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Cointegration in the Oil Market among Regional Blends

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ABSTRACT: The integration of crude oil spot prices, from different geographic regions is examined using the residual-based cointegration test of Gregory and Hansen (1996), which allows for endogenously determined structural breaks. While traditionally, the focus has been on three global benchmark crudes (WTI, Brent and Dubai Fateh), herein the relationship among secondary, regional blends (Edmonton Par, Western Canadian Select, Bonny Light and Mexican Maya) is examined with implications for the 'global pool' hypothesis. Monthly data is examined, with particular emphasis placed on the Canadian perspective. The results indicate that the regional crudes, of similar and differing grades, are cointegrated with a structural break. Events with a direct impact on the crude market are linked to the structural breaks. Indirect impacts are attributed to events which appear to have affected crude oil prices via a decrease in demand, such as the economic uncertainty leading to and during the 'Great Recession'.

Keywords: Spot prices; cointegration; structural breaks
JEL Classifications: C22; Q4

1. Introduction

The synchronicity of world oil markets is a question that has received significant attention in the literature. Early on, Adelman (1984) described the world oil market as 'one great pool', suggesting that crude oil prices from different regions are linked. Theoretical support for the globalization hypothesis is provided by the 'law of one price' and arbitrage, which would suggest that large divergences in crude oil prices should not appear. Rather, prices of crude oils with similar quality should move closely together, such that their price differential is more or less constant. For many years, the Brent – West Texas Intermediate (WTI) spread followed such a pattern – the price differential fluctuating within a relatively constant range. However, since late 2010, there has been a significant widening of this differential, which casts doubt on the integration of such markets. An alternative to the 'global pool' hypothesis is that oil markets are 'regionalized', and therefore react to local market influences and shocks. Such distinctions would have important implications for energy policy, extraction rates for energy firms as well as hedging strategies.

In an early analysis Weiner (1991) applies correlation analysis and a switching regression system to the crude oil market. The results suggest that the crude oil market is highly regionalized, yet the relationships weaken when examined across regions. Milonas and Henker (2001) find that Brent and West Texas Intermediate (*WTI*) markets are not fully integrated. Gulen (1999) argues that regionalization can cause market efficiencies – price differences between markets would give rise to arbitrage opportunities. Such arbitrage would persist until price differentials had been sufficiently reduced, while allowing for transaction costs and differences in quality (sulfur content, API gravity index). More recently, cointegration methods have been used to examine the co-movements of crude oil prices in different markets. Gulen (1997, 1999) provides support for the globalization hypothesis based on the application of such methods. Hammoudeh *et al* (2008) find evidence of a long-run relationship among bivariate spreads (price differential) for several benchmark crudes. Others have used causality tests to demonstrate the existence of a long-run relationship (e.g. Bekiros and Diks, 2008, Ewing and Harter, 2000; Silvapulle and Moosa, 1999). The accumulation of such evidence suggests that the world oil market is indeed unified. Yet, to be considered a truly global oil market, one would expect to find a long-term relationship among the secondary crudes from different regions. Fattouh (2010) studies the adjustment process of crude oil price differentials to the long-run equilibrium, finding that crude oil prices are linked, reinforcing the 'one great pool' hypothesis.

One such 'regional' crude that has recently received much attention, particularly in North American markets originates in Western Canada. Canada has, in recent years become an important producer of crude oil. According to the Energy Information Administration [*EIA*] (2012a), Canada is the world's sixth largest oil producer, with nearly 3.7 million barrels per day (bbl/d) of total oil production in 2011 (an increase of nearly 200,000 bbl/d from 2010). Canada has vast oil reserves of 174 billion barrels, and ranks third in the world for oil reserves behind Saudi Arabia and Venezuela. Some estimates of the amount of total oil reserves that may exist in Canada have reached a staggering 2.5 trillion barrels (Oil and Energy Trends, 2009b). The vast majority of Canadian reserves, currently 98%, are derived from unconventional crude oil sources. Such non-conventional crude reserves are found in geologic formations that are a mixture of sand, water, clay and heavy oil called bitumen and extra-heavy oil. In Canada, the main deposits that are currently being worked in Alberta are classified as 'oil sands' or 'tar sands'. Bitumen, which is in a solid state underground, is both difficult and expensive to extract. Two predominant methods have been developed to extract the petroleum. The deposit can be mined using traditional surface mining methods, which require the bitumen rich earth to be transported to a facility to undergo a separation process. Alternatively, in-situ extraction requires steam be injected into underground to soften the formation, allowing the petroleum to be pumped to the surface. Both techniques require high capital costs as well as large amounts of energy. From 1990 to 2006, Canada has experienced a 50% increase in production of crude oil (NRCAN, 2009). The majority of the recent increases in production are directly attributable to production from the oil sands located in western Canada. The International Energy Agency, [IEA] (2012) forecasts that output from the oil sands will reach 4.3 million barrels per day by 2035. According to the EIA (2012a), Canada is the largest supplier of foreign oil to the United States, with nearly 2.2 million bbl/d of crude imported in 2011. At the same time, Canada is dependent on the US market for exports, with 70% of crude exports being sent to US refineries, particularly to the US Midwest.

