Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Cointegration between oil spot and future prices of the same and different grades in the presence of structural change

Svetlana Maslyuk, Russell Smyth *

Department of Economics, Monash University, 900 Dandenong Road, Caulfield East, 3145 Victoria, Australia

1. Introduction

Over the past century commodity markets, including oil, have been traditionally very volatile (Pindyck, 2001). High volatility levels, irregular patterns of production and seasonal effects make hedging in any available form, including financial derivatives, a vital necessity. In turn, financial derivatives such as futures or forward contracts, options and swaps depend on the underlying commodity and should reflect its spot price. There are several theoretical models in the literature that explain why we should expect a relationship between spot and futures prices. The precise nature of this relationship will depend on the nature of the commodity (i.e. storable or non-storable), its relative importance in the world economy, seasonal factors, market expectations and the random realization of the news. For spot and futures prices to be related, spot–future parity should exist, which is the essence of the law of one price in futures markets. Spot–futures parity implies that constant arbitrage opportunities based on the spot–futures relationship are not possible.

These ideas are also linked to the theories of storage developed by Kaldor (1939), Working (1948, 1949), Brennan (1958) and Telser (1958) among others. In theory, the equilibrium futures price should be equal to the spot price plus the cost of carry, which is defined as the sum of the cost of storage plus the interest rate (Chance, 1991). According to Leuthold et al. (1989, p.50), “because the costs of storage are fairly constant within the storage season, cash and futures prices of storable are functionally related by these costs and the set of prices move together as a cancellation.” The theory of storage postulates that basis1 as well as futures spread is related through the cost of storage, the convenience yield and the risk premium, which arises from holding a physical commodity in inventory form.

The magnitude and the sign of basis (i.e. backwardation or contango) is referred to as a signal of the shortage or surplus of the physical commodity in the market. Moreover, as the futures contract approaches its maturity date, the basis gets smaller, since the costs of storage are “no longer a factor” (Leuthold et al., 1989, p.50). At maturity, basis diminishes to zero because spot and futures prices converge. If these price relationships do not hold, there are possible arbitrage opportunities in the market. Whether spot and futures prices are related also depends on expectations theory. If the market is efficient in the weak form, futures prices $F_{t+k}$ provide expectations about future spot prices at time $t+k$ (Chance, 1991, p.337). Therefore, there can be at least two formulations of the linear cointegrating relationship depending on which theory is assumed to be true.

The theoretical connection between spot and futures prices is a long-run, rather than short-run, concept. In the short-run, there might be deviations between spot prices and derivative prices. These deviations can be induced by thin trading, lags in information transmission, insufficient inventory levels and seasonal patterns of consumption. In the oil market, backwardation or the situation when futures prices are constantly below the respective spot prices is an example of a deviation that occurs in the short-run. In general, commodity spot prices, including oil, are more variable than futures prices in situations where positive
shocks to demand for spot commodities increase convenience yield (Fama and French, 1988). This is because increases in demand for crude oil due to, say, seasonal factors, may lead to a decrease in inventory levels. Since, at every point in time, oil production is fixed, convenience yield will increase, immediately affecting the price. Moreover, the behaviour of prices during the life of the futures contract will also change, becoming more volatile as the time to maturity gets closer. While spot and futures prices might significantly diverge over the life of the futures contract, futures prices have to converge to spot prices once the contract expires. But, in the long-run, it can be argued that spot and futures prices are driven by the same fundamentals, such as interest rates, macroeconomic variables and oil reserves, because futures prices represent expectations of the future spot prices of the physical commodity. For this reason we should expect spot and futures prices for any commodity to be linked through a long-run equilibrium relationship. This relationship can be tested by examining whether spot and futures prices are cointegrated.

The purpose of this article is to study whether crude oil spot and futures prices of the same and different grades are cointegrated with one structural break in the cointegrating vector using the residual-based Gregory and Hansen (1996) cointegration test. Gregory and Hansen (1996) developed augmented Dickey–Fuller (ADF) and Phillips–Perron (PP)-based cointegration tests to test the null hypothesis of no cointegration against an alternative of cointegration in the presence of a regime shift in a series. The regime shift could occur in the intercept, trend or the entire cointegration vector. Our analysis is based on daily data for two crudes, WTI and Brent, which have well-developed spot and futures markets.

