A new way of measuring the WTI – Brent spread. Globalization, shock persistence and common trends.

Abstract

The standard cointegration and the persistence of the spread of the Brent-WTI price have been widely analyzed. However, no studies have been able to present evidence of both issues jointly so far. A novel focus is presented in this paper from the application of the fractionally cointegrated vector autoregressive (FCVAR) approach, which allows the rigidity of the standard cointegration to be solved. As result of the application of the FCVAR model, we identify several degrees of globalization by analyzing the order of integration of the error correction term. Indeed, by using Permanent-Transitory decomposition analysis, we present what drives the relationship between both oil crude prices' information. The findings shown here reveal that the Brent-WTI market is strongly globalized. Nevertheless, the Brent–WTI price spread follows a long memory process, and the Brent drives the Brent-WTI price structure. These results sustain some corollaries on economic policies for economic agents, policy makers and business operators.

Keywords
Crude oil; Brent; WTI; Fractional cointegration; Persistence; PT decomposition

1. Introduction

This paper analyses the possible relationship between two of the main indicators of the oil market, the North Sea Brent (Brent) and West Texas Intermediate (WTI) crude oil prices, by using the Fractional Cointegration Vector Autoregressive (FCVAR hereafter) model to determine whether these markets are regionalized or globalized. We also apply the PT decomposition in order to identify which crude oil drives the common trend and the Brent-WTI price structure. The methodological approaches recently taken to analyse this long-run relationship usually apply the standard cointegration techniques or analyse the persistence of the spread (or relationships) in order to determine whether the markets are globalized or regionalized. However, a controversy emerges between these empirical approaches because it is assumed, on one hand, that the markets are globalized when there is cointegration in the relationship and, on the other hand, that the markets are regionalized when the spread is stationary. In that sense, this article allows us to analyse a previously uncontemplated scenario, the possibility that the series are cointegrated in the globalized market but that the spread is a nonstationary regionalized market. The use of the FCVAR provides important advantages compared to previous approaches. In particular, the rigidity of the traditional approaches is overcome in favour of allowing the series to be cointegrated, and the error term does not necessarily need to be $I(0)$; for example, we allow the error term to be cointegrated in order $I(d - b)$, unlike other techniques that assume the error term is $I(0)$. Under this assumption, we determine a controversy derived from the standard cointegration does not allow the spread to be nonstationary. The FCVAR model breaks these restrictions, providing a more reliable framework for determining if markets are regionalized or globalized.

This empirical interest stems from the well-known strategic role of the crude oil market in the world economy. Crude oil is a widely traded commodity that often affects other commodity prices and other financial markets, and oil price shocks can precipitate macroeconomic adjustments in some countries (Ji and Fan, 2012; or Coronado *et al.*, 2017). Indeed, in developed countries, crude oil has become the main source of energy, accounting for approximately 40% of energy sources, and is present in all productive sectors. Several factors in the past decades have generated important imbalances in this market. On one hand, there is a growing demand for oil from emerging countries such as China and India. On the other hand, the technological innovation of combining horizontal drilling with hydrofracturing has created an oil boom within the United States (Feyrer *et al.*, 2017). In addition, events in unstable producing countries such as Nigeria or Iran, wars in countries such as Syria or Iraq, and attacks on the oil infrastructure in countries such as Saudi Arabia have set a new framework in which the adjustments between supply and demand are becoming increasingly more noticeable in the evolution of oil prices.

Consequently, the configuration of crude oil prices has been a focus of energy economics literature research, producing a generous number of investigations. Weiner (1991) stated that the prices of crude oils with same quality move closely together all the time when sustained by the concept of "globalization" against the hypothesis that states that the oil market is regionalized (see Reboredo, 2011). Therefore, according to Weiner's point of view, the Brent-WTI spread could supposedly be nearly constant over time (Fattouh, 2010). Furthermore, both components of the Brent-WTI price spread are light sweet crude oils, and they are almost identical in physical composition. As such, any substantial deviation in the price between these crude oils can only be a consequence of the spatial price equilibrium and not differences in their intrinsic values (Bennet and Yuan, 2016). However, increasing interest is emerging in the literature to understand the behaviour of the spread between the two indices, and many explanations for this spread are emerging in this literature. This interest is based on risk management, especially after the world's crude oil market began to diverge at the end of 2010 (Ji and Fan, 2015), and derives from the increasing average distance between the different pricing behaviours of this spread that were observed in the period from 2011 to 2013, when the Brent-WTI spread widened to as much as $25 per barrel.