The two major crude oil blends produced by Canada are Edmonton Par (Light) and Western Canadian Select (WCS, Heavy). Edmonton Par, which originates out of Edmonton Alberta, is a similar quality to WTI. Western Canadian Select (WCS) is a relatively recent addition, which originates out of Hardisty, Alberta. WCS is a blend consisting of conventional Canadian heavy crude and bitumen crude oils, which are further blended with sweet synthetic and condensate diluents (Cenovus, 2010). The majority of the Canadian oil flows to the US Midwest for refining. The US refining market is capable of handling the heavy, high sulphur (sour) crudes like WCS and Mexican Maya. These heavy crudes typically sell at a discount to the light, low sulfur (sweet) crudes like WTI, Brent and Edmonton Par. The abundance of secondary ('non-benchmark') blends available from different regions of the world, allows for an examination of the 'globalized crude oil market' hypothesis.

It is hypothesized that if the market for crude oil is truly integrated, then one would expect that the spot prices of secondary blends, from different regions and of different grades, would be cointegrated. In this paper, the relationship among the regional crudes is examined using a residual-based cointegration test, which will allow for possible structural breaks in the relationship among the crude blends. In the next section, the literature of studies applying cointegration to the oil market is reviewed. Section 3 presents the methodology that is applied to the regional crudes, while Section 4 presents the data used in the study. Section 5 presents the empirical results of the cointegration tests and reviews the timing of the structural breaks. Section 6 contains the conclusion.

2. Existing Studies

The literature that examines the linkages among various combinations of crude oil prices is becoming extensive. Two early studies (Serletis and Banack, 1990; Quan, 1992) found a cointegrating relationship between futures prices and spot prices. More recently, Silvapulle and Moosa (1999), examine daily WTI spot and futures prices, with the result suggesting that a cointegrating relationship between spot and front month futures prices exists, but not between spot and longer dated futures prices. Additionally, it is determined that a one-directional (linear) causal relationship exists from futures prices to spot prices. Such results have important implications in terms of market efficiency. The authors interpret the absence of a cointegrating relationship between spot and longer dated futures price as providing support for market inefficiency. Hammoudeh and Li (2004) find a cointegrating relationship when examining daily spot and futures prices for WTI. Using a vector error-correction model (VECM), the results suggest the presence of unidirectional causality from the 3-month futures price to the spot price, for the period prior to the Asian crisis. Hammoudeh *et al.* (2008) find that spot and futures contracts among the benchmark crude oils are cointegrated, with a long-run, stable relationship that offers little room for arbitrage. That finding is confirmed by Maslyuk and Smith (2009), who do incorporate structural breaks in the analysis. From the literature on long memory, Choi and Hammoudeh (2009) examine crude oil spot and futures prices, while incorporating structural changes. The results suggest that structural breaks reduce the long memory parameter for oil price returns. Yet, all such investigations, with the exceptions noted above, examine conventional cointegration analysis which does not allow for structural breaks. The implication of these studies is that the long-run relationship is unchanged. Rather, it is likely that such an assumption is too strong given the dynamic nature and many influences that affect crude prices. Indeed, Hansen (1992) discusses how the long-run relationship between the series can change in the presence of a structural break.

Studies are beginning to emerge, which examine the effect on the long-term relationship and the timing of such breaks. Cunado and Perez de Garcia (2003) utilize the Gregory and Hansen [GH] (1996) residual-based cointegration test to examine whether there is a change in the long run relationship between inflation and national oil prices. Maslyuk and Smith (2009) also employ the GH test and find cointegration between spot and futures prices of the same and different grades. While our study is most similar to that of Maslyuk and Smith (2009), we make several modifications. Foremost, the data of interest is for secondary crudes, rather than for benchmark crudes, which allows for investigation of the hypothesis that world oil markets are highly integrated. In particular, the focus is on Canadian crudes and the potential for long-term relationships with other secondary crudes. With the exception of Hughes (2010), it would appear that the crude oil coming out of Canada has received little attention in the literature. Additionally, our data is less frequent (monthly) which may impact the ability of the test to determine structural breaks. Recent research suggests that with lower frequency data, which experiences more volatility, it may be harder to capture the data generating mechanisms (Wilmot and Mason, 2013). Critically, the sample being studied allows for the possibility that the structural break occurred during the period leading up to and including the Great Recession, which would be expected to impact the demand side of the crude oil market.