The rest of this article is structured as follows: Section 2 presents a brief literature review of existing studies that have applied cointegration tests to the oil market. Section 3 outlines the methodology employed in the article. Section 4 discusses the data, including potential structural breaks. Section 5 presents the results from the cointegration test. Section 6 discusses the implications of the results and Section 6 contains the conclusion.

2. Existing studies

There is a vast literature that explores whether spot and futures prices for oil are linked in a long-run equilibrium relationship. The early studies employed conventional cointegration tests such as those proposed by Engle and Granger (1987) and Johansen (1988) (see Serletis and Banack, 1990; Quan, 1992; Schwartz and Szakmary, 1994). More recent studies have proposed augmented versions of the cointegrating relationship depending on whether the research is concentrated on futures market efficiency (Silvapulle and Moosa, 1999; Peroni and McNown, 1998; McAleer and Sequeira, 2004) and/or examination of the cost of carry hypothesis (McAleer and Sequeira, 2004). A limitation of these studies is that despite the existence of a potential structural break in oil price data, this literature does not accommodate a structural break in the cointegrating vector. In conventional cointegration analysis cointegrating vectors are assumed to be time invariant. This means that the long-run relationship between the variables is assumed unchanged. However, as pointed out by Hansen (1992), this might or might not be true in the presence of structural breaks. It is possible that if the long-run relationship between the series changed due to a break, then the time-invariant formulation of the cointegrating vector will no longer be appropriate. The only study that has employed a cointegration framework that is robust to structural breaks to examine whether there is a long-run relationship between crude spot and futures oil prices is Cunado and Perez de Gracia (2003). That study employed the Gregory and Hansen (1996) residual-based cointegration test to examine whether there is a long-run relationship between various combinations of national oil prices, the world oil price, inflation rates and industrial production for 15 European countries. For most countries Cunado and Perez de Gracia (2003) could only establish a relationship between inflation and national oil prices.

Summarising, we identify the following gaps in the literature. First, Cunado and Perez de Gracia (2003) is the only study that has applied a cointegration test with structural breaks to oil price data. In contrast to that study, which employed monthly data, in this article we use daily data on spot and futures prices to obtain potential gains in power of the test from the increased data frequency. Second, few studies have examined cointegration between spot prices for one crude and the futures prices for another crude. Exceptions are Sequeira and McAleer (2000), Asche and Guttmannsen (2001) and Silvapulle and Moosa (1999). However, none of these studies have allowed for a structural break in the cointegrating vector. This article intends to fill these gaps by employing cointegration methodology that is robust to the presence of structural breaks to test for a long-run relationship between spot and futures prices of the same grades and different grades for WTI and Brent, using data that are sampled at higher frequency than have been employed in previous studies.

3. Methodology

The conventional Engle and Granger (1987) bivariate cointegration procedure without a structural break is a test for a unit root based on the residuals from the regression below:

\[ y_{1t} = \mu + \alpha y_{2t} + \varepsilon_t. \]  

(1)

In this regression \( y_{2t} \sim I(1) \) and \( \varepsilon_t \sim I(0) \). Assuming that the residuals follow an AR(1) process such that \( \hat{\varepsilon}_t = \rho \hat{\varepsilon}_{t-1} + \varepsilon_t \), the null hypothesis entails testing whether the error term stationary or \( \rho = 1 \). We can restate the null hypothesis as \( H_0: 1 - \rho = 0 \) in the equation:

\[ y_{1t} = \mu_1 + \mu_2 \hat{y}_{1t} + \alpha_1 y_{2t} + \alpha_2 y_{2t} \hat{y}_{1t} + \varepsilon_t \]  

(2)

where \( \varepsilon_t \) is white noise. White noise might represent too strong a restriction, therefore, when it is violated, Eq. (2) is augmented by additional lags:

\[ \Delta \hat{y}_t = (1 - \rho) \hat{y}_{t-1} + \gamma_1 \Delta \hat{y}_{t-1} + \gamma_2 \Delta \hat{y}_{t-2} + \cdots + \gamma_k \Delta \hat{y}_{t-k} + v_t. \]  

(3)

Residual-based cointegration tests such as that proposed by Engle and Granger (1987) assume that cointegrating vectors are constant over time. However, if there is a regime shift in the series, there will be a shift in the cointegrating vector as well. In such circumstances, these traditional tests will lead to incorrect inferences about the long-run relationship of the series. Moreover, according to Phillips (1986), if a structural break exists in the data, but is omitted from the cointegration relation, this can lead to spurious rejections when the null of no cointegration is wrongly rejected. For the Engle and Granger (1987) test, such spurious rejections tend to occur for breaks that are located either too early in the sample or when the magnitude of the break increases. Thus, the power of the Engle and Granger (1987) test to find cointegration is severely affected by the presence of breaks in the level or the trend function in the cointegration relationship.

