IS THE LEADERSHIP OF THE BRENT-WTI OIL FUTURES MARKET THREATENED?

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Abstract

The relationship between crude oil prices is a topic that has often been addressed in the energy economics literature. Especially, the question of whether crude oil produced in different countries or locations constitutes a unified world oil market. The new crude oil futures contract in Shanghai has reopened the debate among researchers about the regionalization of the crude oil market. In this paper, we study the impact of the new Medium Sour Crude Oil (SC) futures contract, listed in the Shanghai International Energy Exchange, on the relationship between the main futures crude oil benchmarks, West Texas Intermediate (WTI) and Brent, by a VECM-BEKK framework. Then, we apply non-linear multiple regression to study the ability to influence and to be influenced of the three futures contracts.

Our results suggest that the leadership of the Brent-WTI oil futures is not threatened yet, as the SC is not influencing either the Brent or the WTI markets. Moreover, we identify Brent futures market as the most influential market in the oil price discovery process.

Keywords: oil market, Brent, WTI, SC, market integration

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1. INTRODUCTION

Since Adelman (1984) opened the discussion about whether the oil market is "one great pool", the relationship between different crude oil futures contracts has been extensively studied to determine the degree of integration of the global crude oil market, obtaining mixed results. Given the high liquidity of the Brent and West Texas Intermediate (WTI) futures contracts, traders and academics have chosen both as global oil benchmarks and numerous papers have analysed their role in the price discovery process, reaching different conclusions. However, the recent launch of a new yuan-denominated oil futures contract in Shanghai in March 2018 and its increasing trading volumes, may be affecting both the relationship between Brent and WTI and their benchmark position, as China represents the largest importer and the second largest consumer of crude oil in the world. According to Zhang and Umehara (2019), the Medium Sour Crude oil (SC), quoted on the Shanghai International Exchange (INE), has become the third crude oil futures contract most traded in the world.

The aim of this paper is to study the link between the three markets, to clarify if the SC futures contract quoted in the Shanghai International Energy Exchange represents a new oil benchmark in a globalized market. This study is of interest to academia and practitioners. On the one hand, researchers will become aware of the need to include the spillover effect of these three oil futures contracts in their risk and valuation models. On the other hand, crude oil investors could use this information to improve their trading strategies.

This paper is organised as follows. Section 2 reviews the globalization theory of the crude oil market. Section 3 presents the specifications contracts and trading hours. Section 4 describes data and carries out a preliminary analysis of some liquidity measures. In section 5 the methodology used is described. Firstly, the relationship between Brent and WTI before and after the introduction of the new SC futures contract is analysed by applying cointegration, Vector Error Correction Models techniques, and GARCH models to capture the dynamic structure of multivariate volatility process. Secondly, we apply the model proposed by Peiró et al. (1998) to non-synchronous daily data of SC, Brent, and WTI. This model allows the separation of the ability to influence and to be influenced of the three futures contracts. Section 6 presents the main findings. Finally, section 7 concludes and summarizes.

2. LITERATURE REVIEW

The globalization or regionalization of the crude oil market is an issue that has been widely studied in the literature. Nevertheless, nowadays there is not an agreement between the researchers related to the grade of integration of the global oil market. In this section, we introduce a brief review of the literature related to this topic in order to set the basis of our empirical analysis.

Adelman (1984) was the first one in analysing the globalization of crude oil markets by stating that "the world crude oil market, like the world ocean, is one great pool". In other words, attending to Adelman (1984) international crude oil markets represent a unified market. Otherwise, Weiner (1991) by correlation and switching regression analysis, concludes that the world oil market is not unified as crude oil prices of different regions do not always move together. Moreover, Weiner (1991) observes that oil prices respond to local government policies and supply regional shocks. Following Weiner (1991), the globalization of the crude oil market refers to the fact that crude oil prices from different regions move closely together. There exist many crude oils qualities, but if the assumption of globalization would be fulfilled, crude oil price differentials should be constant over time. In the opposite side, regionalization refers to the absence of information flows between crude oil markets. According to Fattouh (2010), the regionalization hypothesis implies that price fluctuations in one market will have no effect on prices in other markets, as crude oils prices only respond to their own regional market conditions and news. Therefore, if the crude oil market would be regionalised, international arbitrage opportunities may be possible.

Given the difficulty to measure the degree of regionalization or globalization, the discussion about the unification or fragmentation of crude oil markets is a topic that has obtained mixed results by the academia. Furthermore, attending to Bhar et al. (2008) there are different crude oils in the worldwide and their prices are referenced by a handful of crude oil benchmarks. The crude oils futures are quoted as a discount or premium to these benchmarks. Therefore, the literature has focused on the study of the main crude oil benchmarks. For many years Brent and WTI have been the benchmarks for the light sweet crude oil group. Nevertheless, there is not a consensus on the leadership between Brent and WTI. In the case of the medium and heavy crude oils, the benchmarks are Dubai-Oman and Maya, respectively.

Since Adelman (1984), most researches support the theory of the “one great pool”. Fattouh (2010) applies a two-regime threshold autoregressive approach to identify links between seven types of crude oils. Fattouh (2010) finds that price oil differentials follow a stationary process and the adjustment process is different if we consider crude oils of similar or different quality. Reboredo (2011), by a copula dependence structure approach, finds co-movements between WTI, Brent and Argus crude oils in favour of globalization. In addition, the conclusion of Reboredo (2011) is that oil markets are linked with the same intensity during bull and bear markets. Furthermore, the study of crude oil futures price correlations between markets is important to hedging strategies as high correlations reduce the hedging potential between crude oils. In this context, Klein (2018) studies the correlations of Brent and WTI by a fully parameterized Baba-Engle-Kraft-Kroner (BEKK) M-GARCH model, which models the variance-covariance matrix taking into account the effect of market news and volatility spillover transmission between markets. Klein (2018) observes high and volatile correlations between Brent and WTI in the period 2007-2017, reaching its peak level in 2016. Giulietti et al (2014) examine the globalization hypothesis among the prices of 32 oil varieties by time-series and cross-section methods, finding that the majority of crude oil prices have stable long-term relationships. Besides, the cointegration technique has widely adopted in the literature to study if crude oil prices move together over time. Kaufmann and Banerjee (2014) find cointegrate relationships between crude oil pairs and suggest that the globalization of crude oil markets depends on the crude oil quality, economic factors and geographic locations.

There are also some authors that support Weiner's regionalization theory. Milonas and Henker (2001) identify variables that affect the WTI-Brent price differentials and conclude that the crude oil market is not fully integrated. Besides, Candelon et al (2013) study the tail dependence among regional oil markets by applying a new Granger causality test, that allows analysing if the oil market is more or less integrated during periods of extreme energetic prices movements. They find that Brent and WTI are price setters, both in downside and upside price movements. Finally, some authors have studied the possibility that the long-run relationship between crude oils may be not constant over time. Ji and Fan (2015), apply cointegration techniques and find long-term equilibrium between WTI, Brent, Dubai, Nigeria and Tapis crude spot prices from 2000 to 2010. Nevertheless, Ji and Fan (2015) observe that the crude oil market started to be less globalized at the end of 2010. Since that date, crude oil prices from different regions increase their distance. Finally, Aruga (2015) founds that the relationship between WTI, Brent and Oman had changed due to the increase in crude production in recent years in the United States (US). He applies the cointegration technique and concludes that the WTI is moving away from the international scene.

3. CONTRACT SPECIFICATIONS AND TRADING HOURS

The data is comprised of daily series of the West Texas Intermediate (WTI) and Brent futures contracts. These are the two most actively-traded oil futures contracts in the world and are widely considered as the benchmarks for the light/sweet crude group. In addition, we have data regarding the new Chinese oil futures contract listed on March 26, 2018. Daily figures consist of settlement prices, trading volume and open interest. The sample period for the WTI and Brent series goes from January 5, 2016 to May 9, 2019, while the Chinese futures contract series covers the period from March 26, 2018 to May 9, 2019. These periods yield a sample size of 844 daily observations for WTI, 864 daily observations for Brent and 272 daily observations for SC. All the data has been collected from Thomson Reuters database.

3.1. Contracts specifications

The underlying commodity of the three futures contracts analysed is crude oil, which can be classified by the density (also known as gravity). The grade of density is based on the American Petroleum Institute (API) gravity measure.[1] The higher the API gravity of the crude oil, the higher the quality of the liquid petroleum and the "lighter" it is. The other feature is the amount of sulphur content by weight. The high percentage of sulphur in crude oil is a characteristic not desired by crude oil refineries, as it is harder to process. Crude oils with a sulphur content less than

[1] The API degrees indicate how light or heavy a crude oil is compared to water. There are four crude oil classifications depending on this measure: light (higher than 31.1º API), medium (22.3º to 31.1º API), heavy (10º to 22.3º API), and extra-heavy (below 10º API).

0.5% are denominated "sweet", while those with more than this value are classified as "sour".

The West Texas Intermediate is a light sweet crude oil futures contract, quoted on the New York Mercantile Exchange (NYMEX). The WTI is high-quality crude oil, whose properties are 39.6º API and 0.24% sulphur content. The WTI settlement method is physical delivery at Cushing, Oklahoma. The types of crude oil that could be delivered cover a range of domestic and foreign oils. WTI has been the United States crude oil benchmark for the last decade, used for pricing oil crude imports into the US.[2]

The Brent futures contract is traded on the InterContinental Exchange (the ICE). Brent is a light sweet crude oil, with 38.1º API and 0.42% sulphur content, being slightly worse in quality than WTI. Moreover, Brent has been a global benchmark for Atlantic Basin crude oils and light sweet crude oils since 1970. The settlement method is based on Exchange for Physicals (EFP) with an option to cash settle against the ICE Brent Index price, for the last trading day of the futures contract. The ICE Brent Index is calculated as the average price of trading in the BFOE (Brent, Forties, Oseberg, Ekofisk and Troll) market in the relevant delivery month, as reported and confirmed by industry media.[3] This Index is published by ICE Futures Europe on the day after the expiry of the front-month ICE Brent futures contract. This delivery method is a particular Brent futures feature because, at expiry, the contract converges to the price of forward Brent, rather than to the spot price as is usual in futures contracts.[4]

[2] See www.cmegroup.com for more details on this contract.
[3] The BFOE market is an over-the-counter forward market where cargos of Brent, Forties, Oseberg, and Ekofisk are traded. From 1ST January 2018 Platts also takes into account Troll crude oil for the BFOE.
[4] See www.theice.com for more details on this contract.

