is mixed. Reboredo (2011) suggest that crude oil prices are linked with the same intensity during bull and bear markets, thus supporting the hypothesis that oil market is 'one great pool'. Gülen (1999), Hammoudeh et al. (2008), and Wilmot (2013) supports the idea of the globalisation hypothesis. on the other hand, Wiener (1991) find out "the world oil market is far from completely united".
- Kim et al. (2013) have find that long-run relationships among WTI, Brent and Dubai crude oil prices hold during 1997M01 to 2012M07, even when the effects of the breaks are considered.

Literature Review

- Kentanka Aruga (2015) investigate that WTI no longer have a long-run relationship with the Brent and Dubai crude oil markets.
- Büyükşahin et al. (2013) find structural break in the long-term relationship between WTI and Brent occur in 2008 and 2010.
- However, these studies do not test the long-run relationship between WTI and Brent with considering shale oil quantity based on statistical evidence but rather on descriptive data on the movement of the prices.

Methodology

- A necessary but yet not sufficient condition for time series to exhibit a long-run relationships, first, is to show that all variables under consideration are non-stationary at level.
- Then, we perform a cointegration test to find out if there exists some linear combination of this series which produces a stationary trend I(0).
- Gregory and Hansen (1996) cointegration used for cointegration analysis with possible structural breaks.
- After ensuring the existence of the cointegration relationship across the variables, we set a Vector Error Correction Model (VECM) to identify the long-run relationships between these variables before and after structural break.

Methodology - Gregory and Hansen cointegration test

- Gregory and Hansen (1996) cointegration test use when the timing of structural break is unknown. Four models can be applied in order to test cointegration according to the type of structural change.

  Model 1: Standard cointegration

$$y_{1t} = \mu + \alpha^T y_{2t} + e_t, \quad t = 1, ..., n \tag{1}$$

where y_{1t} and y_{2t} are $I(1)$ and e_t is $I(0)$. Model taking into account regime shift either in μ or α by defining the dummy variable:

$$\phi_{t\tau} = \begin{cases} 0 & if \quad t \leq [n\tau] \\ 1 & if \quad t \geq [n\tau] \end{cases}$$

where the unknown parameter $\tau \in (0, 1)$ denotes the timing of the structural change.

Methodology - Gregory and Hansen cointegration test

Model 2: Level shift (C)

$$y_{1t} = \mu_1 + \mu_2 \phi_{t\tau} + \alpha^T y_{2t} + e_t, \quad t = 1, ..., n \qquad (2)$$

where μ_1 is the intercept before the shift, μ_2 is the change in the intercept at the time of the shift.

Model 3: Level shift with trend (C/T)

$$y_{1t} = \mu_1 + \mu_2 \phi_{t\tau} + \beta t + \alpha^T y_{2t} + e_t, \quad t = 1, ..., n \qquad (3)$$

here, introducing a time trend into the level shift model.

Model 4: Regime shift (C/S)

$$y_{1t} = \mu_1 + \mu_2 \phi_{t\tau} + \alpha^T y_{2t} + \alpha_2 y_{2t} \phi_{t\tau} + e_t, \quad t = 1, ..., n \qquad (4)$$

allows a structural break in the cointegrating vector α as well as the intercept μ.

Methodology - Gregory and Hansen cointegration test

- In all four, the null hypothesis of no cointegration can be tested by examining whether the residuals e_t follow $I(0)$.
- The test statistics Z_a^* and Z_t^* are based on Phillips-Perron test statistics, while ADF^* is based on Augmented Dickey-Fuller statistics.
- The null hypothesis is rejected if the statistic ADF^*, Z_a^* and Z_t^* is smaller than the corresponding critical value.

Methodology - Vector error correction model

- To evaluate the existence of the long-run relationships across the three variables we need to show the existence of cointegration between them.
- As the VECM specification only applies to cointegrated series, we refer to the tests of Johansen (1988, 1996) and determine the number of cointegrating relations. The presence of a single cointegration relationship allows for taking into account the VECM described as:

$$\Delta X_t = \alpha\beta' X_{t-1} + \sum_{j=1}^{p} \Phi_j \Delta X_{t-j} + \delta D_t + \varepsilon_t$$

where X_t is the vector of the modeled variables, $\beta' X_{t-1}$ is the disequilibrium error, β contains cointegration coefficients, α contains the adjustment coefficients to past disequilibrium, D_t is a set of deterministic variables, constant and linear trend.