Gregory and Hansen (1996) addressed this issue and proposed a residual-based cointegration test that takes into account regime
shifts either in the intercept or the entire vector of coefficients. Gregory and Hansen analysed four models and then tested the null hypothesis of no cointegration. Model 1 (Eq. (1)) is the standard cointegration model where no changes in the intercept or a trend function are allowed under the null hypothesis. The other three models include shifts in either the intercept (Model C) or trend (Model C/T) or shifts in the intercept and slope (Model C/S). Model C/S is unique in the sense it allows the long-run equilibrium relationship to rotate as well as shift in parallel fashion. The break point \( \tau \) in any model is determined endogenously within the data series.

Model C can be expressed as

\[
y_{1t} = \mu_1 + \mu_2 \phi_{1t} + a_1 y_{2t} + \epsilon_t.
\]

Model C/T can be represented by

\[
y_{1t} = \mu_1 + \mu_2 \phi_{1t} + \beta t + a_2 y_{2t} + \epsilon_t.
\]

Model C/S is

\[
y_{1t} = \mu_1 + \mu_2 \phi_{1t} + a_1 y_{2t} + a_2 y_{2t} \phi_{1t} + \epsilon_t.
\]

In these three models above, the structural break is modelled by the introduction of a dummy variable \( \phi_{1t} \), which takes values (0,1) depending on the nature of the structural break. In all four models postulated, the null hypothesis of no cointegration can be tested by examining whether the residuals of the ordinary least-squares (OLS) regression applied to Eqs. (1) and (4)–(6), respectively are stationary processes or that \( \epsilon_t \sim \ell(0) \).

The procedure for calculating the test statistic for each possible regime shift \( \tau \in T \) involves four steps. In essence it involves the search for the smallest value of either the modified PP \( Z_a^* \) and \( Z_f^* \) or ADF \( ADF^* \) test statistic across all possible break points:

\[
Z_a^* = \inf_{\tau \in T} Z_a(\tau),
\]

\[
Z_f^* = \inf_{\tau \in T} Z_f(\tau),
\]

\[
ADF^* = \inf_{\tau \in T} ADF(\tau)
\]

4. Overview of the data

We use daily spot and futures prices at 1 and 3 months to maturity for the two benchmark crudes over the period spanning January 1991–November 2008. We chose the US WTI and the UK Brent as the representative crudes for this analysis since these two crudes have well-established spot and futures markets. WTI futures are traded on the NYMEX and Brent futures are traded on the Intercontinental Exchange (ICE). The source for the spot prices is the Energy Information Administration (EIA), while futures prices were taken from NYMEX and ICE. For all of the series WTI was priced higher than Brent.

Figs. 1–3 plot spot prices and futures prices at 1 and 3 months to maturity. From January 1991 to September 2001 there were small shocks that affected the mean value of prices, but prices returned to the mean value of approximately 20 USD with different speeds of adjustment. Over the period, from September 2001 to November 2008, the behaviour of oil prices drastically changed and became more volatile. During this timeframe, oil prices were governed by cycles of local upward and downward trends initiated by a particular shock. For example, while prior to 2001 oil prices were mean reverting, from 2001 until July 2008 the prices were on an upward trend. The duration of these cycles substantially differs from time to time and is dependent on the nature of the shock. More adverse shocks caused longer cycles. The downward shocks were generally more abrupt than the upward shocks, which in turn were more cumulative. For example, from September 2001 to July 2008 prices increased almost six times, while from July 2008 until November 2008 prices fell three times. In this article, we use sample trimming, so the first and last 15% (695 observations) of the sample are not...
included into the analysis, that is we do not analyse the impact of the first Gulf war and the drastic price decrease in 2008.

An example of the abrupt downward movement in both spot and futures was a big drop in price on 17 September 2001 when the New York Stock Exchange and the NYMEX reopened after 11 September 2001 for the first time. An example of a series of cumulative upward movements was an increase in prices from May 2003 until prices reached a peak in December 2003. This implies that in the oil market it is possible to have one large shock (such as the first or second Gulf war) as well as a series of combined smaller shocks that change the trajectory of prices. Similar conclusions can be drawn from an examination of futures prices at all maturities. That is, futures prices for the two different crudes and different months to maturity respond to shocks in the same manner. Moreover, futures respond to the same shocks as spot prices. Both spot and futures prices are very volatile and are characterised by large jumps, particularly in the later time period of the sample. If there was a large jump in the spot market, this immediately translated into a jump in the futures market. There are no separate jumps that occur in one market only.