The remainder of this paper is organized as follows. Section 2 reviews the empirical findings concerning the WTI-Brent spread from the long-run perspective. Section 3 develops the empirical strategy followed in this paper. Section 4 presents the results derived from the econometric application, and section 5 presents the main conclusions and policy implications.

2. Theoretical and empirical background

This section summarizes the main drivers of the Brent-WTI spread, which are described in subsection 2.1. Subsection 2.2 shows the empirical approaches that have been used to measure the relationships between crude oil markets, and describes how the literature has defined two possible scenarios to understand the Brent-WTI spread, namely, the "globalized" and "regionalized" market scenarios. Then, subsection 2.3 focuses on understanding several methods involving fractional models to explore time series and some previous applications of the FCVAR model. Finally, the new possibilities for FCVAR model application are shown in subsection 2.4.

2.1 The drivers of the Brent-WTI spread

The body of this literature that has studied the Brent-WTI spread has been devoted to breaking down the causes of the fluctuations in price and analyzing the relationship over the long run. The pioneer's efforts to explain the Brent-WTI spread´s drivers appear linked to the transportation cost literature.[1] Although recently, Bennet and Yuan (2016) maintained that markets that are geographically adjacent to each other tend to be more highly integrated than are markets separated by distance, they recognized that institutional barriers such as exchange rates still cause the no-arbitrage condition to fail in close commodity markets. In Bennet and Yuan´s work, they propose an empirical analysis that confirms many of the previous findings of Büyüksahin *et al.* (2013), where they constructed a tractable theoretical model that allows one to identify the causes of the changes in the Brent-WTI price spread over time, and it is flexible to other commodities markets' price spread patterns. This set of arguments found in the literature may explain the asymmetric adjustment back to the equilibrium position, and the paper of Milonas and Henker (2001) summarized these as temporary demand/supply divergences, seasonal factors, transportation costs, convenience yields and the volatility of the underlying cash commodity.

Since the Brent-WTI price spread is the underlying crude oil futures market of the New York Mercantile Exchange (NYMEX) and the Intercontinental Exchange (ICE), the good performance of the spread underlying both guarantees to the economic agents of the world the minimization of the risks associated with price fluctuations in their oil investments around the world. Nevertheless, Silvério and Szklo (2012) explain how over time the markets for benchmark oils have become more sophisticated and complex due to two main factors. On the one hand, the political and market conditions at that time that are the result of instantaneous and decentralized assessments of the market conditions by the participants produce uncertainty, volatility and, consequently, greater risks for the participants. On the other hand, the physical markets in which the benchmark crudes are traded depend on a relatively broad base to exist, and the spread of new information about the market in terms of prices has been impaired.

The close links with other crude oil markets result in (financial) risk-aversion where market participants with heterogeneous expectations or some compulsive or noisy trading activities may also cause an asymmetric adjustment process where a price is pushed up (or down), causing the spread to widen (or narrow) until informed traders react to the temporary deviation and push prices back to the equilibrium position (Cootner, 1962). Financial market frictions, futures contracts availability, and institutional and regulatory constraints are also major factors in oil market price mechanisms and may affect the convergence to the equilibrium. In particular, the financial markets determine oil prices in recent years, facilitate the price discovery and offer a means of transferring risk (Silvério and Szklo, 2012).[2] Consequentially, price discovery is the process of uncovering an asset's full information or permanent value, and the unobservable permanent price reflects the fundamental value of the stock or commodity.

All these factors play roles in the observable price, which can be decomposed into its fundamental value and transitory effects. The latter consists of price movements due to factors such as the bid-ask bounce, temporary order imbalances or inventory adjustments (see Figuerola-Ferretti and Gonzalo, 2010). Furthermore, the benchmarks are

[1] For a wide explanation concerning transportation costs, see for instance Dumas *et al.* (1995) or Sercu *et al.* (1995).