3. Methodology

Residual-based cointegration tests are routinely employed by time series researchers. While many tests are based on the assumption that the cointegrating vector remains unchanged over the sample period, it is possible that structural changes could occur causing the cointegrating vector to shift. Such changes may be caused by technological shocks, policy changes or regime changes. Several tests have been developed to explicitly account for the possibility of one or more structural breaks (Gregory and Hanson, 1996; Bai and Perron, 2003; Hatemi-J, 2008). Gregory and Hansen, (GH) (1996) show that the power of conventional cointegration tests is significantly compromised, when a structural break is present. To account for an unknown structural break, GH provides augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) – based cointegration tests. The test allows for the shift to occur in the intercept, trend or cointegrating vector, while the timing of the break is endogenously determined. The GH methodology is applied in the current analysis, allowing for comparisons with existing literature.

Engle and Granger (1987) provided critical values for the ADF test for cointegration, without any structural break. The rejection of the Engle and Granger (1987) null hypothesis implies the variables are cointegrated, whereas acceptance of the null hypothesis is taken as evidence against a stationary distribution of the linear combination of variables. The residuals for the standard model of cointegration (no structural change) are obtained from

$$y_{1t} = \mu + \alpha y_{2t} + e_t, \qquad (1)$$

where y_{it} is $I(1)$, for $i = 1, 2$ and e_t is $I(0)$. To allow for the possibility that the long-run relationship changes over time, the intercept, μ, and / or slope, α, could adjust to reflect the change. Gregory and Hansen (1996) introduce a residual-based cointegration test that allows for structural changes that would be reflected in the intercept, the vector of coefficients or both. Through the introduction and application of the dummy variable defined as

$$\varphi = \begin{cases} 0 & \text{if } t \le [n\tau] \\ 1 & \text{if } t > [n\tau] \end{cases}, \tag{2}$$

the authors analyze four unique models. The first model is the standard cointegration model, described by equation (1) – the parameters are assumed to be time-invariant. The second model, denoted C, allows for a shift of the intercept,

$$y_{1t} = \mu_1 + u_2\varphi_{t\tau} + \alpha y_{2t} + e_t, \tag{3}$$

where the subscripts $i = 1, 2$ on μ, denote the periods before and after the regime shift, respectively. The third model, denoted C/T introduces a time trend to the previous model,

$$y_{1t} = \mu_1 + u_2\varphi_{t\tau} + \beta t + \alpha y_{2t} + e_t. \tag{4}$$

The fourth possibility, model C/S, allows for a shift in the intercept and slope, and is represented as

$$y_{1t} = \mu_1 + u_2\varphi_{t\tau} + \alpha_1 y_{2t} + \alpha_2 y_{2t}\varphi_{t\tau} + e_t. \tag{5}$$

The procedure for testing the null hypothesis of no cointegration involves examining the residuals of the OLS regression applied to equations (1) and (3) – (5).

The single break date is endogenously determined in each of the models. It requires estimating the cointegrating equations for all possible break dates in the sample, within the permitted range of $[0.15T] \le \tau \le [0.85T]$. The break date is determined where the test statistic is the minimum value (most negative) of either the *ADF* test statistics or the Phillips-Perron (*PP*) test statistics,

$$ADF^* = \inf_{\tau \in T} ADF(\tau) \quad Z_t^* = \inf_{\tau \in T} Z_t(\tau) \quad Z_a^* = \inf_{\tau \in T} Z_a(\tau)$$

The null hypothesis is rejected if the test statistic is less than the critical values provided by Gregory and Hansen (1996; Table 1). This approach has the advantage in that the data is used to determine if there is a structural break and when it occurs.