There are several potential structural breaks that have impacted on oil prices over the period studied. We hypothesise that the regime shifts will reflect events that have impacted directly on oil markets, rather than events not directly related to oil markets, but which have affected the economy more generally. The reasoning is that events that have impacted directly on oil markets are more closely tied to oil prices, while the impact of more general events are indirect. A prime example of a direct event is the second Gulf War in March 2003, which caused an immediate drop in oil prices. In the few months prior to the War, WTI and Brent futures prices increased due to fears of market participants that Iraq’s oil pipelines and oil fields would be destroyed in the first days of the war. However, this did not happen. Indirect effects that impacted on the economy, or financial markets more generally, were the Asian financial crisis and Russian default, the 11 September 2001 terrorist attack and the outbreak of severe acute respiratory syndrome (SARS) in 2002.

We also hypothesise that events that were connected to oil-producing countries or the largest consumers of oil, such as the United States, will have a greater impact on oil prices than events unrelated to the oil market. For example, unrest in Venezuela, in the first 6 months of 2002, caused an increase in oil prices. This was not a separate event, but a series of events in Venezuela that kept oil markets in a perpetual state of unrest. Similarly, disruptions to oil supply in Nigeria in April–May 2007 had a similar effect on oil prices. In addition, extreme weather conditions in the United States have had an impact on the oil prices. For example, following Hurricanes Ivan on 14 September 2004, Dennis on 11 July 2006, Katrina on 28 August 2006 and Rita on 24 September 2006, oil prices dropped.

5. Results

Prior to employing the Gregory and Hansen (1996) cointegration test, we employed the conventional ADF and PP unit root tests as well as the Lagrange multiplier (LM) unit root test with one structural break proposed by Lee and Strazicich (2003) to establish the order of integration of the variables. The results are not reported to conserve space, but the findings for all three unit root tests suggest that spot and futures prices at 1 and 3 months to maturity for the two benchmark crudes are integrated of order one (I(1)). We tested for a bivariate cointegration relationship using the Gregory and Hansen (1996) test for spot prices and futures prices for the same grade of crude oil as well as spot prices and futures prices for different grades of crude oil; that is, spot WTI and futures prices for Brent at 1 and 3 months to maturity and spot Brent and futures prices for WTI at 1 and 3 months to maturity. In the case of conflicting test results, we based our conclusions on the Zt statistic, which according to Gregory and Hansen (1996), is the most powerful of all the three statistics considered. The results are presented in Tables 1–4.

We find that spot and future prices of the same grade, as well as spot and futures prices of different grades, are cointegrated. For almost all of the series the same break dates were estimated by the Zt and Za statistics for the same model. The break date suggested by the ADF statistic often occurred within at least 1 month of the date of the break estimated by the ADF and the Zt/Za tests for the same model, although it sometimes varied by as much as a year. Another important feature of our results is that the Za test statistic in some cases was extraordinarily large, particularly in those cases when both the ADF and the Zt test statistics were significant at the 5 per cent level. This can be attributed to the high degree of autocorrelation in the series. It should also be noted that the dates of the break do not need to be exact. That is the break date say in January could be a reflection of the events occurring several months prior to the break date. In addition not only actual events could trigger the break, but also anticipation of such events could trigger the break.

The majority of the break points across the models fall in 2003. As hypothesised these break dates reflect events directly related to oil markets, in particular the second Gulf War, events in major oil-producing countries or events directly related to oil markets in the United States. In March 2003 the Second Gulf war began and there was an outbreak of violence in the Nigerian region of the Niger Delta, which led three oil major companies to shut down

Table 1
Gregory and Hansen (1996) cointegration between daily spot WTI and WTI futures prices.