The Sour Crude oil (SC), quoted on the Shanghai International Exchange (INE), is a Yuan-denominated crude oil futures contract listed on March 26, 2018. The INE is an international exchange open to global investors promoted by the Shanghai Futures Exchange (SHFE). Unlike the previous two futures contracts, SC's underlying asset is medium sour crude oil, whose quality specifications are 32.0º API and 1.5% sulphur content. The settlement method is physical delivery. The INE announced seven bonded storage warehouses at eight locations of China. The deliverable crude oil varieties include China's Shengli crude oil and six crude oils from the Middle East.[5]

It is necessary to make two qualifications. Firstly, NYMEX and the ICE Exchanges publish WTI and Brent daily trading volumes, respectively, as the number of contracts traded during the day. Nevertheless, SC daily volume is double counted, therefore, the SC daily trading volume and open interest figures need to be divided by 2. Secondly, WTI and Brent futures contracts are quoted in US dollars per barrel and SC in yuan per barrel. Consequently, SC prices have been converted into US dollars in order to homogenise the three series. Table 1 summarizes the contract specifications of the three futures contracts. The quality specifications and premium/discount of these crude oil varieties are described in Annex 1.

[Please Insert Table 1]

[5]See www.ine.cn for further details on this contract.

3.2. Trading hours

The three markets analysed have different trading schedules. This implies that the knowledge and correct treatment of their trading hours is essential in order to determine the methodology and to interpret the results obtained. Figure 1 shows the diagram of trading hours. It is notable that the WTI and Brent futures contracts are traded almost 24 hours per day. Firstly, WTI trading hours start at 22:00 and go until 21:00 Greenwich Mean Time (GMT), with a one-hour break per day between 21:00 and 22:00. Secondly, the Brent market starts its trading session at 00:00 and goes until 22:00 (GMT). In contrast, the trading hours of the SC market are less than the two previous markets. Officially, the trading hours of the SC fluctuate between 1:00 - 3:30 and 5:30-7:00 (GMT). However, the INE, jointly with SHFE, established a "night session" for all their products with the aim of improving the internationalization of the market. This session runs from 13:00 until 19:00 (GMT). Therefore, the Chinese market has two differentiated periods during the day. On the one hand, the morning-afternoon session, which has more national investors and is expected to have more trading volume, and, on the other hand, the overnight session, which could be more volatile and less liquid.

[Please Insert Figure 1]

Figure 2 exhibits daily settlement hours of SC, WTI and Brent for a day t. The settlement price of SC is calculated at 7:00 (GMT), while WTI and Brent coordinate the calculus of the settlement prices at the same time 18:30 (GMT). However, ICE publishes two prices of Brent at 8:30 and 15:30 (GMT), named

Brent AM and Brent PM[6] respectively, with the aim of coinciding with the release of other OTC and standardised European energy benchmarks.

[Please Insert Figure 2]

[6] The Brent AM or Brent Crude Futures Singapore Minute Maker is calculated as a weighted average of trades done during a one minute period from 8:29 to 8:30 (GMT), while the Brent PM or Brent Crude Futures Minute Maker is calculated for each marker month as a weighted average of trades done during a one minute period from 15:29 to 15:30 (GMT). For more information of Brent AM and Brent PM please see www.theice.com.

4. DATA AND PRELIMINARY ANALYSIS

4.1. Data and summary statistics

The close prices transactions for all monthly deliveries were collected through Thomson Reuters. For our analysis, we have decided to use the near-to-maturity contract, as is usually the most liquid. Moreover, to generate the daily close prices series, we have taken the close prices of the nearby contract up to five days before its delivery. On this date, we have made the rollover to the next near-to-maturity contract. The use of this criterion responds to the fact that the crude oil market participants close positions in the front contract five days before its expiry and, as a consequence, the liquidity passes to the next nearby contract. The series of daily returns follow the same criterion, with the particularity that when there is a change of contract, the returns of that day are calculated with the prices of the same contract, in order to avoid artificial jumps in the return series. Therefore, the prices and returns series have been calculated separately to take into account the contract changes that take place during the entire sample period and to not fall into the error of mixing different contract prices. Besides, we calculate crude oil returns using the following relation: $r_{OIL,t} = \ln(\frac{P_{OIL,t}}{P_{OIL,t-1}})$, where $P_{OIL,t}$ is the -th price level at time t and where OIL is WTI, Brent or SC.

For our daily analysis, two sample periods have been considered. The first sample has been used to analyse if the launch of SC has changed the relationship between WTI and Brent. Daily settlement prices have been taken into account and the sample covers the period from January 5, 2016 through May 9, 2019. In the second sample, the daily settlement prices and returns of the three markets have been used to study the links among the three markets. This second sample goes from March 26, 2018 to May 9, 2019.

Table 2 and Table 3 show the summary statistics of both samples. The results of table 2 show that, in the last three years, the mean of Brent prices have been higher than WTI. Moreover, as we can see in Figure 3.A, during the 2016-2019 period the Brent prices have been above WTI. WTI is sweeter and lighter than Brent, therefore, it is supposed to have a higher average price than Brent. However, examining Table 3 and Figure 3.B, we notice that the SC contract have also a higher price, during the sample period than WTI, being the Brent the most expensive contract. Location, transporting cost and level production can help to explain these crude oil prices differentials. The Brent is a seaborne oil grade because is extracted from locations of UK coast and well connected to the global trade routes. The warehouses of the SC are also connected to the coasts of China. Nevertheless, the WTI must be transported from Cushing, Oklahoma, by pipelines. These transporting differences are known as “location spread” and help to explain the prices differences among the three contracts.

[Please Insert Table 2]

[Please Insert Table 3]

In addition, Table 2 and Table 3 show the results of the Jarque-Bera test. All the variables taken into account in our study do not follow a normal distribution. In addition, return series are leptokurtic, as the kurtosis is higher than the normal distribution.

[Please Insert Figure 4]

Figures 4.A, 4.B and 4.C show the daily returns for WTI, Brent and SC, respectively. We can observe in the three series the following tendency: large (small) changes in oil prices are followed by large (small) changes. This phenomenon is known in the financial literature as volatility clustering and provokes that the current volatility tends to be positively correlated with the preceding level. It justifies the use of GARCH models that allow the conditional variance to be dependent on past variances.

4.2. Preliminary analysis on volume and open interest

Figure 5 presents the monthly near-contract daily volume of the three contracts. Sample period goes from April 2018 to May 2019. The WTI is the futures contract with the highest monthly volume, followed by Brent. One remarkable fact of SC nearest contract to maturity is the low monthly volume quoted in August and September 2018. When the first SC futures contract was launched on March 26, 2018; the near-to-maturity contract was the one delivered at September 2018 and the rest of the contracts were delivered monthly consecutively from October 2018 to March 2019. In August 2018, the daily trading volume of the near-maturity contract (September 2018) began to drop, while the fourth maturity contract increased in daily volume. As we have previously mentioned, both academia and practitioners used to choose the nearest maturity futures contract for econometric analysis because, usually, it has more trading volume and open interest. Nevertheless, as we can notice in Figure 5 for the SC contract this assumption does not perform. For this reason, testing commences by analysing the effects of the listing of the SC futures contracts on total trading volume and open interest data and not only for the nearby contract.

[Please Insert Figure 5]

Table 4 reports the results for the mean and median of the daily trading volume and open interest data for all the futures contracts traded at the same moment in the three markets. Two periods have been differentiated: before and after the launch of the SC futures contract that took place on March 26, 2018. The equality of means has been checked with the F-test. However, given the absence of normality in these samples, non-reported in the paper, the equality of medians has been tested with the Kruskal-Wallis test. WTI and Brent total volume features do not exhibit significant changes. The same issue is observed for Brent open interest data. However, the WTI open interest has significantly increased, after the introduction of the SC futures contract. Following Lucia and Pardo (2010), an increase in the daily open interest data relative to the volume of trading indicates that there is either a decrease in the activity of the speculators or an increase in the activity of hedgers. Therefore, these preliminary results suggest that the introduction of the SC futures contract has been accompanied by an increase in the degree of hedging only in the WTI market.

[Please Insert Table 4]

5. METHODOLOGY

The purpose of this section is to describe the methods used in our empirical analysis. The research is divided into two parts. Firstly, using daily synchronous data, we analyse the relationship between Brent and WTI and the possible influence of the SC in their long- and short-run dynamics. The second part of this research is focused on the study of the links among the three markets, using asynchronous daily data. In each analysis, we have used the data corresponding to the days when the markets considered are simultaneously open.

5.1. VECM-BEKK

Firstly, we study the relationship between the two most important crude oil futures contracts. Following previous studies on crude oil dynamics (Kaufmann and Banerjee (2014) and Aruga (2015), among others), we analyse cointegration between Brent and WTI. Cointegration is a helpful tool to examine if crude oil prices in different markets move together. In fact, if we find a cointegration relationship between Brent and WTI, it would be an argument for the globalization hypothesis of the crude oil market.

To test cointegration, we first need to examine the integration order of the time series. A variable y_t is integrated of order d ($y_t \sim I(d)$) if it is necessary to difference it d times for getting a stationary transformation and it has d unit roots. The stationary of Brent and WTI log prices is examined by the augmented Dicky-Fuller (ADF) test. The null hypothesis of the ADF test is that a unit root is present in a time series sample. If we do not reject the ADF null hypothesis, log-price first differences would be applied and we will test again the presence of unit roots in the returns.

After testing the presence of unit roots, we will continue with the cointegration analysis. Considering two time series $y_{1,t}$ and $y_{2,t}$, which both are $I(d)$. In general, any linear combination of $y_{1,t}$ and $y_{2,t}$ will be $I(d)$. Nevertheless, there is a vector $(1, -b)'$ such as the linear combination "$z = y_{1,t} - a - by_{2,t}$" is $I(d-b)$, being $d \geq b > 0$.