4. Data

Monthly spot prices for seven varieties of crude oil are examined over the period of 1991 to the middle of 2012. Canadian crude oil prices were obtained from Natural Resources Canada, WTI and Brent were obtained from EIA, while the remaining blends were obtained from Bloomberg. Table 1 gives summary statistics for the monthly prices of the seven blends analyzed. The table also contains information on the API gravity, an inverse measure of the density of a petroleum liquid relative to water. A value of 22° or below represents heavy crude oil, while larger numbers represent medium or light crudes (above 31°), which have a lower density relative to the heavy crudes. Additionally, the table contains information on the sulphur content of the various crude blends, which determines the sweet / sour classification of the crude. Accordingly, the EIA (2012b) lists these two characteristics as the main variables in determining the purchase cost of crude oil, with factors such as location and transportation costs also considered important. Furthermore, the EIA notes that the lighter, sweet crude oils command a premium price on world markets, relative to the heavier, sour cousins (Mexican Maya, WCS).

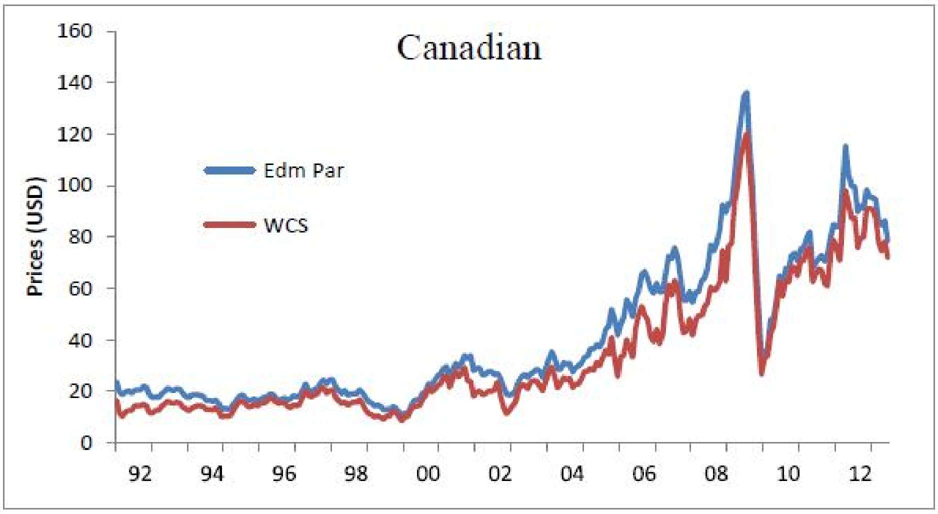
The period of study covers a number of events that, a priori, would be capable of causing changes in the relationship among the crude oils examined. Figure 1 plots the spot prices of Edmonton Par and Canadian Heavy over the period 1991 through June, 2012. As is typically observed with the traditional benchmarks, the 1990s were a period of relative calm, with prices experiencing very little variance. The post 1990s period has seen a dramatic increase in both the price and volatility of these crudes; an experience similar to the more familiar benchmark crudes.

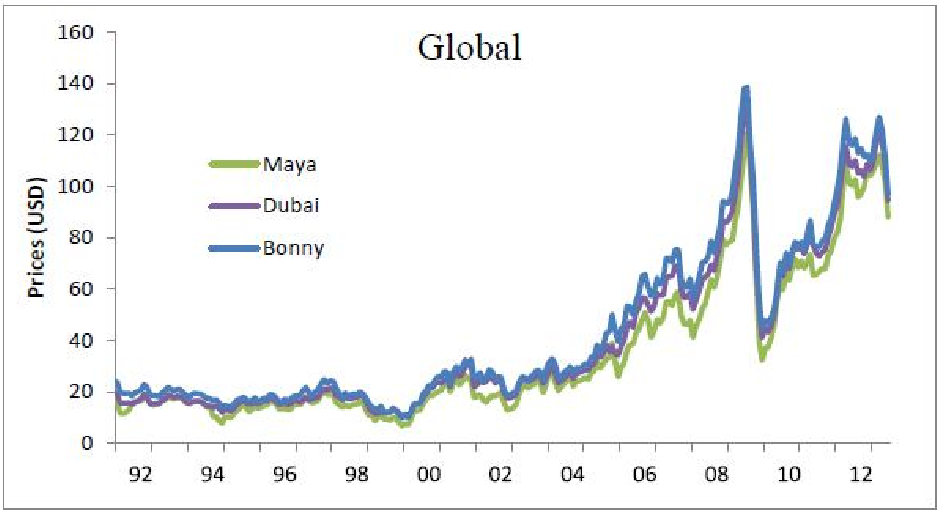
Table 1. Summary Statistics: Monthly Crude Oil Spot Returns