|               | ADF                      | Zt                        | Za                        |
|---------------|--------------------------|----------------------------|----------------------------|
|               | Test statistic | Break point | Test statistic | Break point | Test statistic | Break point |
| Spot WTI and WTI 1 month |                         |                           |                           |
| C             | −5.4434**   | 5/16/2003       | −60.8221*        | 6/05/2003         | −4702.3425*     | 6/05/2003         |
| C/T           | −5.4258**   | 5/16/2003       | −60.8110*        | 6/05/2003         | −4701.8312*     | 6/05/2003         |
| C/S           | −5.5307**   | 4/19/2004       | −60.8382*        | 3/29/2004         | −4701.3528*     | 3/29/2004         |
| Spot WTI and WTI 3 months |                     |                           |                           |
| C             | −4.3141     | 7/02/2003       | −34.6295*        | 7/23/2003         | −2221.1552*     | 6/11/2003         |
| C/T           | −4.3004     | 7/02/2003       | −34.6196*        | 6/11/2003         | −2224.3561*     | 6/11/2003         |
| C/S           | −4.2907     | 7/02/2003       | −34.7739*        | 5/22/2003         | −2244.1295*     | 5/22/2003         |

Note: * and ** denote statistical significance at 1% and 5% level, respectively.
their operations. In May 2003 the UN ended 13 years of economic sanctions on Iraq. In June 2003 Iraq commenced exporting oil for the first time since the start of the Second Gulf War. In July 2003 Hurricane Claudette shut down oil production in the Gulf of Mexico for several days. In August 2003 there were electric power blackouts in the United States and southern Canada as well as the creation of the first Russian supermajor oil company. Only a few of the breakpoints fall outside 2003. These include breaks in January and October 2002 and March and April 2004. The January 2002 break could be a reflection of events affecting oil prices in the previous months. For example, in December 2001 Enron filed for Chapter 11 bankruptcy. Also, in December 2001 the WTI price on NYMEX hit a record high in the anticipation of the OPEC decision on production cuts. In January 2002 OPEC crude oil production cuts came into effect. The break date in early October 2002 could be explained by Hurricane Lili and a terrorist attack on a French oil tanker. In March 2004 OPEC agreed to implement production cuts. And in April 2004 there was the first major terrorist attack on government installations in Riyadh, the capital of Saudi Arabia, which is the largest crude oil producer in the world.

6. Implications of the results

Here we discuss implications of our results for arbitrage opportunities and portfolio diversification. We also discuss implications of our results for the Efficient Market Hypothesis. Our results suggest that spot and futures prices are governed by the same set of fundamentals, such as the exchange rate of the US dollar, macroeconomic variables and demand and supply.

Table 2
Gregory and Hansen (1996) cointegration between daily spot Brent and Brent futures prices.

| ADF | Test statistic | Break point | Zc | Test statistic | Break point | Zs | Test statistic | Break point |
|-----|----------------|-------------|----|----------------|-------------|----|----------------|-------------|
| Spot Brent and Brent 1 month | C  | −8.8785∗ | 6/25/2003 | −39.4759∗ | 5/22/2003 | −2311.1148∗ | 5/22/2003 |
|     | C/T            | −8.8962∗ | 6/25/2003 | −38.4730∗ | 5/22/2003 | −2310.4696∗ | 5/22/2003 |
|     | C/S            | −9.2224∗ | 5/02/2003 | −40.2823∗ | 5/22/2003 | −2383.3008∗ | 5/22/2003 |
| Spot Brent and Brent 3 month | C  | −6.7652∗ | 6/25/2003 | −21.3169∗ | 5/26/2003 | −782.4055∗ | 5/26/2003 |
|     | C/T            | −6.8329∗ | 6/25/2003 | −21.4127∗ | 5/26/2003 | −787.9280∗ | 5/26/2003 |
|     | C/S            | −6.9766∗ | 6/20/2003 | −22.7728∗ | 5/22/2003 | −882.8678∗ | 5/22/2003 |

Note: ∗and ** denotes statistical significance at 1% and 5% level, respectively.

Table 3
Gregory and Hansen (1996) cointegration between daily spot WTI and Brent futures prices.

| ADF | Test statistic | Break point | Zc | Test statistic | Break point | Zs | Test statistic | Break point |
|-----|----------------|-------------|----|----------------|-------------|----|----------------|-------------|
| Spot WTI and Brent 1 month | C  | −5.9219∗ | 9/24/2003 | −18.6888∗ | 4/09/2004 | −615.3963∗ | 4/09/2004 |
|     | C/T            | −5.9611∗ | 9/24/2003 | −18.8318∗ | 8/07/2003 | −622.9091∗ | 8/07/2003 |
|     | C/S            | −6.0522∗ | 9/24/2003 | −19.6105∗ | 8/07/2003 | −672.2120∗ | 8/07/2003 |
| Spot WTI and Brent 3 month | C  | −5.9770∗ | 9/25/2003 | −13.8695∗ | 8/22/2003 | −14.1560 | 8/22/2003 |
|     | C/T            | −6.0336∗ | 9/25/2003 | −35.8613∗ | 8/22/2003 | −368.6914∗ | 8/22/2003 |
|     | C/S            | −6.2013∗ | 7/17/2003 | −15.0380∗ | 8/07/2003 | −411.5823∗ | 8/07/2003 |

Note: ∗and ** denotes statistical significance at 1% and 5% level, respectively.