In order to test if Brent and WTI are cointegrated, we apply Johansen (1991) tests. Johansen's multivariate maximum likelihood approach is based on the vector autoregressive model (VAR) of order p:

$$\boldsymbol{y_t} = \boldsymbol{\mu_t} + \boldsymbol{A_i y_t} + \ldots + \boldsymbol{A_p y_{t-p}} + \boldsymbol{DX_t} + \boldsymbol{\varepsilon_t} \tag{1}$$

where $\boldsymbol{y_t} = \{y_{1,t}, y_{2,t}\} = \{ln(P_{BRENT,t}), ln(P_{WTI,t})\} \sim I(1) \;\; \forall \, t = 1, \ldots, T$; $\boldsymbol{X_t}$ is a vector of deterministic variables (linear time trends, dummies, etc…) and ε_t is the vector of innovations.

The VAR (p) can be re-written as VECM (p-1) (Vector Error Correction Model):

$$\Delta \boldsymbol{y_t} = \boldsymbol{\mu_t} + \boldsymbol{\pi y_{t-1}} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{p-1}} \boldsymbol{\Gamma_i} \Delta \boldsymbol{y_{t-1}} + \boldsymbol{DX_t} + \boldsymbol{\varepsilon_t} \tag{2}$$

where

$$\boldsymbol{\pi} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{p}} \boldsymbol{A_i} - \boldsymbol{I} \;\; and \;\; \boldsymbol{\Gamma_i} = -\sum_{\boldsymbol{j=1}}^{\boldsymbol{p}} \boldsymbol{A_i}$$

The VAR (p) model is estimated by maximum likelihood. Then, the estimation of the rank of the $\boldsymbol{\pi}$ is analysed. If $rk(\boldsymbol{\pi}) = 1$, Brent and WTI log prices are cointegrated, there would exist 2x1 matrices $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$, each with rank 1, such as

$\boldsymbol{\pi} = \boldsymbol{\alpha\beta}'$ and $\boldsymbol{\beta}'\boldsymbol{y_t}$ is stationary. The elements of $\boldsymbol{\alpha}$ are the adjustment parameters of the VECM and $\boldsymbol{\beta}$ is the cointegrating vector.

Johansen (1991) proposed two tests for contrast the rank of the matrix $\boldsymbol{\pi}$: the trace and the maximum eigenvalue tests. The trace test contrasts the following null hypothesis:

$$H_o: Rank(\pi) \leq m$$

$$H_1: Rank(\pi) > m$$

For test the cointegrating relationship between WTI and Brent log prices, we will apply two tests with m=0 and m=1.

The trace test statistic is defined as:

$$L_{Tr}(m) = -T \sum_{i=m+1}^{k} \ln(1 - \hat{\lambda}_i) \tag{3}$$

where $\hat{\lambda}_i$ are the generalized eigenvalues estimated for a given matrix arising in the estimation process by Maximum eigenvalue.

The maximum eigenvalue tests the following null hypothesis:

$$H_o: Rank(\pi) = m$$

$$H_1: Rank(\pi) = m + 1$$

where the maximum eigenvalue statistic is defined as:

$$L_{max} = -T \ln(1 - \hat{\lambda}_{m+1}) \tag{4}$$

It is well-known that Johansen's (1991) approach to cointegration is the most popular technique for estimating long-run economic relationships. Nevertheless, Ahking (2002) finds that the modelling of the deterministic components of the cointegration equation has an important role in the power of Johansen's test to detect cointegration relationships. In some cases, the model miss-specification can provoke misleading conclusions about the existence of cointegration. Moreover, the number of observations can influence the power of the Johansen test to detect cointegration. For this reason, we are going to check if oil log prices are cointegrated by Engle and Granger (1987) and Phillips and Oularis (1990) cointegration tests, apart from Johansen (1991) cointegration test

If there is a cointegration relationship between the variables, then we apply *the Granger and Engel representation theorem*, which states that if two variables $\{y_{1,t}, y_{2,t}\}$ are $I(1)$ and are cointegrated, $CI(1,1)$, then their dynamic relation is characterized by a Vector Error Correction Model (VECM). The VECM represents a long and short-run dynamic system in the joint behaviour of $y_{1,t}$ and $y_{2,t}$ over time and takes the following form:

$$\Delta \mathrm{y}_{1,\mathrm{t}} = \alpha_{y1} + \sum_{i=1}^{m} \delta_{11} \Delta \mathrm{y}_{1,\mathrm{t-i}} + \sum_{i=1}^{n} \delta_{12} \, \Delta \mathrm{y}_{2,\mathrm{t-i}} + \gamma_{y_1} z_{t-1} + \varepsilon_{y1,t} \tag{5}$$

$$\Delta \mathrm{y}_{2,\mathrm{t}} = \alpha_{y2} + \sum_{i=1}^{p} \delta_{21} \Delta \mathrm{y}_{1,\mathrm{t-i}} + \sum_{i=1}^{q} \delta_{22} \Delta \mathrm{y}_{2,\mathrm{t-i}} + \gamma_{y_2} z_{t-1} + \varepsilon_{y2,t} \tag{6}$$

$$\varepsilon_t = \left(\varepsilon_{y1,t}, \varepsilon_{y2,t}\right)' iid \sim N(0, \Sigma)$$

Δ indicates the first-order time differences (i.e., $\Delta \mathrm{y}_\mathrm{t} = y_t - y_{t-1}$). The variable z_{t-1} is the lagged error correction term of the cointegration relationship between the logarithms of Brent and WTI prices. γ is the speed of adjustment parameter and high values will indicate a fast convergence rate toward equilibrium. Additionally, to capture the effect of the SC futures launch in the dynamic relation, we have introduced a dummy variable in the VECM, that is equal to 0 before March 26, 2018 and is equal to 1 after that date.

$$\Delta \mathrm{y}_{1,\mathrm{t}} = \alpha_{y1} + \sum_{i=1}^{m} \delta_{11}\Delta \mathrm{y}_{1,\mathrm{t-i}} + \sum_{i=1}^{n} \delta_{12}\,\Delta \mathrm{y}_{2,\mathrm{t-i}} + \gamma_{y_1} z_{t-1} + x_1 \mathrm{d} + \varepsilon_{y1,t} \tag{7}$$

$$\Delta \mathrm{y}_{2,\mathrm{t}} = \alpha_{y2} + \sum_{i=1}^{p} \delta_{21}\Delta \mathrm{y}_{1,\mathrm{t-i}} + \sum_{i=1}^{q} \delta_{22}\Delta \mathrm{y}_{2,\mathrm{t-i}} + \gamma_{y_2} z_{t-1} + x_2 \mathrm{d} + \varepsilon_{y2,t} \tag{8}$$

$$\varepsilon_t = \left(\varepsilon_{y1,t}, \varepsilon_{y2,t}\right)' iid \sim N(0, \Sigma)$$

Equations (9) to (12) have been estimated by Ordinary Least Squares. In addition to the long- and short-run dynamics that are jointly governing Brent-WTI relationship, we are interested in the volatility spillover transmission between both markets. To study this phenomenon, we apply the BEKK approach proposed by Engle and Kroner (1995). The residual series of both VECM models (equations (9) – (12)) have been saved in order to use them as observable data to estimate the BEKK models. Therefore, the VECM-BEKK models have been estimated by two steps procedure, reducing in this way the number of parameters to estimate and allowing faster convergence in the estimation procedure. The compact form of the BEKK multivariate model is as follows:

$$\boldsymbol{\varepsilon_t} = \mathbf{u_t}\,\mathbf{H}_\mathbf{t}^{\frac{1}{2}} \quad and\; \boldsymbol{u_t} \sim N(0,1)$$

$$\boldsymbol{H_t} = \boldsymbol{CC'} + \boldsymbol{A'\varepsilon_{t-1}\varepsilon'_{t-1}A} + \boldsymbol{B'H_{t-1}B} \tag{9}$$

where $\boldsymbol{H_t}$ is the conditional variance-covariance matrix in t, and $\boldsymbol{C}$**,** $\boldsymbol{A}$ and $\boldsymbol{B}$ are matrices of parameters to be estimated. $\boldsymbol{C}$ is an upper-triangular positive definite matrix; $\boldsymbol{A}$ is a matrix that captures the effects of market news; matrix $\boldsymbol{B}$ characterize the extends to which current levels of conditional variances are related to past conditional variances, and $\boldsymbol{\varepsilon_{t-1}}$ are the unexpected shock series obtained from VECM estimation.

In the particular case of two assets, the extended form of BEKK-GARCH model is:

$$\begin{bmatrix} h_{11,\mathrm{t}} & h_{12,\mathrm{t}} \\ h_{21,\mathrm{t}} & h_{22,\mathrm{t}} \end{bmatrix} = \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix}' + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' \quad (10)$$

where, $h_{11,t}$ and $h_{22,t}$ are the conditional time-varying variances of Brent and WTI, respectively. The elements $h_{12,t} = h_{21,t}$ are the conditional covariance of Brent and WTI.

In order to test the impact of the new Chinese crude oil futures contract, we have introduced a dummy variable in the conditional variance matrix equation. Following Bala and Takimoto (2017), we include the dummy variable in the BEKK model as follows:

$$\boldsymbol{H_t} = (\boldsymbol{C} + \mathbf{V}\mathrm{d}_\mathrm{t})'(\boldsymbol{C} + \boldsymbol{V}d_t) + \boldsymbol{A}'\varepsilon_{t-1}\varepsilon_{t-1}'\boldsymbol{A} + \boldsymbol{B}'\boldsymbol{H_{t-1}}\boldsymbol{B} \quad (11)$$

$$where\ d_t\ is\ a\ dummy\ variable\ that \begin{cases} \boldsymbol{0\ if\ t < \tau^*} \\ \boldsymbol{1\ \ if\ t \geq \tau^*} \end{cases} \quad \text{and} \quad \boldsymbol{\tau}^* = \boldsymbol{SC's\ launch}$$

$\boldsymbol{V}$ is a lower triangular matrix. By including the dummy variable in this way, we help to preserve the restriction of positive definitive matrix $\boldsymbol{H_t}$ and we avoid the imposition of higher long-run variance. If estimated parameters of **V** matrix are positive and significant, it suggests that volatility after the launch of the SC is bigger than the period prior to the launch of the SC.

The parameters of equations (13) and (15) are estimated by maximizing the following likelihood function, assuming normally distributed errors:

$$\boldsymbol{L(\theta) = -T\, ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T} ln|H_t(\theta)| + \varepsilon_t{}' H_t^{-1}(\theta)\varepsilon_t} \qquad (12)$$

where T is the total sample number and $\boldsymbol{\theta}$ represents the parameter vector to be estimated. Numerical techniques have been used to minimize -$\boldsymbol{L(\theta)}$.