Data

- We use monthly real spot prices of WTI and Brent crude oil (US dollars per barrel) and monthly shale oil quantities and US crude oil production (Thousand barrels per day) from US Energy Information Administration (EIA)
- The observation period ranges from January 2000 to August 2016, for a total of 200 observations per variable

Data Analysis

- Table 1 shows that WTI and Brent prices growth rates are, on average, negative in the second subsample, while US crude oil production (WTI quantity) increases from February 2011 onward, mostly due to the increase in shale oil production Table 1
- Perron (1997) unit root test that allows for a break at an unknown location, suggest that all series are non-stationary at level and they are integrated of order one, $I(1)$ and the break dates with a minimum test statistics occur in February 2011 and June 2012 Table 2

Empirical Analysis

- Gregory and Hansen (1996) results demonstrate the existence of a cointegration relationship among WTI and Brent prices, all three statistics point out that a structural break occurred in October 2010 and February 2011. Table 3
- In case of WTI, Brent prices and shale oil quantity, the test results indicates the existence of cointegration and the break occur in February 2011 and April 2013.
- This confirms the location of the break as rise in shale oil production from early 2011, that affect the relationships among the WTI and Brent prices in the form of structural breaks.

Empirical Analysis

- In first column, Table 4, Johansen's test result indicates the presence of cointegration when accounting for a break as a step dummy variable assuming value 1 from February 2011
  Table 4
- VECM model reclaim the existence of long-run relationship between WTI and Brent prices in full sample
- In second column, Table 4, empirical evidence suggests the presence of a single cointegration relationship among three variables.
- VECM model recover the presence of a long-run equilibrium among WTI and Brent prices and shale oil quantity in full sample

Empirical Analysis

- To assess the role played by rise of shale oil production, we replicate the analysis, by splitting the whole sample period into two sub-samples, January 2000 to January 2011, and February 2011 to August 2016 Table 5
- First and third column in Table 5, we see the presence of a long-run equilibrium.
- In contrast, the second and forth column in Table 5, show that there is no longer long-run relationship between variables.
- The sub-sample evidence confirms that the relationship between WTI and Brent prices has been affected by rise of shale oil production

Conclusions

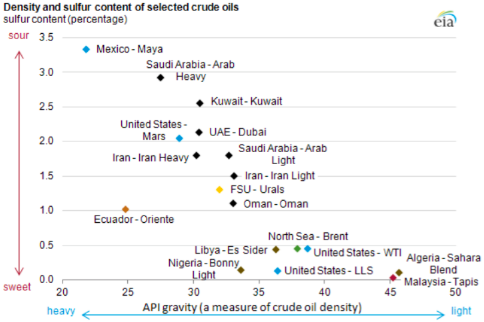
- We test the long-run behaviour applying VECM and show that the prices exhibit a long-run relationship in full-sample.
- We then replicate the analysis by splitting the data into sub-samples, we find out there is no longer long-run relationship among the prices from 2011 onward.
- However, due to insufficient time series length it is not possible to assess whether or not a new long-run relationship has been established between time series after 2011, and thus further research is needed on this topic.

Recent WTI - Brent spread

- The WTI-Brent spread has narrowed considerably over the past several months:
  - Brent prices are lowered because Brent crude imports to North America have been displaced by increased US shale oil production, reducing Brent crude demand
  - WTI prices raised because the infrastructure limitation that had lowered WTI prices are lessening - new pipelines at Cushing
  - In 2014, US allowed export of a type of minimally processed ultra-light oil called as condensate
  - Lifting the 40-year-old ban on US crude oil export in December 2015 Figure 4
  - In response to continued low oil prices, in both WTI and Brent, shale oil production decline from late 2015

Thank you!