Table 4
Gregory and Hansen (1996) cointegration between weekly spot Brent and WTI futures prices.

| ADF | Test statistic | Break point | Zc | Test statistic | Break point | Zs | Test statistic | Break point |
|-----|----------------|-------------|----|----------------|-------------|----|----------------|-------------|
| Spot Brent and WTI 1 month | C  | −3.5581 | 1/29/2002 | −18.7701∗ | 4/21/2004 | −847.6537∗ | 4/21/2004 |
|     | C/T            | −3.5740 | 12/29/2003 | −18.8926∗ | 4/21/2004 | −855.0786∗ | 4/21/2004 |
|     | C/S            | −3.5902 | 5/20/2003 | −18.7011∗ | 8/07/2003 | −843.1281∗ | 4/21/2004 |
| Spot Brent and WTI 3 months | C  | −2.9268 | 3/10/2003 | −16.1220∗ | 4/09/2003 | −650.3731∗ | 4/09/2003 |
|     | C/T            | −2.9280 | 3/10/2003 | −16.1495∗ | 4/29/2003 | −651.4705∗ | 4/29/2003 |
|     | C/S            | −2.9283 | 3/10/2003 | −16.3405∗ | 10/10/2002 | −671.5756∗ | 10/10/2002 |

Note: ∗and ** denotes statistical significance at 1% and 5% level, respectively.
conditions, which are similar and interrelated in North American and European markets for crude oil. As stated above, cointegration implies the existence of a long-run relationship between two or more non-stationary series. Therefore, it is related to arbitrage, which is a representation of a long-run steady-state equilibrium relationship in a particular market (Karbuz and Jumah, 1995, p. 237). Arbitrage can be formally defined as any activity that would generate a riskless profit through substitutability between spot and futures markets (Schwartz and Szakmary, 1994). If two markets are cointegrated, in the long-run arbitrage is the force that brings these markets together (Narayan and Smyth, 2005). As oil spot and futures prices are cointegrated, the potential for making riskless excess profits on, say, the WTI spot market based on information from the Brent futures market is limited in the long-run. The fact that in some of our models, the break points were found to be statistically significant indicates that the equilibrium relationship between spot–spot, spot–futures and futures–futures pairs changed during the sample period. Therefore, the appropriate cointegration model between the oil price series should include a structural break. This finding can be related to the properties of the convenience yield and the risk premium on the oil market. Masih and Masih (2002) suggested that cointegration of commodity markets does not exist if there is either a non-stationary risk premium or a non-stationary convenience yield. Since we found all bivariate relationships to be cointegrated, this is an indication of a stationary risk premium or convenience yield.

Our findings are of relevance to energy hedge funds, which tend to be long in the market (Fusaro and Vasey, 2004a). In past years energy hedge funds as well as macro funds have been very active on the spot and futures markets contributing to greater intra-day activity. The recent tendency for these funds is to purchase physical oil and gas reserves as well as assets across the energy value chain from downstream to upstream (Fusaro and Vasey, 2004b), which will affect prices for these two commodities in the future. Interestingly enough, in the literature there has been little research on trading strategies based on cointegration. According to Alexander et al. (2002), a great deal of trading is still done based on the correlation between assets, which is commonly used by market participants to select financial assets for portfolio diversification. In this sense, cointegration is superior to correlation analysis in terms of selection of assets for one’s portfolio. This is because portfolios selected on the basis of correlation might hold in one period, but break down in the next (Wilson, et al., 2003). If the researcher uses standard cointegration techniques when there is a structural break, this can be misleading since the cointegration vector has changed. In our analysis all of the series are cointegrated with a structural break, which means that the equilibrium relationship between spot and futures pairs changed at least once over the sample period. Therefore, the correct formulation of the cointegrating relationship of oil prices in the portfolio should include a structural break, otherwise it will be specified incorrectly. However, the existence of the cointegrating relationship does not mean that opportunities for portfolio diversification are endless.