5.2. Multiple non-linear regression analysis

As we have described in Section 3, trading times of the three markets of our interest do not perfectly overlap. Therefore, the non-simultaneity of trading times for WTI, Brent and SC may affect the results of cross-correlations and regressions with daily returns. Peiró et al. (1998) proposed a multiple regression system that distinguishes between the influencing ability and the sensitivity of a market to be influenced, solving the problem of non-simultaneity. On the one hand, we have applied the model to Brent, WTI and SC futures contracts, taking the official settlement prices both for Brent and WTI. Given the simultaneity of the settlement prices of WTI and Brent, this equation system (A) has a purely historical descriptive purpose:

$$r_{brent,t} = \alpha_{brent} + \beta_{wti}\lambda_{brent}r_{wti,t} + \beta_{sc}\lambda_{brent}r_{sc,t} + u_{brent,t} \tag{13}$$

$$r_{wti,t} = \alpha_{wti} + \beta_{brent}\lambda_{wti}r_{brent,t} + \beta_{sc}\lambda_{wti}r_{sc,t} + u_{wti,t} \tag{14}$$

$$r_{sc,t} = \alpha_{sc} + \beta_{brent}\lambda_{sc}r_{brent,t-1} + \beta_{wti}\lambda_{sc}r_{wti,t-1} + u_{sc,t} \tag{15}$$

On the other hand, we have estimated another system (B) where the dependent variables are Brent PM, WTI and SC. As we have shown in Figure 2, all these variables are non-synchronous and, therefore, the prediction purpose with this system would be possible:

$$r_{Bpm,t} = \alpha_{Bpm} + \beta_{wti}\lambda_{Bpm}r_{wti,t-1} + \beta_{sc}\lambda_{Bpm}r_{sc,t} + u_{Bpm,t} \tag{16}$$

$$r_{wti,t} = \alpha_{wti} + \beta_{Bpm}\lambda_{wti}r_{Bpm,t} + \beta_{sc}\lambda_{wti}r_{sc,t} + u_{wti,t} \tag{17}$$

$$r_{sc,t} = \alpha_{sc} + \beta_{Bpm}\lambda_{sc}r_{Bpm,t-1} + \beta_{wti}\lambda_{sc}r_{wti,t-1} + u_{sc,t} \tag{18}$$

One problem of this model is the equality of some parameters in the system equations. To incorporate the restriction of equal parameters across equations, the equations (17)-(19) have been estimated jointly. In the case of the system (A), the equations are stacked obtaining the following regression:

$$\begin{bmatrix} r_{brent,2} \\ r_{brent,3} \\ \vdots \\ r_{brent,T} \\ r_{wti,2} \\ r_{wti,3} \\ \vdots \\ r_{wti,T} \\ r_{sc,2} \\ r_{sc,3} \\ \vdots \\ r_{sc,T} \end{bmatrix} = \begin{bmatrix} 1 & r_{wti,2} & r_{sc,2} & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & r_{wti,3} & r_{sc,3} & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & r_{wti,T} & r_{sc,T} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & r_{brent,2} & r_{sc,2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & r_{brent,3} & r_{sc,3} & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 1 & r_{brent,T} & r_{sc,T} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & r_{brent,1} & r_{wti,1} \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & r_{brent,2} & r_{wti,2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & r_{brent,T-1} & r_{wti,T-1} \end{bmatrix} \begin{bmatrix} \alpha_{brent} \\ \beta_{wti}\lambda_{brent} \\ \beta_{sc}\lambda_{brent} \\ \alpha_{wti} \\ \beta_{brent}\lambda_{wti} \\ \beta_{sc}\lambda_{wti} \\ \alpha_{sc} \\ \beta_{brent}\lambda_{sc} \\ \beta_{wti}\lambda_{sc} \end{bmatrix} + \begin{bmatrix} u_{brent,2} \\ u_{brent,3} \\ \vdots \\ u_{brent,T} \\ u_{wti,2} \\ u_{wti,3} \\ \vdots \\ u_{wti,T} \\ u_{sc,2} \\ u_{sc,3} \\ \vdots \\ u_{sc,T} \end{bmatrix} \qquad (19)$$

We have followed the same procedure in the case of equations (20) – (22). Both systems have been estimated using non-linear least squares, applying the Marquardt algorithm. Following Peiró et al. (1998), we arbitrarily fix λ_{wti} equal to 1. This implies that the values of the other parameters should be understood as their ratios to λ_{wti}.

6. RESULTS AND DISCUSSION

6.1. VECM-BEKK results

Table 3 provides the results of the ADF test. The outcome of the ADF test indicates that the log prices of Brent and WTI contain a unit root at the 1% level. Therefore, log prices are not stationary. In the case of the first order differences, the null hypothesis is rejected at the 1% level, confirming that the first order differences of the log prices are stationary.

[Please Insert Table 3]

Table 4 (Panel A) shows Johansen Cointegration test results. The trace statistic indicates that the π matrix has full rank (r=2) at the 10% significance level. This contradictory result reveals a low power of the Johansen Cointegration test to detect the presence of a cointegrating relationship among the variables. Furthermore, the Maximum eigenvalue statistic result is that Brent and WTI log prices are not cointegrated. Conversely, the results of Engle-Granger and Philips-Oularis cointegration tests, that are shown in Table 4 (Panel B), indicate that Brent and WTI log prices are cointegrated at the 10% significance level. Given these results, we continue the study investigating the short- and long-run causality by the estimation of the VECM model.

[Please Insert Table 4]

Table 5 shows the estimation results of the VECM without and with SC dummy variable. Qualitatively, the results of both models are similar. The short-run transmission parameters are not significant at any level. The Brent's speed of adjustment parameter is not statically significant and the WTI's adjustment parameter is positive and significant at the 5% level. During the period 2017-2019, Brent prices have been above WTI prices. Therefore, WTI prices need to rise to restore equilibrium. The statically significance of the WTI's adjustment parameter respects to Brent's adjustment parameter indicates that Brent leads WTI in the long-run.

The dummy parameters estimated, that have been included in equations (11) and (12), are significant and negative at the 1% level only in the case of the WTI equation. This parameter is directly affecting the intercept term of WTI equation. The negative value of the dummy parameter suggests that the unconditional mean of WTI has been reduced since the launch of the new Chinese futures contract. Nevertheless, there are factors that could be affecting this result, such as the Organization of Petroleum Exporting Countries (OPEC) events that took place during the 2018 year.

Another relevant result is the change in the values of the speed of adjustment parameters in the VECM with dummy variable respects to the VECM without dummy variable. The WTI adjustment parameter has increased. Therefore, the launch of SC has strengthened the leadership of Brent on WTI. Table 5 (Panel B) exhibits diagnostic tests of both VECM models. Akaike and Schwarz's criterions present closest values for both models.

[Please Insert Table 5]

Table 8 shows the results of BEKK-GARCH estimation. Panel A.1 in Table 8 exhibits estimations of equation (14) and panel A.2 in Table 8 shows the estimations of equation (15). The results indicate that the volatilities of WTI and Brent are affected by their own past shocks and volatilities. Moreover, the crossmarket effects are statistically significant at the 1% level in either direction, indicating a bi-directional volatility spillover among both markets. In addition, the estimations of the dummy parameters are negative and significant at the 1% level. The launch of the SC has reduced the long-run variance of Brent and WTI. Therefore, the volatility transmission patterns have changed since the launch of SC.

[Please Insert Table 8]

Figure 6 (A) shows the daily conditional volatility and covariance for BEKK including SC dummy variable. Both volatility series have similar patterns, but the conditional volatility of WTI is above Brent during all period. Moreover, Figure 6 (B) exhibits conditional covariance time-varying. Figure 6 shows a drop on conditional volatilities and covariance in June 2016, this date coincides with the OPEC meeting in Vienna. On June 2, 2016 crude oil prices suffered a drop as a response to the OPEC meeting on that date, when oil ministers ended the meeting reaching any kind of consensus on regulating the price and supply of crude oil.

Moreover, conditional volatilities and covariance increased during December 2018 and January 2019. This increase can be explained by the fact that in December 2018 monthly U.S crude oil production reached 11.96 million b/d, the highest monthly level of crude oil production in U.S history. The U.S. historical production levels on December 2018 has resulted in low crude oil prices and high conditional volatilities and covariances during December 2018 and January 2019.

[Please Insert Figure 6]

6.2. Multiple non-linear regression results

Table 9 reports crossed correlations between the returns of WTI, Brent, Brent PM and SC. Given the absence of normality in the returns, we have used Kendall's tau correlation coefficient, that is one descriptive measure of association in a bivariate sample. The Tau-test is a nonparametric test that tests the null hypothesis of independence between two series. Panel A in Table 9 shows contemporaneous daily returns cross-correlations. The returns of WTI are high and positively correlated at the 1% level with the returns of Brent and Brent PM. In addition, returns of Brent PM are positively correlated at the 5% level with SC's returns. Panel B in Table 9 reports a similar analysis between the OIL returns and the OIL returns lagged one period. In this case, $r_{WTI,t}$ and $r_{BRENT,t}$ are negatively correlated at the 10% level with $r_{WTI,t-1}$ and $r_{BRENT,t-1}$. The correlation between $r_{SC,t}$ and the returns of WTI, Brent and Brent PM lagged one period is positive and significant at the 1% level.

The trading times may help to explain the cross-correlation results. As we have previously mentioned, SC settlement time is at 7:00 (GMT), whilst Brent and WTI report settlement prices at 18:30 (GMT). Moreover, the settlement time of Brent PM is at 15:30 (GMT). Therefore, it makes sense that returns on the day $t-1$ of WTI, Brent and Brent PM are correlated with the SC's returns on day t. These results indicate that a model that tries to explain OIL returns should take into account not only contemporaneous information but also past information about OIL returns.

Furthermore, it is remarkable that the highest correlation is observed between contemporaneous returns of WTI and Brent on day t. The settlement times of

WTI and Brent coincide at 18:30 (GMT). If there exist global innovations in the OIL market, the relationship between two variables should be higher the longer the overlapping between their trading times. Hence, the overlapping of trading times could be an explanation of the high correlation observed on day t between WTI-Brent returns pairs. The feature that Brent and WTI are futures contracts that can be traded almost 24 hours during the day could enlighten this event. It opens the discussion about the usefulness of analysing daily returns in markets that can be traded continuously by electronic platforms, as is the case of WTI and Brent futures contracts.