	Bonny	Dubai	Maya	WTI	Brent	Edm Par	WCS
Average	0.0054	0.0061	0.0064	0.0046	0.0054	0.0046	0.0057
Median	0.0156	0.0154	0.0219	0.0139	0.0156	0.0142	0.0158
Standard Deviation	0.0861	0.0808	0.1064	0.0808	0.0858	0.0881	0.1172
Coefficient of Variation	1592.50	1325.17	1660.63	1757.10	1579.53	1893.84	2047.03
JB	28.348	102.426	108.562	60.582	37.145	181.502	46.687
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
n	257	257	257	257	257	257	257
API	37 Light	31 Medium	22 Heavy	40 Light	37 Light	38 Light	20.5 Heavy
Sulfer	0.10 Sweet	2.00 Sour	3.30 Sour	0.30 Sweet	0.30 Sweet	0.50 Sweet	3.33 Sour

Notes: The sample period is January 1991 through June 2012. The returns are the natural log difference in monthly prices. The *API* gravity values and sulfur contents were obtained from Appendix A of the Monthly Foreign Crude oil acquisition report (http://www.eia.gov/survey/form/eia_856/eia856appa.pdf).

Figure 1. Monthly Crude Oil Spot Prices





In assessing which events are likely to have a structural impact on crude oil prices, we follow the logic of Maslyuk and Smith (2009). It is expected that direct events – events likely to have a direct impact on crude oil market – would impact oil markets, while indirect events – events likely to have impacted the economy – would not directly affect oil markets. For example, the closure of several Gulf Coast refineries, due to the impact of hurricane Katrina in 2006 would be expected to directly affect the oil market. The outbreak of severe acute respiratory syndrome (SARS), however, would be considered an indirect effect. Additionally, it is expected that events related to the largest oil consuming or producing nations would have an impact on oil prices. For example, the economic uncertainty and turmoil leading to the recent 'Great Recession' acutely impacted several large oil consuming nations (United States and some European nations among others) and would be expected to adversely impact the crude oil market. Similarly, disruptions in supply (Nigeria, Venezuela) and changes to production levels (Iraq, Libya, Canada, U.S.) would have an impact on oil prices during this period.

5. Empirical Results

Conventional unit root tests (*ADF, PP, KPSS*) were applied to the individual crude oil price series. The results, which are not reported for brevity, indicate that the series are integrated of order one ($I(1)$). Such results correspond to those observed by others in the literature (e.g. Sivapulle and Moosa, 1999; Ewing and Harter, 2000; Postalie and Picchetti, 2006). A bivariate cointegration relationship was tested for using the Gregroy and Hansen (1996) test among the regional spot prices, for crude oils of both a similar and different grades. The conclusions are based on the Z_t statistic which is described by Gregory and Hansen (1996) as the most powerful statistic considered. The results of the test, which are presented in Table 2, indicate that 'regional' crudes, of similar and varying densities, are cointegrated. Notably, the results are all significant at the traditional levels, with the majority significant at the 1% level.

Interest lies in examining the timing of the structural break, based on the test statistics. There seems to be very little variation in the timing of the structural breaks. The earliest structural break is determined to be in October 2007, while the latest date is March 2009, both of which are indicated with vertical lines on Figure 2. This time period covers the rapid ascent and subsequent and equally rapid descent of crude oil prices. A number of events which directly relate to oil markets correspond to the dates listed in the table.[1]

The late 2007 date corresponds to an increase in OPEC production, while the early 2008 dates align with a number of disruptive events in oil-producing countries. A bomb attack in Iraq forced the closure of a pipeline, while nearly 40% of Nigeria's production was shut-in due to militant attacks, sabotage and labor strikes. The summer 2008 dates correspond to the 'peaking' of crude oil prices (July, 2008), as well as several hurricanes which impacted the extraction and refinement processes in the US Gulf Coast. In July, Hurricane Dolly affected production in the Gulf, while hurricanes Gustav and Ike, in September closed several Gulf coast oil refineries, resulting in 30 million barrels of crude oil being shut-in. Additional regional attacks (Turkish pipeline, Nigerian pipeline attacks) also affected supply. Demand side impacts – in particular, the decline in demand for gasoline in the U.S. market – are also deemed important. Since gasoline prices had reached more than \$4 a gallon in the U.S., consumers were reducing consumption. This cut in the demand for gasoline is also linked to the onset of the 'Great Recession' which was already eight to ten months old in the U.S. by this time according to the National Bureau of Economic Research (NBER). The severity of this recession was rather slow to develop, but started to become apparent in the summer of 2008, and highlighted by the bankruptcy of Lehman brothers (September 2008). While particularly severe, it seems that the recession could only be responsible for some of the later structural breaks.

[1] Much of the information regarding the events that are likely to impact the oil markets was obtained through correspondence with the EIA directly, as the EIA's Energy Chronology is no longer available online.