Finally, we comment on our results in terms of market efficiency. Futures market efficiency can be defined as the combined efficiency of the commodity spot and futures markets. In the weak form it can be tested by either risk premium or cost-of-carry approaches (for details see Fama and French, 1988). If two markets are cointegrated each market contains information on the common stochastic trends, which bind the stock market prices together, meaning that the predictability of each stock market can be enhanced through using information contained in the other stock market. Granger (1986) suggests that cointegration between two prices reflects an inefficient market on the basis that if two prices share a common trend in the long-run, this implies predictability of each price's movement, which indicates that one market may be caused by another. Newberry (1992) suggests that futures markets provide opportunities for market manipulation. According to this view, the futures market can be manipulated either by the better informed at the expense of the less informed or by the larger at the expense of the smaller. For example, OPEC may find it profitable to intervene in the futures market to influence the production decisions of their competitors in the spot market (Silvapulle and Moosa, 1999). If markets are inefficient the policy implications are that there is a greater role for regulation to improve information flows and reduce market manipulation (Stout, 1995). The preferable view, and the view with which the weight of opinion now lies, is that finding cointegrating oil price pairs does not necessarily mean that futures markets efficiency holds. This is because cointegration does not imply efficiency or inefficiency (Crowder and Hamed, 1993; Masih and Masih, 2002). Masih and Masih (2002) suggest that a market is inefficient only if by using the predictability, investors can earn risk-adjusted excess returns, but predictability does not necessarily say anything about risk-adjusted excess rates of return.

Masih and Masih (2002, p. 87) take the example of spot and forward prices. The spot price might diverge from the forward price for a number of reasons. One reason would be a non-stationary risk premium, or in the case of storable commodities, a convenience yield, and/or another relevant omitted variable. If the premium is zero and/or stationary and there is no third variable, cointegration might exist, although even if there is cointegration one cannot conclude whether the market is efficient or inefficient. In addition, market efficiency assumes risk neutrality, rationality on the part of economic agents and knowledge of the past history of oil spot and futures prices as well as other publicly available information. These are not assumptions made in cointegration tests.

7. Conclusion

The purpose of this study was to examine whether crude oil spot and futures prices of the same and different grades are cointegrated with one structural break in the cointegrating vector using the residual-based Gregory and Hansen (1996) cointegration methodology. We chose the US WTI and the UK Brent as the representative crudes for this analysis since these two crudes have well-established spot and futures markets. We found that spot and future prices of the same grade as well as spot and futures prices of different grades are cointegrated. We have discussed potential causes of structural change as revealed by the Gregory and Hansen (1996) test in terms of events that have impacted on world oil markets as well as the implications of our results for hedge managers and investors.

Future research could proceed in several directions. One of the limitations of the current study is that we only allow for one structural break in the cointegrating vector when there is no reason to think there is just one break. Future research could employ the residual-based cointegration test with two structural breaks recently developed by Hatemi-J (2008). Second, future research could examine the long-run and short-run relationship between oil production and oil futures prices. Since crude oil production is constrained at any point of time, it is possible that in the short-run futures prices can become disconnected from actual production levels and be driven more by news, profit considerations and other variables than actual production. Recent studies have employed threshold cointegration tests to examine the relationship between crude oil prices and retail gasoline prices.
(Chen et al., 2005; Grasso and Manera, 2007). The relationship between crude oil production and futures prices could also be examined using asymmetric cointegration techniques.

Third, falling levels of production in Brent and WTI have acted as a catalyst for the establishment of new futures contracts that depend on different types of oil and not just Brent and WTI. For example, in 2004 China commenced trading oil on the Shanghai Futures Exchange. In 2007, the first Middle East crude oil futures contract based on Oman crude commenced trading on the Dubai Mercantile Exchange. As further observations for these nascent futures contracts become available, future studies could examine the long-run relationship between crude oil spot and futures prices for a panel of crudes using panel cointegration techniques such as those proposed by Pedroni (1999) or Westerlund (2006). This would further understanding of the relationship between different prices and production for crude oil of different grades and different countries of origin.

References

Alexander, C., Giblin, L., Weddington, W., 2002. Cointegration and asset allocation: a new active hedge fund strategy. Research in International Business and Finance 16, 65–90.

Asche, F., Guttmersen, A.G., 2001. Lead lag relationships between futures and spot prices. Working Paper, Stavanger University College and Norwegian School of Economics and Business Administration.

Brennan, M.J., 1958. The supply of storage. American Economic Review 47, 50–72.