The SC contract is not contemporaneous correlated with Brent and WTI. This cross-correlations result indicates that SC may is not influencing WTI and Brent markets. We will conduct a more detailed analysis of the links between the three markets to clarify these empirical results.

[Please Insert Table 9]

Table 10 shows the joint estimation of systems A and B. Panel A in Table 10 exhibits the joint estimation of equations (17), (18) and (19). In this system, only the parameters $\hat{\beta}_{BRENT}$ and λ_{SC} are significant at the 1% level. We are interested in the relative values of these parameters to $\lambda_{SC} = 1$. These results indicate that Brent is the only influential market, since its beta is positive and significant at the 1% level and the betas of WTI and SC are not significant at any significance level. WTI is the most sensitive market, as its ability to be influenced compared to SC is higher. Moreover, Brent market appears as an insensitive market.

Panel B in Table 10 shows the joint estimation of equations (20), (21) and (22). The significant parameters of system B are similar to the estimation of system A.

Nevertheless, the influential capacity of Brent PM is lower than the estimation of the influential capacity of Brent. In the case of the SC ability to be influenced, the estimation output of System B is higher than the results of System A. These results are consistent with the previous cross-correlation analysis and our hypothesis that the three markets are related in a contemporaneous and non-contemporaneous way, depending on their trading times.

[Please Insert Table 10]

7. SUMMARY AND CONCLUDING REMARKS

This paper investigates two main questions. Firstly, testing if the launch of SC futures contract has been accompanied by a change in the relationship between the two main crude oil benchmarks, Brent and WTI. Secondly, the information flows among the three futures markets: Brent, WTI and SC. These objectives are framed within a common theme: the globalization of the crude oil market.

Since the launch of the SC contract, there has been speculation about the impact of the SC on Brent and WTI markets. In a first analysis of the total volume and open interest of Brent and WTI, we have observed that the trading of SC contracts has been accompanied by a significant increase in the open interest of WTI market. In addition, we have analysed the impact of the SC on the short- and long-term relationship between Brent and WTI markets by including a dummy variable in the VECM model. Firstly, similar to previous studies, we conclude that Brent and WTI share a common tendency in the long-run. Moreover, our findings suggest that Brent leads WTI in the long-run and the launch of the SC has accompanied by the strengthening of the leadership of Brent on WTI. Secondly, our findings suggest that there is no causal relationship between both oils in the short-run. Therefore, the oil market is integrated, at least between the two main benchmarks. To investigate the integration hypothesis, further research could be an intraday cointegration analysis, including another crude oil futures contract such as the SC.

Additionally, we have performed a volatility analysis between the two benchmarks by applying a BEKK model. The results indicate that short-term volatility relationship between both markets is explained by the volatility spillover between

WTI and Brent markets. Furthermore, we showed that since the launch of the SC contract, the long-term variance and covariance of both markets have been reduced.

Regarding the results of the analysis of the market linkages among the three markets, our findings indicate that Brent is the most influential market, while SC appears as the most sensitive. In addition, the SC contract has no influence on WTI and Brent daily prices. Therefore, the leadership of the Brent-WTI oil futures market is not threatened yet.

Given the high degree of overlap between the trading times among the main oil futures benchmarks, we highlight the importance of studying the information flows between international markets by models such as Peiró et al. (1998) or by an intraday analysis. Moreover, our results are of interest to practitioners and individual investors as the knowledge of which crude oil futures contract is exercising leadership in the crude oil market is important to take positions in crude oil futures and get gains in price and time.

REFERENCES

Adelman, M. A. (1984). “International Oil agreement.” *International association for Energy Economics* 5(3): 1-9.

Ahking, F. W. (2002). "Model Mis-Specification and Johansen's Co-Integration Analysis: An Application To The US Money Demand". Journal Of Macroeconomics 24 (1): 51-66.

Aruga, K. (2015). “Testing the International Crude Oil Market Integration with Structural Breaks.” *Economics Bulletin* 35(1): 641-649.

Bala, D. A., and Takimoto T. 2017. "Stock Markets Volatility Spillovers During Financial Crises: A DCC-MGARCH With Skewed- T Density Approach". *Borsa Istanbul Review* 17 (1): 25-48.

Bhar, R., Hammoudeh, S. and Thompson, M. (2008). “Component structure for nonstationary time series: Application to benchmark oil prices”. *International Review of Financial Analysis* 17(5): 971-983.

Candelon, B., Joëts, M. and Tokpavi, S. (2013). “Testing for Granger causality in distribution tails: An application to oil markets integration.” *Economic Modelling* 31: 276-285.

Fattouh, B. (2010). “The dynamics of crude oil price differentials.” *Energy Economics* 32(2): 334-342.

Engle, R.F. and C.W.J. Granger (1987) "Co-integration and Error Correction: Representation, Estimation, and Testing". *Econometrica* 55(2): 251-276.

Engle, R. F. and Kroner, K. F. (1995). “Multivariate Simultaneous Generalized ARCH.” *Econometric Theory* 11(1): 122-150.

Giulietti, M., Iregui, A. and Otero, J. (2014). “Crude oil price differentials, product heterogeneity and institutional arrangements”. *Energy Economics* 46: 28-32.

Kaufmann, R. and Banerjee, S. (2014). “A unified world oil market: Regions in physical, economic, geographic, and political space*.” Energy Policy* 74: 235-242.

Klein, T. (2018). “Trends and contagion in WTI and Brent crude oil spot and futures markets - The role of OPEC in the last decade”. *Energy Economics* 75: 636-646.

Ji, Q. and Fan, Y. (2015). “Dynamic integration of world oil prices: a reinvestigation of globalisation vs. regionalisation.” *Applied Energy* 155: 171-180.

Johansen, S. (1991). “Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models”. *Econometrica* 59(6): 1551-1580.

Lucia, J. J., and Pardo, A. (2010). “On measuring speculative and hedging activities in futures markets from volume and open interest data.” *Applied Economics*, 42(12): 1549-1557.

MacKinnon, J. G., Haug, A. A. and Michelis, L. (1998). “Numerical distribution functions of Likelihood Ratio Test for Cointegration”. *Department of Economics, University of Canterbury.*

Milonas, N. and Henker, T. (2001). “Price spread and convenience yield behaviour in the international oil market.” *Applied Financial Economics* 11(1): 23-36.

Peiró, A., Quesada J. and Uriel E. (1998) “Transmission of movements in stock markets.” *The European Journal of Finance* 4(4): 331-343.

Phillips, P. and Ouliaris, S. (1990). "Asymptotic Properties of Residual Based Tests for Cointegration". Econometrica 58 (1): 165–193.

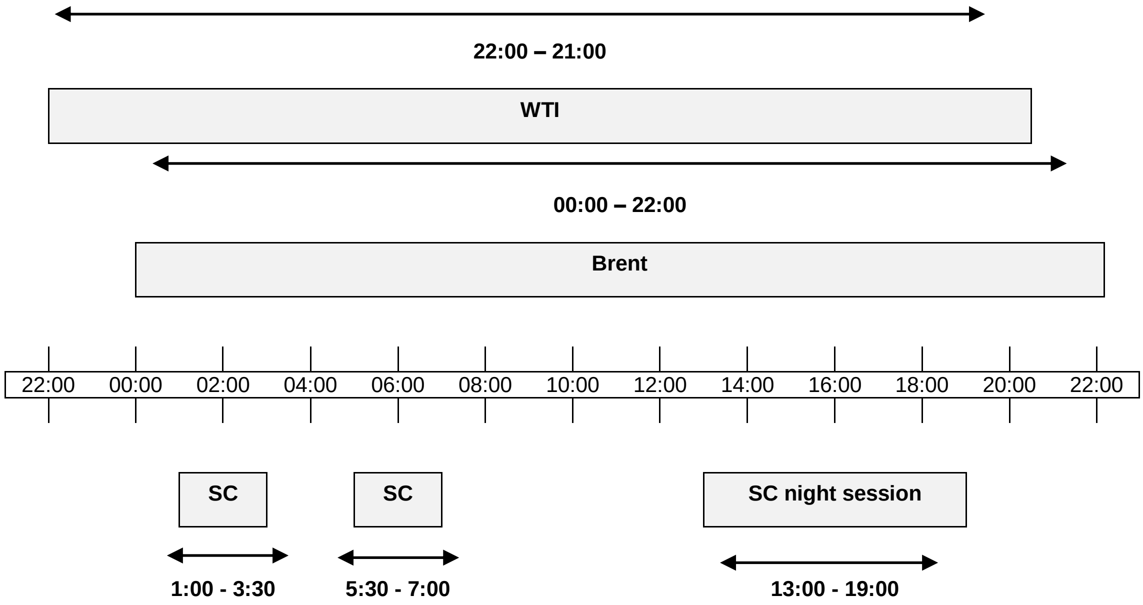
Reboredo, J. (2011). “How do crude oil prices co-move? a copula approach.” *Energy Economics* 33(5): 948-955.