Figure 1. Classification of conventional crude oil benchmarks



Source: US Energy Information Administration. MARS refers to an offshore drilling site in the Gulf of Mexico. WTI = West Texas Intermediate. LLS = Louisiana Light Sweet. FSU = Former Soviet Union. UAE = United Arab Emirates

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Figure 2. WTI, Brent monthly spot prices and their spread

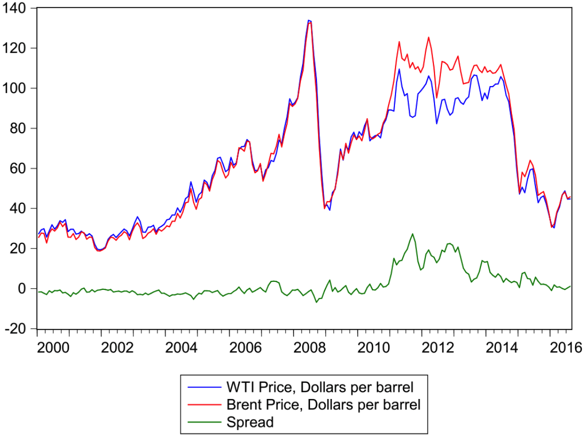

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Figure 3. US Crude oil and Shale oil Production

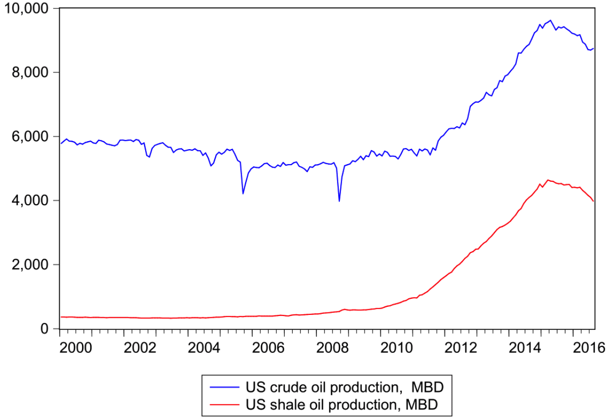

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Figure 4: US Export of Crude oil, TBD

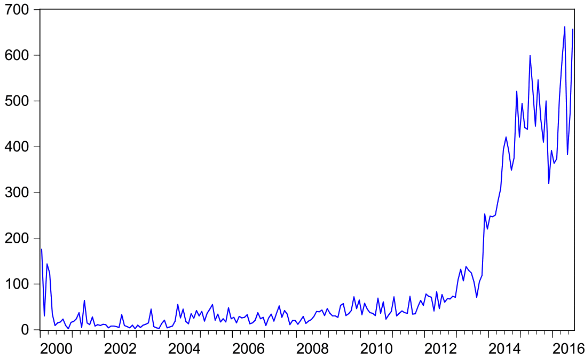

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Table 1: Descriptive analyses of monthly growth rates

	WTI Price	Brent Price	WTI Quantity	Shale Oil Quantity	WTI without Shale Oil	WTI Price	Brent Price	WTI Quantity	Shale Oil Quantity	WTI without Shale Oil
	Full sample									
Mean	0.003	0.003	0.002	0.012	-0.001					
Median	0.014	0.017	0.002	0.008	-0.002					
Maximum	0.214	0.198	0.175	0.081	0.189					
Minimum	-0.332	-0.311	-0.230	-0.029	-0.264					
Std. Dev.	0.089	0.093	0.032	0.021	0.036					
Skewness	-0.830	-0.907	-2.468	0.590	-2.394					
Kurtosis	4.419	4.133	29.334	3.039	27.199					
	2000M01 - 2011M01					2011M02 - 2016M08				
Mean	0.009	0.010	-0.001	0.007	-0.002	-0.010	-0.010	0.007	0.021	0.000
Median	0.023	0.030	-0.000	0.004	-0.001	0.013	-0.003	0.007	0.024	-0.002
Maximum	0.204	0.198	0.175	0.073	0.189	0.214	0.196	0.056	0.081	0.060
Minimum	-0.332	-0.311	-0.230	-0.022	-0.264	-0.245	-0.266	-0.027	-0.029	-0.052
Std. Dev.	0.091	0.097	0.037	0.018	0.041	0.086	0.085	0.017	0.024	0.022
Skewness	-1.088	-1.055	-2.258	0.929	-2.365	-0.333	-0.683	0.548	-0.096	0.340
Kurtosis	5.080	4.246	23.799	4.205	23.327	3.534	4.281	3.336	2.558	3.045

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Table 2: Perron unit root test