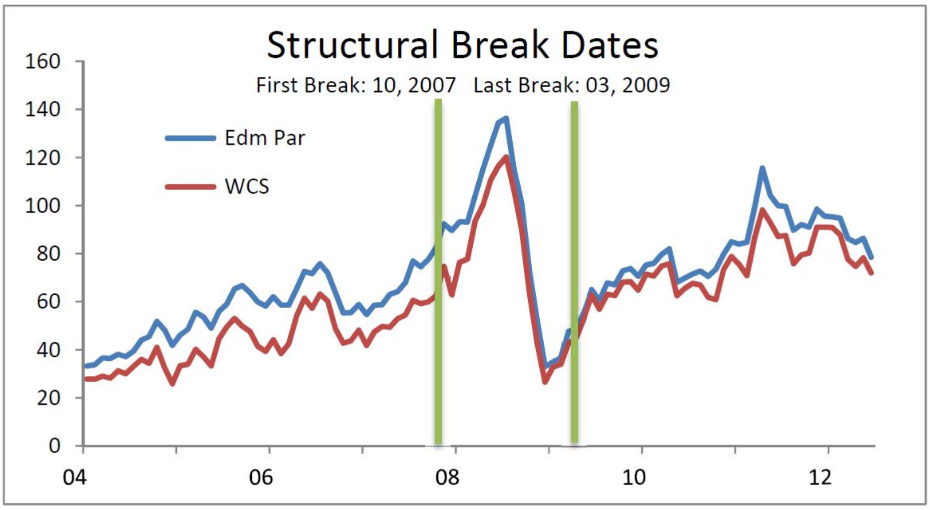
Table 2. Gregory and Hansen (1996) Cointegration Test Results

	ADF		Z_t		Z_α	
	Test Statistic	Break	Test Statistic	Break	Test Statistic	Break
Spot Edm and WCS						
C	-6.3933 *	12/2007	-7.2825 *	01/2008	-88.5057 *	01/2008
C/T	-6.2489 *	04/2008	-7.1523 *	01/2008	-85.6950 *	01/2008
C/S	-6.7015 *	04/2008	-7.9136 *	01/2008	-103.2839 *	01/2008
Spot Edm and Maya						
C	-4.9067 **	01/2009	-4.8542 **	01/2009	-47.0358 **	01/2009
C/T	-5.4213 **	01/2009	-5.2977 **	01/2009	-55.1295 **	01/2009
C/S	-6.6715 *	09/2008	-6.6456 *	08/2008	-80.6308 *	09/2008
Spot Edm and Bonny						
C	-7.1336 *	01/2009	-6.7750 *	01/2009	-88.6153 *	01/2009
C/T	-7.5212 *	01/2009	-7.0827 *	01/2009	-96.6794 *	01/2009
C/S	-8.7573 *	07/2008	-8.0995 *	07/2008	-120.5791 *	07/2008
WCS and Bonny						
C	-7.5683 *	10/2007	-7.2025 *	10/2007	-95.0455 *	10/2007
C/T	-7.6388 *	10/2007	-7.2737 *	10/2007	-97.0131 *	10/2007
C/S	-7.8510 *	07/2008	-7.8992 *	03/2009	-106.2795 *	03/2009
WCS and Maya						
C	-5.8538 *	01/2009	-5.9359 *	01/2009	-65.7556 *	01/2009
C/T	-6.2146 *	01/2009	-6.2883 *	01/2009	-73.2546 *	01/2009
C/S	-8.1892 *	03/2009	-8.3998 *	03/2009	-118.3459 *	03/2009
Bonny and Maya						
C	-7.0177 *	09/2008	-6.6744 *	09/2008	-86.3884 *	09/2008
C/T	-7.2662 *	09/2008	-6.7886 *	09/2008	-87.8551 *	09/2008
C/S	-7.4049 *	09/2008	-6.9834 *	09/2008	-93.2722 *	09/2008

Note: * and ** denote statistical significance at the 1% and 5% level, respectively. The critical values were obtained from Gregory and Hansen (1996), Table 1.

The resulting drop in demand from this period of economic uncertainty led to the extended shutdown of several US refineries. While Canada was relatively protected from the "Summer 2008" meltdown, the majority of Canadian crude exports are directed to the US. Thus, it is apparent that the Canadian crudes were also affected by such a pronounced event. Indeed, the falling price of oil forced BA Energy into bankruptcy protection with the result that work on its heavy oil upgrader near Edmonton was suspended. Additionally, the reluctance of banks to lend forced several companies to reduce or postpone capital expenditures. According to Oil and Energy Trends (2009a), this contraction in the availability of credit has caused the postponement of numerous development projects in western Canada (Petro-Canada, Nexen, Total), three of which had been proposed by Shell. As an additional direct factor, it is noted that in January of 2009, Canada raised its royalty rate on crude oil, increasing the costs of crude production in Canada.