Weiner, R. (1991). “Is the World Oil Market “One great pool”?”. *The Energy Journal 12(3): 95-107.*

Zhang, J. and Umehara, N. (2019). “How far is Shanghai INE Crude Oil Futures from an International Benchmark in Oil Pricing?”. *Institute for International Monetary Affairs* (4, 2019)

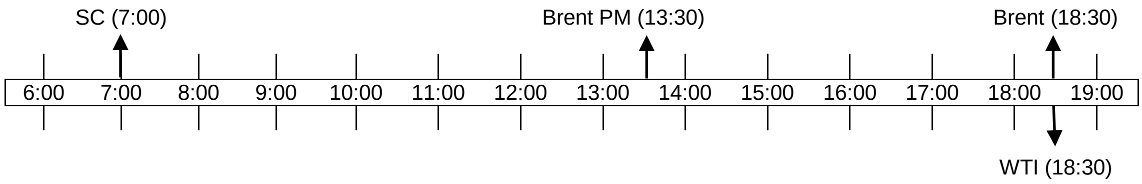
FIGURES APPENDIX

Figure 1. Trading hours



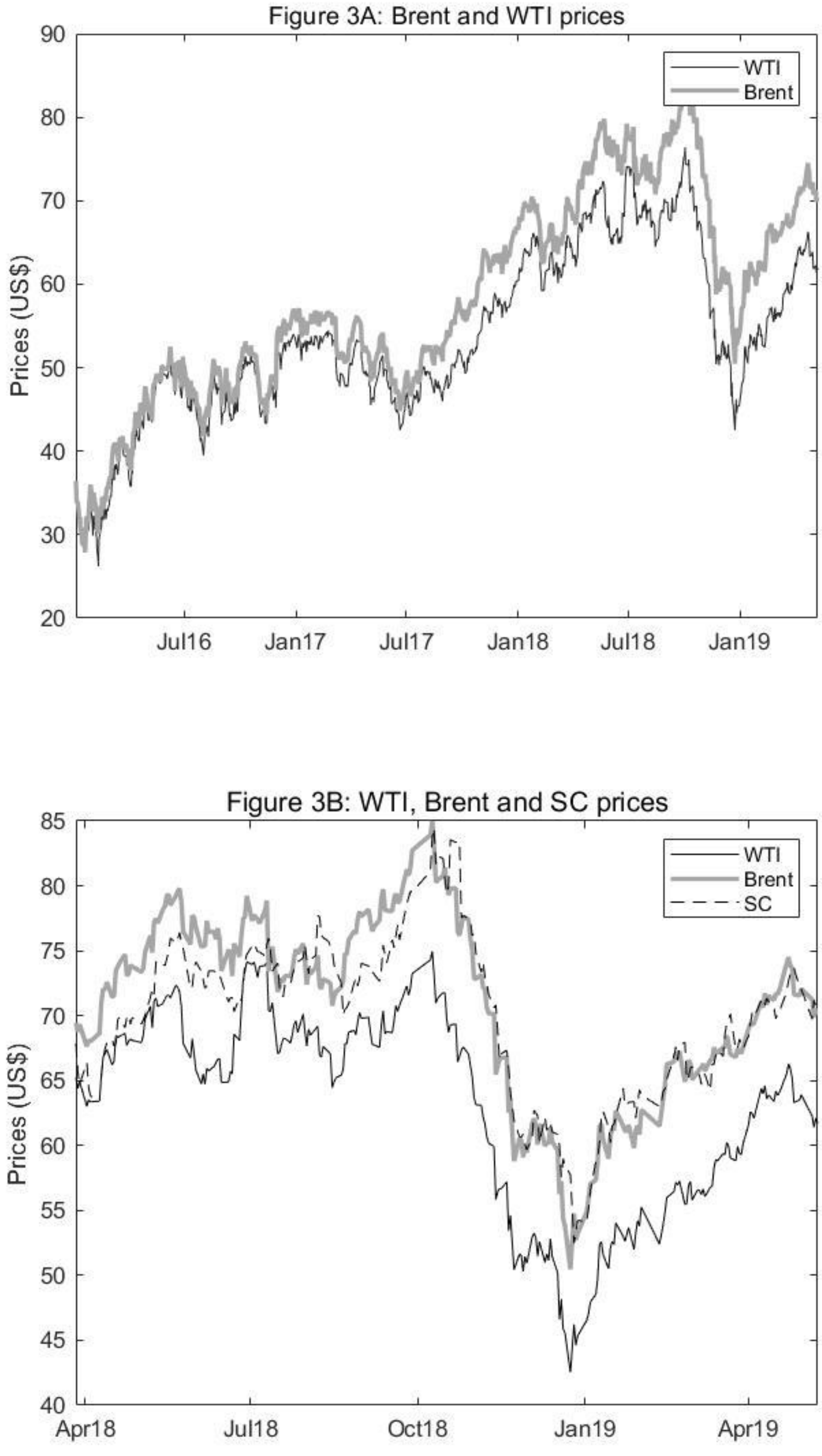
Notes. Trading times are in Greenwich Mean Time (GMT). WTI and Brent are futures contracts that can be traded almost 24 hours per day by electronic platforms. SC can be traded by INE Exchange during the morning and afternoon sessions or by electronic platforms during the night session.

Figure 2. Settlement times



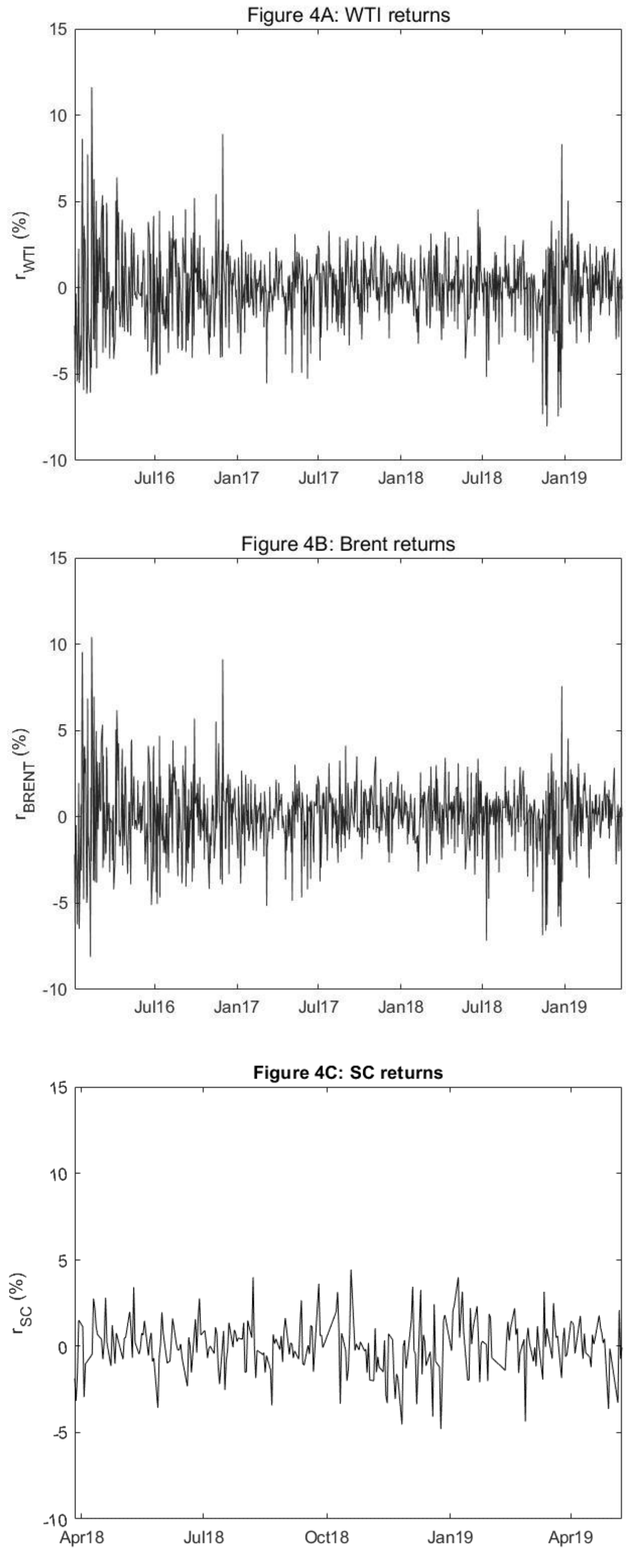
Notes. Settlement times are in Greenwich Mean Time (GMT).

Figure 3. Daily prices



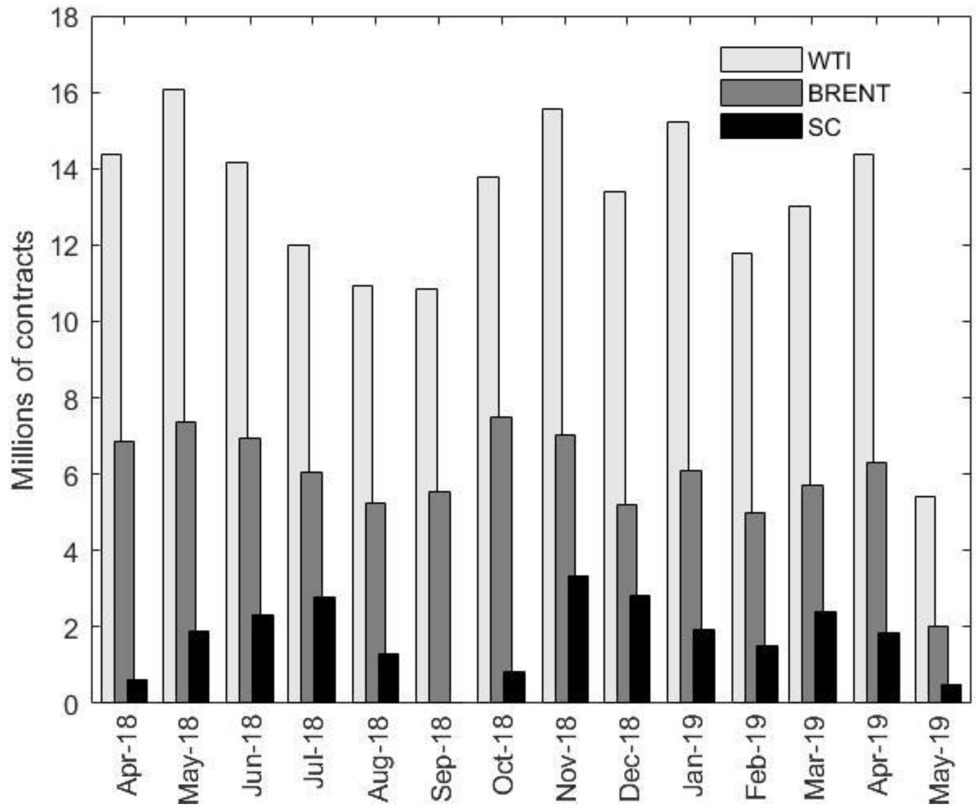
Notes. Figure 3A shows WTI and Brent daily prices for the period of January 5, 2016 to May 9, 2019. In Figure 3B, WTI, Brent and SC daily prices are plotted and covers the period from March 26, 2018 to May 2019. The prices series are in US$.