[2] Price discovery refers to the use of futures prices for pricing cash market transactions (Figuerola-Ferretti and Gonzalo (2010)).

economically important because they are traded in the commodity centers, and the spreads between the two benchmarks are also traded and are vital in the price discovery process of crude oil and its derivatives in order to be able to maintain a balanced pricing relationship among the different grades of crude in their categories (Hammoudeh *et al.*, 2008). Since the extent to which the benchmarks were used by economic agents was unreliable, this gap can be deepened. For this reason, it has become a matter of priority for researchers, economic agents and policy makers to know the evolution of the Brent-WTI price spread in order to guarantee the stability of the oil market, as instrumented by the crude oil futures market.

Overall, in the last two decades, a large number of both theoretical and empirical studies have emerged that have provided solid arguments concerning these factors that drive the Brent-WTI spread (see among others Bacon and Tordo, 2004; Lanza *et al.*, 2005; Hammoudeh *et al.*, 2008; Schmidbauer and Rösch, 2012; Büyüksahin *et al.*, 2013; Liao *et al.*, 2014; Balcilar *et al.*, 2014; Mensi *et al.*, 2014; Giulietti *et al.*, 2014; Borenstein and Kellogg, 2014; Deeney *et al.*, 2015; Dowling *et al.*, 2016; Loutia *et al.*, 2016; Zhang and Yao, 2016; or Bennet and Yuan, 2016). Among the other factors at play in the relationship that drive to stationary crude oil differentials (Giuletti *et al.*, 2014) are the role that the system of OPEC has on the volatility of prices, especially for WTI during low prices (see Schmidbauer and Rösch, 2012; or Mensi *et al.*, 2014; and Loutia *et al.*, 2016). In this line, a strand of literature also tries to explain these factors from a behavioral perspective (see Deeney *et al.*, 2015; or Dowling *et al.*, 2016) or speculation (Balcilar *et al.*, 2014; or Zhang and Yao, 2016). Overall, this body of literature has studied the Brent-WTI spread in a wide context, but unfortunately, the 2010 dramatic change in the spatial price spreads of tradable commodities (e.g., oil) cannot be readily explained with standard models from the economic literature (Bennet and Yuan, 2016).

2.2 Brent-WTI in the long run; *'regionalized'* or *'globalized' market.*

Leaving aside the factors that contribute to determining the spread fluctuations, the long-term relationship has been considered as the main objective in the articles of this literature. This vast empirical evidence has resulted in a large number of investigations that have supported the idea that the adjustment process moves under the 'one great pool', 'integrated markets' or 'globalized market' hypotheses as opposed to the hypothesis of 'regionalized markets'. Therefore, the key factor in many recent articles is devoted to exploring the long-term spread behaviors and detecting the stability of the long-term relationship. Some papers show evidence of greater light crude oil market integration (see for instance Ji and Fan, 2012), even in the 1990s, when there were significant transaction costs between oil markets (Kleit, 2001). Nevertheless, no consensus exists regarding explaining the long-run relationship. In recent years, strong evidence supports that the Brent-WTI crude oil price spreads changed from a stationary time series to a nonstationary time series in 2010 due to two breakpoints in 2008 and 2010, thus motivating a large number of studies that have recently focused on the behaviors of this long-term relationship (see Büyüksahin *et al.*, 2013; Chen *et al.*, 2015; or Liu *et al.*, 2016).

This long-run analysis has been applied using several approaches, such as aiming to develop the Granger causality method for testing the relationship among the spread indices (see Kolodziej and Kaufmann, 2013; Berk, 2016; or, more recently, Coronado *et al.*, 2017). Under a very general vision, the studies measuring this long-term relationship have studied the dynamic of the relationship (see, for instance, Ghoshray and Trifonova, 2014). Additionally, recently, Narayan and Narayan (2007) and Jia *et al.* (2017) focused on the volatility and time-varying market integration and diversification during different typical stages of the global oil price. Nevertheless, the distribution of articles devoted to testing this long-term relationship can be grouped into two large groups, including the studies analyzing the cointegration of both markets and the studies dedicated to studying the persistence of this relationship, as a way of demonstrating whether it is a globalized or regionalized market (Gülen 1997, 1999).