Figure 2. Date Range for the Endogenously Determined Structural Breaks



It is important to note that the March 2009 date represents the latest possible time that a structural break can emerge given the range of data utilized. The implication of this suggests that the break may actually be outside the permitted range. The prominence of this date, and the fact that it was derived from the relationship between the benchmark crudes WTI and Brent, leads to the inference that it may relate to the factors surrounding the recent reversal of the typical spread between WTI and Brent. During the period prior to August 2010, WTI traded at a premium to Brent, but since that time, the spread has been reversed. While several factors have been put forth in explaining this reversal, the main reason has been the excess supply of North American crude oil being directed to Cushing, OK, which has had the effect of driving down the price of WTI. Much of the oil coming out of Western Canada flows through pipelines into Cushing. In addition, the US has seen a significant increase in production relating to the development of tight oil. Both the Bakken oil formation in North Dakota and the Eagle Ford shale formation in Texas have recently experienced rapid increases in production of crude oil. The current level of pipeline capacity is unable to keep up with the increases in production, contributing to the discount of WTI relative to other waterborne crudes, most notably Brent. Unfortunately, the current sample does not allow for a break to occur beyond late 2009 and therefore, future work would certainly need to incorporate this potential direct event.

6. Conclusion

An interesting feature of recent oil markets has been the wide variation in prices experienced across the various types of crude oil. Prices have seen record highs, followed by rapid declines - a feature that is common across numerous varieties of crude oil. It would certainly seem, on the surface at least, that many crude oil prices are linked. Such a high degree of interconnectedness would provide support for the hypothesis that the world crude oil market should be treated as one great pool. The purpose of this study was to quantitatively investigate the theory that world oil markets are 'one great pool' by examining the interconnectedness of secondary crude oil spot markets. Time invariant cointegration tests are contrasted with tests that allow for a structural break in the cointegrating vector. The findings of the analysis indicate all of the series are cointegrated with a structural break. This would imply that the equilibrium relationships among the crude oils were subject to change at least once during the period examined. Such results have important policy implications not only for policy makers in the various regions, but also for energy market hedging, arbitragers, and individuals and firms in the oil industry.

Future research should proceed in two directions. Firstly, as discussed by Masyluk and Smith (2009) the need to include more than one structural break should be investigated. For those crude oil series which overlap, the break dates of Masyluk and Smith (2009) are much earlier than those reported herein. While the sample periods are identical, the earlier dates could potentially been chosen in the current study. The subsequent boom and bust in oil prices suggest later dates dominate those found previously. Thus, allowing for a greater number of breaks over a larger sample seems appropriate, particularly in a market that is affected by a number of direct and indirect factors. Secondly, the effect and timing of the congestion experienced in Cushing, and its impact on the price of WTI and other crudes should be further investigated. It is possible that the scale of this direct event could change the relationship between production and world prices. To alleviate current capacity constraints will require the construction of infrastructure, or the reversal of pipelines, both of which take time to complete. With production in the US and Canada continuing to increase, it seems that capacity constraints will continue to be a concern. Gradually, with the construction of infrastructure or reversal of pipelines these restraints will be reduced. Thus, a model that incorporates gradual change might better capture the nature of the structural break present in crude oil markets. Furthermore, the falling levels of Brent production are likely to increase the notoriety and appreciation for regional crudes and their development. In 2010 the CME introduced a Canadian Heavy Crude Oil Index Futures contract, which was supplemented in 2011, with the introduction of the Western Canadian Select (WCS) crude oil futures contract. Clearly, the rise of Canadian crude and the continued development of the US crude oil market, through important shale oil developments, have and will continue to fundamentally alter the wider crude oil market dynamics.

References

Adelman, M.A. (1984), *International oil agreements*. The Energy Journal, 5(3), 1–9.

Bai, J., Perron, P. (2003), *Computation and analysis of multiple structural change models*. Journal of Applied Econometrics, 18, 1–22.

Bekiros, S. D. Diks, C. G. H. (2008). *The Relationship Between Crude Oil Spot and Futures Prices: Cointegration, Linear and Nonlinear Causality.* Energy Economics, 30, 2673–2685.