Figure 4. Daily returns



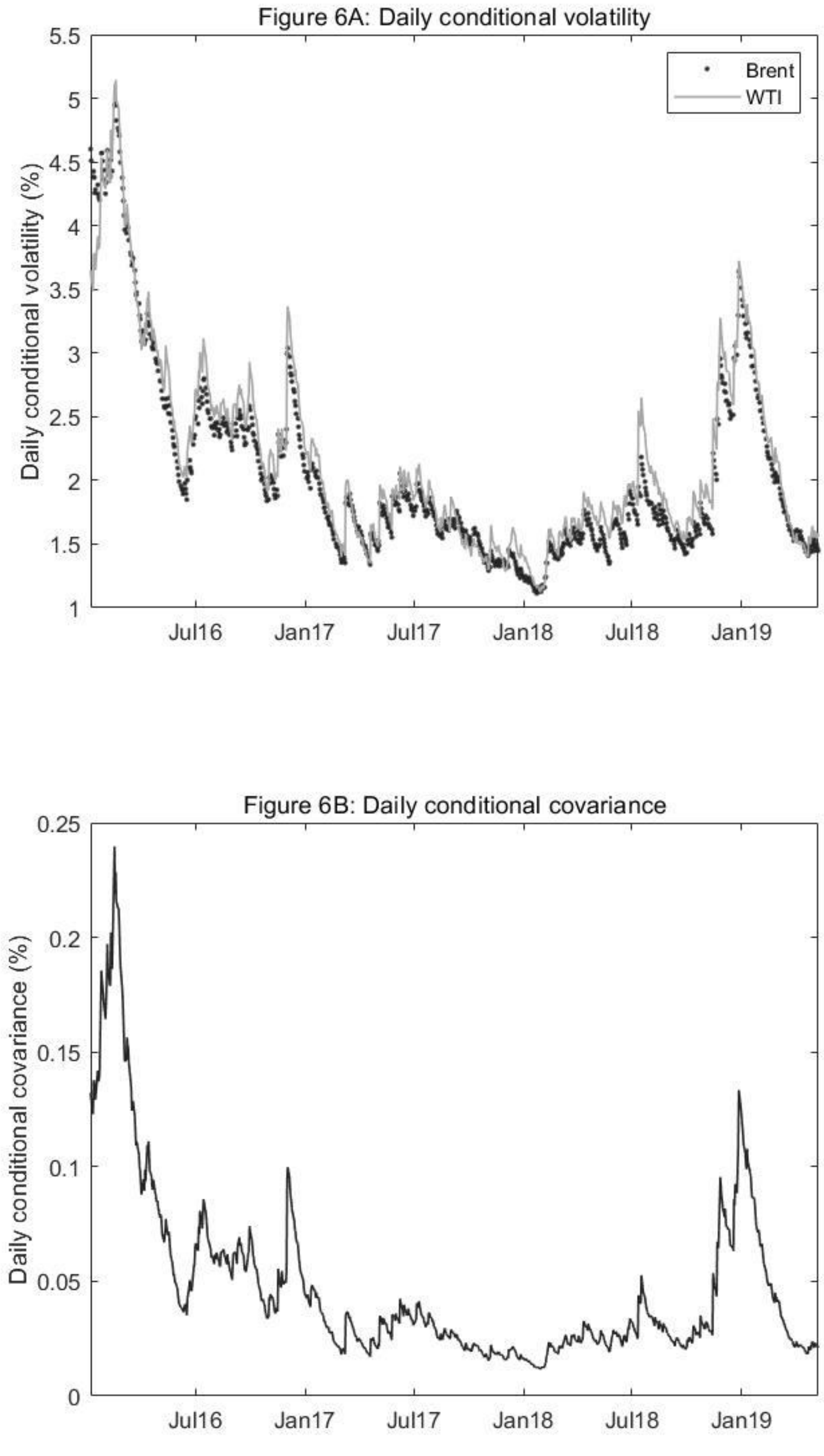
Notes. WTI, Brent and SC daily returns are plotted. Returns are represented in percentages terms. The sample period of Brent and WTI daily returns goes from January 2016 to May 2019. The sample period of SC daily returns goes from March 27, 2018 to May 9, 2019.May 9, 2019.

Figure 5. Nearby contract monthly volume



Notes**.** Each bar represents the monthly volume of WTI, Brent and SC nearest to maturity future contract. The sample starts from April 2018 to May 9, 2019. The monthly volume series have been calculated by accumulating daily volume data. The SC's volume data has been divided by two as is doubled-side counted. The monthly volume's unit is millions of contracts for each future contract.

Figure 6. Conditional volatility and covariance



Notes. Panel A shows daily conditional volatilities and Panel B exhibit daily conditional covariances. Conditional volatilities and covariances are represented in percentages terms. The sample period goes from January 5, 2016 to May 9, 2019. The daily conditional volatility and covariance have been estimated by BEKK including SC dummy variable using the residuals obtained in equations (11) and (12).

TABLES APPENDIX

Table 1. WTI, Brent and SC contract specifications

	WTI	Brent	SC
Market	NYMEX (New York Mercantile Exchange)	ICE (InterContinental Exchange)	INE (Shanghai International Exchange)
Region	United States	Northwest Europe	China
Barrels per contract Unit	1,000	1,000	1,000
Sulphur Content	0.24 %	0.42 %	1.5 %
API grades	39.6º	38.1º	32.0º
Contract Months	Monthly contracts listed for the current year and the next 8 calendar years and 2 additional consecutive contract months	Up to 96 consecutive months	Monthly contracts of recent twelve consecutive months followed by eight quarterly contracts
Price quotation	U.S. dollars and cents per barrel	U.S. dollars and cents per barrel	Yuan per barrel
Minimum price fluctuation	$ 0.01 per barrel	$ 0.01 per barrel	¥ 0.1 per barrel
Daily price limits	7% in each trading session	None	± 4% from the settlement price of the previous day
Last trading day	Three business day before the twenty-fifth calendar day of the month prior to the contract month. If the twenty-fifth calendar day is not a business day, trading terminates 3 business day prior to the business day preceding the twenty-fifth calendar day	The last trading day of the month prior to the delivery month	The last trading day of the month prior to the delivery month
Delivery period	Delivery shall take place no earlier than the first calendar day of the delivery month and no later than the last calendar day of the delivery month	Stablished by EFP and, in case of the cash settlement, the next trading day following the last trading day for the contract month.	Five consecutive trading days after the last trading day
Settlement Method	Physical delivery	EFP with an option to cash settle against the ICE Brent Index price	Physical delivery
Product code	CL	B	SC
Data source:	www.cmegroup.com	www.theice.com	www.ine.cn

Table 2. Daily summary statistics sample 1

	P_{Brent}	P_{WTI}	r_{Brent}	r_{WTI}
Mean	58.1611	53.6339	0.0006	0.0002
Median	55.9900	52.1150	0.0020	0.0019
Max	86.2900	76.4100	0.1042	0.1162
Min	27.8800	26.2100	-0.0811	-0.0802
Std	12.2939	10.2114	0.0206	0.0215
Skewness	0.0247	0.0130	0.0476	0.0408
Kurtosis	2.3388	2.5796	5.6536	5.3618
JB	15.8249	6.2390	253.5218	196.1714
p-value	0.0022	0.0434	0.0000	0.0000
Observations	864	844	863	843

Notes. The prices series of Brent and WTI are represented as P_{Brent} and P_{WTI}. The returns series are represented as r_{Brent} and r_{WTI}. Returns are expressed in 1% terms. All the prices are in US/dollar. The sample covers the period from January 5, 2016 to May 9, 2019.

Table 3. Daily summary statistics sample 2

	P_{Brent}	P_{WTI}	P_{SC}	r_{Brent}	r_{WTI}	r_{SC}
Mean	70.8725	63.0313	69.9113	0.0001	-0.0002	0.0001
Median	72.1300	65.2500	70.8718	0.0020	0.0021	0.0012
Max	86.2900	76.4100	84.4568	0.0757	0.0832	0.0442
Min	50.7700	42.5300	52.4879	-0.0718	-0.0802	-0.0479
Std	7.1730	7.6100	6.1531	0.0183	0.0198	0.0155
Skewness	-0.4505	-0.5809	-0.3138	-0.8122	-0.6829	-0.2004
Kurtosis	2.5842	2.3479	2.9303	6.1243	6.0826	3.7043
JB	12.0642	20.7539	4.5428	149.3213	134.0420	7.4152
p-value	0.0024	0.0000	0.1032	0.0000	0.0000	0.0245
Observations	290	284	272	289	283	271

Notes. The prices series of Brent, WTI and SC are represented as P_{Brent}, P_{WTI} and P_{SC}. The returns series are represented as r_{Brent}, r_{WTI} and r_{SC}. Returns are expressed in 1% terms. All the prices are in US/dollar. The sample covers the period from March 26, 2018 to May 9, 2019.

Table 4. Daily trading volume and open interest

	Volume		Open Interest	
	WTI	Brent	WTI	Brent
	From 4 January 2016 to 23 March 2018			
Mean	1183684	841795	2096316	2307936
Median	1157999	835971	2135534	2311180
	From 26 March 2018 to 9 May 2019			
Mean	1192424	839101.3	2234658	2310569
Median	1169334	826742	2197986	2276531
	Equality Tests			
F-test	0.1564	0.0275	49.3317	0.0771
p-value	0.6926	0.8684	0.0000	0.7814
Kruskal-Wallis test	0.6292	0.0083	37.1275	0.7226
p-value	0.4277	0.9273	0.0000	0.3953

Notes. This table reports the mean and the median of the sum of the total daily trading volume and open interest of all the WTI and Brent futures contract. The first period goes from January 4, 2016 to March 23, 2018 and the second one runs from March 26, 2018 to May 9, 2019. The F statistic tests the null hypothesis of equality of means. Kruskal–Wallis statistic is the non-parametric equivalent of the F test and is distributed as a $\chi 2$ with one degree of freedom. All the p-values appear below the corresponding statistics. Daily trading volume and open interest are expressed in the number of contracts.

Table 5. Augmented Dickey-fuller unit roots test

	Brent	WTI
Level series	-2.2390	-2.3604
	(0.1926)	(0.1535)
First order differences	-20.034	-19.8033
	(0.0000)	(0.0000)

Note. Augmented Dickey-fuller test is used to examine the stationarity of the series. First-row test level series by using the log prices of the WTI and Brent. In the second row, the ADF test for first-order differences is analysed. Numbers in parenthesis indicate p-values. The number of lags has selected by the Akaike criterion. The sample goes from January 5, 2016 to May 9, 2019 for both futures contracts.