From this long-run analytical perspective, one of the first works dedicated to the analysis of cointegration is that of Ardeni (1989), who uses tests of nonstationarity and cointegration for a group of commodities and shows that the law of one price fails in the long-run relationship. He argues that the failure of the law of one price can be rationalized with two factors, namely, the high costs of arbitrage (Richardson, 1978) and institutional barriers, a conclusion that was supported more recently by Goldberg and Verboven (2005), Fattouh (2010) and Olsen *et al*., (2015). Other authors highlighted the asymmetric adjustment process in the long-run equilibrium (Hammoudeh *et al*., 2008) or that these markets were not totally integrated (Milonas and Henker, 2001). Furthermore, there was strong evidence of threshold effects in the adjustments to long-run equilibrium, which implies that markets are not necessarily integrated in every time period, which was demonstrated by Milonas and Henker (2001). In this context, the threshold cointegration analysis has also been implemented by Chen *et al*. (2005), Ewing *et al*. (2006) and Mann and Sephton (2016), where they found strong evidence of asymmetric adjustments. This long-run relationship has also been emphasized by the work Liu *et al*. (2016) that analyzed the dynamics of the Brent-WTI price spread using a procedure suggested by Bai and Perron (1998, 2003) to test the structural breaks in the spread. They found that the Brent-WTI price spread changed from a stationary time series to a nonstationary time series in December 2010. Additionally, they show how the Brent-WTI price spread responds to different shocks in the physical market, including shocks to the WTI supply, Brent supply, US demand and international demand (see also Scheitrum *et al.*, 2018). For its part, Ye and Karali (2016) analyzed the structural breaks in the long-run relationship during the 1993-2016 time period, revealed that the spread is found to experience multiple structural changes during the sample period, and found that the price impact of the breaks that occurred in the later time period were larger. In this structural change analysis, Zavaleta *et al*. (2015) also evidenced that a structural break during the financial crisis of 2008 changed the long-run equilibrium price relationships and the short-run price dynamics. However, in this set of empirical studies against the intuition and theory, Azar and Salha (2017) support that the samples chosen in their paper do not contain calendar structural breaks and that the regionalization of the oil market is strongly denied. These results reject the underlying theory and set the stage for a possible financial anomaly.

Considering the analysis of the persistence of the spread, Liao *et al*. (2014) investigate the spread of the relationship by distinguishing the quantiles with structural breaks of the Brent-WTI price spread crude oil prices as a benchmark, and they find that the spreads contain a unit root in the lower quantiles but display mean reversion behaviors in the upper quantiles. Other papers analyze the comovements of different crude oil prices and markets as well as the deviation of these comovements. In particular, Klein (2017) identifies high but volatile correlations, thus indicating that the long-term movements of the Brent-WTI price spread are driven by the same dynamics. Indeed, he also confirms the 'globalized market' hypothesis and the leading effects of the WTI over Brent using short-term trends of several days, especially in the negative direction.

Finally, the leading role in the crude oil market has also been recently analyzed. The paper of Ji and Fan (2015) also determined that WTI behaved as the price setter before 2010, while Brent has played the leading role in the crude oil market since 2011. For its part, from a different focus using a wavelet-based complex network, Jia *et al.* (2017) recently determined the multiperiod evolution characteristics of leading oil prices and the key spreading paths that play a special role in driving the global oil price comovement tendency towards globalization and regionalization. In particular, the authors support that there are various typical evolutionary features during the changes in leading oil prices and key spreading paths from the weekly cycle to the long yearly cycle in different volatile stages.