Cenovus (2010), *Western Canadian Select (WCS) fact sheet.* Downloaded 10/01/2012. Available: http://www.cenovus.com/operations/doing-business-with-us/marketing/western-canadian-select-fact-sheet.html

Choi, K., Hammoudeh, S. (2009), *Long memory in oil and refined products markets*. The Energy Journal 30, 97–116

Cunado, J., Perez de Garcia, F. (2003), *Do oil price shocks matter? Evidence for some European countries*. Energy Economics 25, 137–154.

Energy Information Administration, [EIA]. (2012a), *Countries analysis brief: Canada*. Downloaded 12/29/2012. Available at: http://www.eia.gov/countries/analysisbriefs/Canada/canada.pdf

Energy Information Administration, [EIA]. (2012b), *Attributes of crude oil at U.S. refineries vary by region*. Downloaded 11/01/2012. Available at http://www.eia.gov/todayinenergy/detail.cfm?id=8130

Engle, R.F., Granger, C.W.J. (1987), *Cointegration and error correction; representation, estimation and testing*. Econometrica, 55, 251–276.

Ewing, B.T., Harter, C.L. (2000), *Co-movements of Alaska North Slope and UK Brent crude oil prices.* Applied Economic Letters, 7(8), 553–558.

Fattouh, B. (2010), *The dynamics of crude oil price differentials.* Energy Economics, 32, 334–342.

Gregory A.W., Hansen, B.E. (1996), *Residual-based tests for cointegration in models with regime shifts.* Journal of Econometrics, 70, 99-126

Gulen, S.G. (1997), *Regionalization in the world crude oil market*. The Energy Journal, 18, 109–126.

Gulen, S.G. (1999), *Regionalization in the world crude oil market: further results*. The Energy Journal, 20, 125–139.

Hammoudeh, S., Li, H. (2004), *The impact of the Asian crisis on the behavior of US and international petroleum prices.* Energy Economics, 26, 135–160.

Hammoudeh, S., Thompson, M., Ewing, B. (2008), *Threshold cointegration analysis of crude oil benchmarks*. The Energy Journal, 29(4), 79–95.

Hansen, B.E. (1992), *Test for parameter instability in regressions with I(1) processes*. Journal of Business and Economic Statistics 10, 321–335.

Hatemi-J, A. (2008). *Tests for cointegration with two unknown regime shifts with an application to financial market integration*. Empirical Economics, 35, 497–505.

Hughes, L. (2010), *Eastern Canadian crude oil supply and its implications for regional energy security.* Energy Policy, 38, 2692–2699

International Energy Agency, [IEA]. (2012), *World Energy Outlook*. International Energy Agency. Paris, France. Available: http://www.worldenergyoutlook.org/

Maslyuk, S., Smyth, R. (2008), *Unit root properties of crude oil spot and futures prices*. Energy Policy, 36, 2591–2600.

Maslyuk, S., Smyth, R. (2009), *Cointegration between oil spot and futures prices of the same and different grades in the presence of structural change*. Energy Policy, 37, 1687–1693.

Milonas, N.T., Henker, T. (2001), *Price spread and convenience yield behavior in the international oil markets*. Applied Financial Economics, 11, 23–36.

Natural Resources Canada, [NRCAN]. (2009). *About crude oil and petroleum products*. Downloaded 10/01/2012. Available: http://www.nrcan.gc.ca/energy/sources/petroleum-crude-prices/1225#production

Oil and Energy Trends. (2009a), *Focus: Non-conventional oil production reassessed as oil prices fall.* Oil and Energy Trends, 34(1), 3–7.

Oil and Energy Trends. (2009b), *The Month in Brief*. Oil and Energy Trends 34(2), 6–7.

Postali, F., Picchetti, P. (2006), *Geometric Brownian motion and structural breaks in oil prices: a quantitative analysis*. Energy Economics, 28, 506–522.

Quan, J. (1992), *Two-step testing procedure for price discovery role of futures prices*. Journal of Futures Markets, 12, 139–149.

Serletis, A., Banack, D. (1990), *Market efficiency and cointegration: An application to petroleum markets*. The Review of Futures Markets, 9(2), 372–380.

Silvapulle, P., Moosa, I.A. (1999), *The relationship between spot and futures prices: evidence from the crude oil market*. Journal of Futures Market. 19(2), 175–193.

Weiner, R.J. (1991), *Is the world oil market 'one great pool'.* Energy Journal, 12(3), 95–102.

Wilmot, N.A., Mason, C.F. (2013), *Jump processes in the market for crude oil*. Energy Journal, 34(1), 33–48.