	Break in Trend & Intercept				Break in Intercept				Break in Trend			
	Break dates	Lags	Test statistics	C.V. at 5%	Break dates	Lags	Test statistics	C.V. at 5%	Break dates	Lags	Test statistics	C.V. at 5%
WTI Price	2012M06	1	-4.00	-5.59	2014M02	1	-3.44	-5.23	2012M12	1	-3.90	-4.83
Brent Price	2012M06	1	-4.01	-5.59	2014M02	1	-3.33	-5.23	2013M05	1	-3.86	-4.83
Shale oil Q.	2002M11	4	-2.13	-5.59	2011M02	4	-4.06	-5.23	2002M10	4	-2.12	-4.83

[1] The table reports the critical values of the Perron (1997) unit root test in the presence of a structural break in a series intercept and/or linear trend. We consider three different cases: break in both trend and intercept; break in intercept only; break in trend only. The table also includes the optimal break date for each series and the optimal number of lags used for the computation of the test statistic. The null hypothesis of the test is the presence of a unit root.

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Table 3: Gregory - Hansen cointegration test results

	ADF^* Test statistics	Break dates	Z_t^* Test statistics	Break dates	Z_a^* Test statistics	Break dates	ADF^*, Z_t^* C.V. at 5%	Z_a^* C.V. at 5%
WTI and Brent								
C	-5.7108	2011M02	-5.8022	2010M10	-59.2108	2010M10	-4.61	-40.48
C/T	-5.9822	2010M10	-6.0670	2010M10	-64.0348	2010M10	-4.99	-47.96
C/S	-6.1006	2010M10	-6.2026	2011M02	-66.3670	2010M10	-4.95	-47.04
WTI, Brent, Shale oil								
C	-6.4989	2013M04	-6.5811	2013M04	-72.2465	2013M04	-4.92	-46.98
C/T	-6.7044	2013M04	-6.8293	2013M04	-76.9138	2013M04	-5.29	-53.92
C/S	-7.2399	2011M03	-7.2885	2011M02	-86.1468	2011M02	-5.50	-58.33

[1] Note that C.V. stand for critical value.

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Table 4: Full sample cointegration estimation

Included Variables	WTI Price Brent Price	WTI Price Brent Price Shale Oil Quantity
Lags	2	2
No. of cointegration	1	1
Trace	45.48*	84.13*
P-value	0.0034	0.0000
Critical value at 5%	36.10	57.43
Max. Eig.	42.21*	47.79*
P-value	0.0001	0.0161
Critical value at 5%	26.10	43.22
Deterministic	IC, IV	IC, IV
Exogenous	D11, D11*T	D11, D11*T
Cointegration equation: $WTI_t - \mu - \beta_1 Brent_t - \beta_2 ShaleQ_t = \epsilon_t$		
WTI Price	1	1
Shale Oil Quantity		0.091 (0.033)
Brent Price	-0.951 (0.012)	-0.948 (0.017)
Adjustment coefficients:		
WTI Price	-0.528 (0.175)	-0.379 (0.170)
Shale Oil Quantity		0.084 (0.031)
Brent Price	-0.156 (0.190)	-0.033 (0.183)

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Table 5: Sub-samples cointegration estimation and coefficients for VECM

Included Variables	WTI Price Brent Price	WTI Price Brent Price	WTI Price Brent Price Shale Oil Quantity	WTI Price Brent Price Shale Oil Quantity
Sample	2000M01 - 2011M01	2011M02 - 2016M08	2000M01 - 2011M01	2011M02 - 2016M08
Lags	2	1	2	4
No. of cointegration	1	0	1	0
Trace	27.44*	12.16	42.77*	34.44
P-value	0.0005	0.1491	0.0062	0.0574
Critical value at 5%	15.49	15.49	35.01	35.01
Max. Eig.	26.57*	11.70	31.06*	18.72
P-value	0.0004	0.1223	0.0054	0.2274
Critical value at 5%	14.26	14.26	24.25	24.25
Deterministic	IC, IV	IC, IV	IC, IV, TC	IC, IV, TC
Cointegration equation: $WTI_t - \mu - \beta_1 Brent_t - \beta_2 ShaleQ_t = \epsilon_t$				
WTI Price	1		1	
Shale Oil Quantity			0.100 (0.037)	
Brent Price	-0.945 (0.010)		-0.945 (0.020)	
Adjustment coefficients:				
WTI Price	-0.816 (0.268)		-0.721 (0.287)	
Shale Oil Quantity			0.111 (0.051)	
Brent Price	-0.496 (0.299)		-0.369 (0.322)	

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