2.3 Several methods that deal with fractional models to explore time series.

The empirical approaches used in this body of empirical literature are very extensive. This subsection provides a brief review of the applications of fractional models in oil markets and contrast them with empirical applications of the FCVAR model for these types of time series. It is well known that fractional models are suitable for studying long-term memory in commodity and energy prices. Studies have used fractional models, including the ARFIMA model, to evidence the level of integration of the oil market and their long-term equilibrium relationships (see Bachmeier and Griffin (2006) or Coakley *et al.* (2011), for instance), the local Whittle estimator to test the relationship between financial and physical oil markets (Ghorbel and Souissi, 2016), and decompositions of the price discovery to determine which crude oil holds the dominant position as a benchmark in the crude oil market (Elder *et al.*, 2014; and Liu *et al.*, 2015). Predictability and market efficiency have also been analysed through price volatility, revealing different events affecting long-term memory and persistence in the series, by using the local Whittle estimator, the ARFIMA model and the FIAPARCH model (Wang and Wu (2012, 2013), Chkili *et al.* (2014), or David *et al.* (2018), respectively). Finally, in this focus on long-term equilibrium perspectives, the cyclicity, persistence and/or structural breaks of selected commodity price series have been studied in the empirical literature by using different fractional integration approaches, such as the ARFIMA model or Whittle functions (see Gil-Alana and Gupta (2014), Gil-Alana *et al.* (2015), or Monge *et al.* (2017), for instance).

Regarding the empirical application of the fractional CVAR model, the major empirical studies have been performed in the areas of financial markets and macroeconomics. In particular, this approach has been applied to analyse the relationship between spot and futures markets (Rossi and Santucci de Magistris (2013) and to predict the stock prices by connecting high and low prices (Caporin *et al.*, 2013). Similarly, Barunik and Dvorakova (2015) applied the FCVAR model to contrast the volatility in the selected stock markets. Gagnon and Power (2016) used the FCVAR model with regard to the Brent and WTI relationship, focusing on imperfect integration during the Cushing bottleneck period and the Brent and WTI linked in risk anticipation. Additionally, other recent studies have applied the FCVAR to examine the fractional relationship between political support and macroeconomic variables (Jones *et al.*, (2014); Nielsen and Shibaev (2018)) and to investigate the inflation hedging ability of gold from 1257 to 2016 (Aye *et al.*, 2017), exchange rates (Yaya and Gil-Alana, 2018) and the behaviour of high and low prices of four commodities (Gil-Alana and Carcel, 2018). Finally, Dolatabadi *et al.* (2015, 2016, 2018) used the FCVAR model to analyse and forecast the commodity market. In this context, the FCVAR model is applied in the current study to provide a previously uncontemplated view in the crude oil market literature. The insights for this topic are developed in the following subsection, where that previously uncontemplated view is detailed, highlighting the added value of this study.

2.4 New possibilities by applying the FCVAR

Our new approach uses the FCVAR model developed by Johansen and Nielsen (2012, 2016) and further developed by Nielsen and Popiel (2016). The FCVAR model is an expansion of the traditional cointegrated VAR (CVAR) model proposed by Johansen (1995), and it allows us to determine the number of equilibrium relations via cointegrating rank testing to estimate memory parameters, long-run cointegrating relations with adjustment parameters, and short-run lagged dynamics. In this respect, our purpose is to analyse the dynamics of the crude oil market, i.e., the relationship between Brent and West Texas Intermediate, aiming to determine if these markets are regionalized or globalized by testing the long-run relationship between both crudes and the spread simultaneously. This paper recognizes that the premises of standard cointegration testing (*I(1)/I(0)* dichotomy) time-series variables, integrated at order one and comoved at order zero, are too restrictive, i.e., linear combinations of *I(1)* nonstationary processes are *I(0)* stationary. In this sense, the empirical literature has shown that many economic and financial time series hold long-range dependence in the autocorrelation function but do not precisely exhibit a unit root process, i.e., the long memory process. For this reason and according to our research, we discard traditional cointegration assumptions that crude oil prices cannot move away from one another for long periods of time and that they are unit roots or *I(1)*; they follow dichotomy *I(0)/I(1)* such that they follow a fractional process *I(d)*. We also shed the notion that the error term follows a stationary process (*I(0)*) in cases of cointegration of both variables. In turn, the rigidity of the traditional approach is overcome in favour of allowing for the series to be cointegrated, and the error term does not necessarily need to be *I(0)*; for example, we allow for the error term to be cointegrated in order *I(d – b)*, unlike other techniques that assume the error term is *I(0)*. Indeed, the study of the long-run relationship and the behaviour of the error term may be analysed jointly, which is one of the main advantages of this methodology. Overall, the FCVAR model allows several previously unconsidered scenarios to be determined (see Table 3).