Chance, D.M., 1991. An Introduction to Options and Futures. Dryden Press, Chicago.

Chen, L-H., Finney, M., Lai, K.S., 2005. A threshold cointegration analysis of asymmetric price transmission from crude oil to gasoline prices. Economics Letters 89, 233–239.

Crowder, W.J., Hamed, A., 1993. A cointegration test for oil futures market unbiasedness. Journal of Futures Markets 13, 933–941.

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

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

Fama, E.F., French, K.R., 1988. Permanent and temporary components of stock prices. Journal of Political Economy 96, 246–273.

Fusaro, P.C., Vasey, G.M., 2004a. Energy hedge funds: why have they appeared now? Commodities Now 3.

Fusaro, P.C., Vasey, G.M., 2004b. The role of financial players in energy trading. Energy Finance and Risk 3.

Granger, C.W.J., 1986. Developments in the study of cointegrated economic variables. Oxford Bulletin of Economics and Statistics 48, 213–228.

Grasso, M., Manera, M., 2007. Asymmetric error correction models for the oil–gasoline price relationship. Energy Policy 35, 156–177.

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

Hansen, B.E., 1992. Tests for parameter instability in regressions with I(1) processes. Journal of Business and Economics 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, 495–505.

Johansen, S., 1988. Statistical analysis of cointegrating vectors. Journal of Economic Dynamics and Control 12, 231–254.

Kaldor, N., 1939. Speculation and economic stability. Review of Economic Studies 7, 1–27.

Karbuz, S., Jumah, S., 1995. Cointegration and commodity arbitrage. Agribusiness 11, 235–243.

Lee, J., Strazdicic, M.C., 2003. Minimum Lagrange multiplier unit root test with two structural breaks. Review of Economics and Statistics 85, 1082–1089.

Leuthold, R.M., Junkus, J.C., Cordier, J.E., 1989. The Theory and Practice of Futures Markets. Lexington Books, D.C. Health and Co., Lexington, MA.

Masih, A.M.M., Masih, R., 2002. Propagative causal price transmission among international stock markets: evidence from the pre and post globalization period. Global Finance Journal 13, 63–91.

McAleer, M., Sequeira, J.M., 2004. Efficient estimation and testing of oil futures contracts in a mutual offset system. Applied Financial Economics 14, 953–962.

Narayan, P.K., Smyth, R., 2005. Cointegration of stock markets between New Zealand, Australia and the G7 economies: searching for co-movement under structural change. Australian Economic Papers 44, 231–247.

Newberry, D.M., 1992. Futures markets: hedging and speculation. In: Newman, P., Milgate, M., Eatwell, J. (Eds.), The New Palgrave Dictionary of Money and Finance, vol. 2. Macmillan, London, pp. 207–210.

Pedroni, P., 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford Bulletin of Economics and Statistics 61, 653–670.

Peroni, E., McNow, R.F., 1998. Noninformative and informative tests of efficiency in three energy futures markets. Journal of Futures Markets 18, 936–964.

Phillips, P.C.B., 1986. Understanding spurious regressions in econometrics. Journal of Econometrics 33, 311–340.

Pindyck, R.S., 2001. The dynamics of commodity spot and futures markets: a primer. Energy Journal 22, 1–29.

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

Schwartz, T.V., Szakmary, A.C., 1994. Price discovery in petroleum markets: arbitrage, cointegration and the time interval of analysis. Journal of Futures Markets 14, 147–167.

Sequeira, J.M., McAleer, M., 2000. A market-augmented model for SIMEX Brent crude oil futures contracts. Applied Financial Economics 10, 543–552.

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

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

Stout, L.A., 1995. Are stock markets costly casinos? Disagreement, market failure and securities regulation. Virginia Law Review 81, 611–712.

Teler, L.G., 1958. Futures trading and the storage of cotton and wheat. Journal of Political Economy 66, 233–255.

Westerlund, J., 2006. Testing for panel cointegration with multiple structural breaks. Oxford Bulletin of Economics and Statistics 68, 101–132.

Wilson, P.J., Gerlach, R., Zurbruegg, R., 2003. Potential diversification benefits in the presence of unknown structural breaks: an Australian case study. Australian Economic Papers 42, 442–453.

Working, H., 1948. Theory of the inverse carrying charge. Journal of Futures Markets 12, 139–149.

Working, H., 1949. The theory of price of storage. American Economic Review 39, 1254–1262.