Table 6. Johansen results

Panel A: Johansen test	Hypothesised cointegrating equations	
	None	At most 1
Eigenvalues	0.0194	0.0053
Trace statistic	20.9181 (0.0069)*	4.4368 (0.0352)**
Max-eigen statistic	16.4814 (0.0219)**	4.4368 (0.0352)**

Panel B: Engle-Granger and Phillips-Oularis tests

	Engle-Granger	Phillips-Oularis
Tau-statatistic	-3.0193 (0.1068)	-3.0756 (0.0945)***
Z-statistic	-18.2932 (0.0777)***	-18.9577 (0.0680)***

Note. Panel A shows Johansen cointegration test results. MacKinnon et al. (1999) p-values are reported in (.). Panel B exhibits Engle-Granger and Phillips-Oularis test. The null hypothesis of both tests is that variables are not cointegrated. MacKinnon et al. (1996) p-values are reported in parenthesis. The variables taken into account in the three tests are Brent and WTI log prices. These variables have been obtained applying natural logarithms to the Brent and WTI prices, both in US$ currency. The sample goes from January 5, 2016 to May 9, 2019. The ** and *** indicate significance at 5% and 10% level, respectively.

Table 7. VECM results

Panel A: VECM estimation

Model 1

$$\Delta y_{1,t} = \alpha_{y1} + \sum_{i=1}^{m} \delta_{11}\Delta y_{1,t-i} + \sum_{i=1}^{n} \delta_{12}\,\Delta y_{2,t-i} + \gamma_{y_1} z_{t-1} + \varepsilon_{y1,t}$$

$$\Delta y_{2,t} = \alpha_{y2} + \sum_{i=1}^{p} \delta_{21}\Delta y_{1,t-i} + \sum_{i=1}^{q} \delta_{22}\Delta y_{2,t-i} + \gamma_{y_2} z_{t-1} + \varepsilon_{y2,t}$$

	α_{Brent}	δ_{11}	δ_{12}	γ_{Brent}
Brent	0.0009	-0.0917	-0.0065	0.0258
	[1.3185]	[-0.9081]	[-0.0680]	[1.5498]
	α_{WTI}	δ_{21}	δ_{22}	γ_{WTI}
WTI	0.0007	-0.1234	0.0457	0.0432**
	[1.0394]	[-1.1569]	[0.4511]	[2.4570]

Model 2

$$\Delta y_{1,t} = \alpha_{y1} + \sum_{i=1}^{m} \delta_{11}\Delta y_{1,t-i} + \sum_{i=1}^{n} \delta_{12}\,\Delta y_{2,t-i} + \gamma_{y_1} z_{t-1} + x_1 d + \varepsilon_{y1,t}$$

$$\Delta y_{2,t} = \alpha_{y2} + \sum_{i=1}^{p} \delta_{21}\Delta y_{1,t-i} + \sum_{i=1}^{q} \delta_{22}\Delta y_{2,t-i} + \gamma_{y_2} z_{t-1} + x_2 d + \varepsilon_{y2,t}$$

	α_{Brent}	δ_{11}	δ_{12}	γ_{Brent}	x_1
Brent	0.0017***	-0.0857	-0.0151	0.0172	-0.0024
	[1.7799]	[-0.8456]	[-0.1579]	[0.7499]	[-1.2002]
	α_{WTI}	δ_{21}	δ_{22}	γ_{WTI}	x_2
WTI	0.0022**	-0.1236	0.0415	0.0500**	-0.0044**
	[2.1997]	[-1.1557]	[0.4094]	[2.0606]	[-2.0915]

Panel B: Diagnostic test

Model 1	R-sq.	Adj. R-sq.	Akaike	Schwarz SC
Brent	0.0129	0.0129	-4.9309	-4.9084
WTI	0.0093	0.0094	-4.8229	-4.8004
Model 2	R-sq.	Adj. R-sq.	Akaike	Schwarz SC
Brent	0.0117	0.0119	-4.9274	-4.8992
WTI	0.0070	0.0072	-4.8195	-4.7914

Note. Panel A shows estimations of equations (9)-(12). T-statistics are shown in brackets below each parameter estimation. The *, ** and *** indicates significance at 1%, 5% and 10% level, respectively. Panel B shows diagnostic tests. Sample cover the period from January 5, 2016 to May 9, 2019.

Table 8. BEKK results

Panel A: BEKK estimation	Panel A.1: BEKK without dummy variable	Panel A.2: BEKK with dummy variable
c_{11}	0.0057 (0.0000)*	0.0007 (0.0000)*
c_{21}	0.0057 (0.0000)*	0.0014 (0.0000)*
c_{22}	0.0018 (0.0000)*	0.0013 (0.0000)*
α_{11}	0.0200 (0.0000)*	0.0151 (0.0000)*
α_{12}	0.0134 (0.0000)*	0.2512 (0.0000)*
α_{21}	0.0110 (0.0000)*	0.2201 (0.0000)*
α_{22}	0.0200 (0.0000)*	0.0183 (0.0000)*
β_{11}	0.9500 (0.0000)*	0.9714 (0.0000)*
β_{12}	0.0368 (0.0000)*	0.0099 (0.0000)*
β_{21}	0.0050 (0.0000)*	-0.0037 (0.0003)*
β_{22}	0.9499 (0.0000)*	0.9574 (0.0000)*
v_{11}		-0.0016 (0.0000)*
v_{21}		-0.0029 (0.0000)*
v_{22}		-0.0035 (0.0000)*
Akaike	-14500.84	-10487.1398

Notes. Panel A.1. shows estimations of equation (13), while Panel A.2. exhibit estimations of equation (15). The sample covers the period from January 5, 2016 to May 9, 2019. The p-values are shown in parenthesis below each parameter estimation. The * indicates significance at the 1% level.

Table 9. Cross-correlation analysis

Panel A: contemporaneous analysis

	$r_{WTI,t}$	$r_{BRENT,t}$	$r_{BRENT\ PM,t}$	$r_{SC,t}$
$r_{WTI,t}$	1.0000			
	-			
$r_{BRENT,t}$	0.7350	1.0000		
	(0.0000)*	-		
$r_{BRENT\ PM,t}$	0.4715	0.5359	1.0000	
	(0.0000)*	(0.0000)*	-	
$r_{SC,T}$	0.0398	0.0086	0.0895	1.0000
	(0.3374)	(0.8368)	(0.0309)**	-

Panel B: non-contemporaneous analysis

	$r_{WTI,t}$	$r_{BRENT,t}$	$r_{BRENT\ PM,t}$	$r_{SC,t}$
$r_{WTI,t-1}$	-0.0736	-0.0723	0.0632	0.4174
	(0.0767)***	(0.0818)***	(0.1286)	(0.0000)*
$r_{BRENT,t-1}$	-0.0725	-0.0808	0.0903	0.4246
	(0.0811)***	(0.0518)	(0.0295)*	(0.0000)*
$r_{BRENT\ PM,t-1}$	-0.0508	-0.0811	-0.0802	0.4707
	(0.2218)	(0.0512)**	(0.0536)***	(0.0000)*
$r_{SC,T-1}$	0.0196	0.0085	-0.0383	0.0637
	(0.6381)	(0.8375)	(0.3564)	(0.1252)

Notes. Panel A (B) show cross-correlation contemporaneous (non-contemporaneous) analysis in logarithmic price differences between the WTI, Brent, Brent PM and SC. Cross-correlation between Brent and Brent PM are not reported in this paper. Sample period consists of data from March 27, 2018 to May 9, 2019. The null hypothesis is that tau is equal to 0. P-values are shown in parenthesis. The *, ** and *** indicate rejection of the null hypothesis at 1%, 5% and 10% level respectively.

Table 10. Multiple non-linear regression estimation

Panel A: Joint estimation of equations (9), (10) and (11)

Market	$\hat{\beta}$	$\hat{\lambda}$
Brent	1.0161 (0.0000)*	0.8004 (0.1577)
WTI	1.0957 (0.1574)	1.0000 (-)
SC	0.0070 (0.8010)	0.2247 (0.0097)*
R-squared	0.7695	
Adjusted R-squared	0.7674	

Panel B: Joint estimation of equations (12), (13) and (14)

Market	$\hat{\beta}$	$\hat{\lambda}$
Brent PM	0.7900 (0.0000)*	-1.6990 (0.3314)
WTI	0.0197 (0.5200)	1.0000 (-)
SC	-0.0730 (0.2250)	0.6987 (0.0000)*
R-squared	0.3147	
Adjusted R-squared	0.3085	

Notes. Estimation of models (9) – (14) is presented in this table. System A and system B were estimated jointly, as shown in equation (15) and (16), by non-linear least squares. The sample covers the period March 27, 2018 through May 9, 2019. P-values are presented in parenthesis, were * indicated 1% significance level.

ANNEX

Annex 1. Deliverable foreign crudes

Panel A: WTI deliverable foreign crudes

Type	Zone	Minimum API Gravity	Maximum Sulphur content	Premium/Discount (Yuan/barrel)
Brent Blend	UK	36.4	0.46%	-0.30
Bonny Light	Nigeria	33.8	0.30%	0.15
Qua Iboe	Nigeria	34.5	0.30%	0.15
Oseberg Blend	Norway	35.4	0.30%	-0.55
Cusiana	Colombia	36.9	0.40%	0.15

Source: www.cmegroup.com

Panel B: Brent deliverable foreign crudes

Type	Zone	Minimum API Gravity	Maximum Sulphur content	Premium/Discount (Dollars/barrel)
Brent Blend	UK	36.4	0.46%	-
Forties	UK	40.3	0.56%	-
Oseberg Blend	Norway	35.4	0.30%	-
Ekofisk	UK	37.5	0.23%	-
Troll Blend	Norway	35.8	0.21%	-

Source: www.theice.com

Panel C: SC deliverable foreign crudes

Type	Zone	Minimum API Gravity	Maximum Sulphur content	Premium/Discount (Dollars/barrel)
Dubai	United Arab Emirates	30	2.8%	0
Upper Zakum	United Arab Emirates	33	2.0%	0
Oman	Sultanate of Oman	30	1.6%	0
Qatar Marine	State of Qatar	31	2.2%	0
Masila	Republic of Yemen	31	0.8%	5
Basra Light	Republic of Iraq	28	3.5%	-5
Shengli	China	24	1.0%	-5

Source: http://www.shfe.com.cn

Notes.INE may adjust deliverable crude stream, grades and price differentials based on the market conditions. ICE calculates monthly the differentials based on the BFOE basket published by Platt's.