As we have seen in the previous subsections, the empirical review of the literature on this long-term relationship reveals two fundamental blocks of approaches. On the one hand, there are studies that measure the cointegration of the Brent-WTI Market, and on the other hand, there are studies that measure the persistence of the Brent-WTI price spread. In both cases, the approximations are understood as a globalized or regionalized market, but no study applies both approaches jointly. To try to understand both approaches made in the literature, table 1.a is presented, which aims to illustrate the empirical approaches. As seen in Table 1.a, it presents separate evidence of the cointegration and spread, and it shows that the traditional approaches can generate two types of controversies in the interpretation of results depending on the applied empirical approach.

Table 1.a
Standard empirical approaches

		Cointegration /Long-run relationship	
		Yes	No
S	n	Globalization	Controversy 1

Stationary		Globalization (Not Cointegrated) / Regionalization (Spread)
Nonstationary	***Controversy 2*** Globalization (Cointegrated) / Regionalization (Spread)	Regionalization

In response to that in table 1.a, our approach seeks to respond to controversy 2 detected in the traditional approaches. This controversy is given because the analysis of the cointegration does not allow the spread to be nonstationary.[3] To this end, the empirical framework could be changed by the application of an FCVAR model, which would allow us to break from these restrictions, thus providing a more reliable framework when making decisions on the adopted policies to take control of the spread of oil crude prices.

To the best of our knowledge, derived from the assumptions of the traditional cointegration approach, when the series are cointegrated, the relationship is persistent, and the fractional cointegration could solve this rigidity by allowing for intermediate stages. That is, even when having cointegrated series, any shock could be long-lived, and this possibility has not been studied before in this literature. Therefore, the FCVAR model allows us to identify several degrees of globalization. Once the testing shows that there is cointegration, the degree of integration of the spread permits us to detect up to three different degrees of globalization. This idea is illustrated more fully in the next section and is illustrated in Table 1.b, where the new possibilities allowed by the application of the FCVAR as a generalization of traditional approaches are broken down.

Table 1.b
New possibilities by applying the FCVAR

		Cointegration /Long-run relationship	
		Yes	No
Spread	Stationary	**Several degrees of globalization (see table 2)**	Controversy 1 Globalization (Not Cointegrated) / Regionalization (Spread)
	Nonstationary		Regionalization

Whole, this approach allows both the cointegration and the stationarity of the spread to be simultaneously analyzed by studying the order of integration of the error correction term. Consequently, new scenarios could be researched. In this regard, in the following section, by means of the development of the empirical approach of the FCVAR, the new possibilities and the set of new scenarios aforementioned by controversy 2's ideas are more fully detailed and summarized according to several degrees of globalization. Likewise, this approximation has also the advantage of understanding what relative weights each of the indices has with respect to the behaviors of the other by following a similar approach as that proposed by Ji and Fan (2016), which is a factor that is understood as fundamental in the study of the relation. In this context, the empirical evidence presents a fault in the long-run Brent-WTI spread.

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[3] Additionally, the stationary of the spread must be cointegrated, so controversy 1 in our application is not studied.

3. Data and Methodology

3.1 Data

For our empirical analysis, we employ a weekly sample of the Brent and WTI crude oil prices over the period from 15th May 1987 to 19th April 2019 (amounting to 1667 observations for each crude oil series). The data correspond to the Brent (B_t) crude oil and West Texas Intermediate (W_t) crude oil measured in (US $) prices. The data are collected from the US Energy Information Administration (EIA).

As a preview on the selected variables, Figure 1 presents a graphical analysis of the time series dynamics plotted for Brent and West Texas Intermediate. This plot shows a similar behavior in both variables, which could confirm our subsequent results.

Figure 1. Dynamics of Brent and West Texas Intermediate

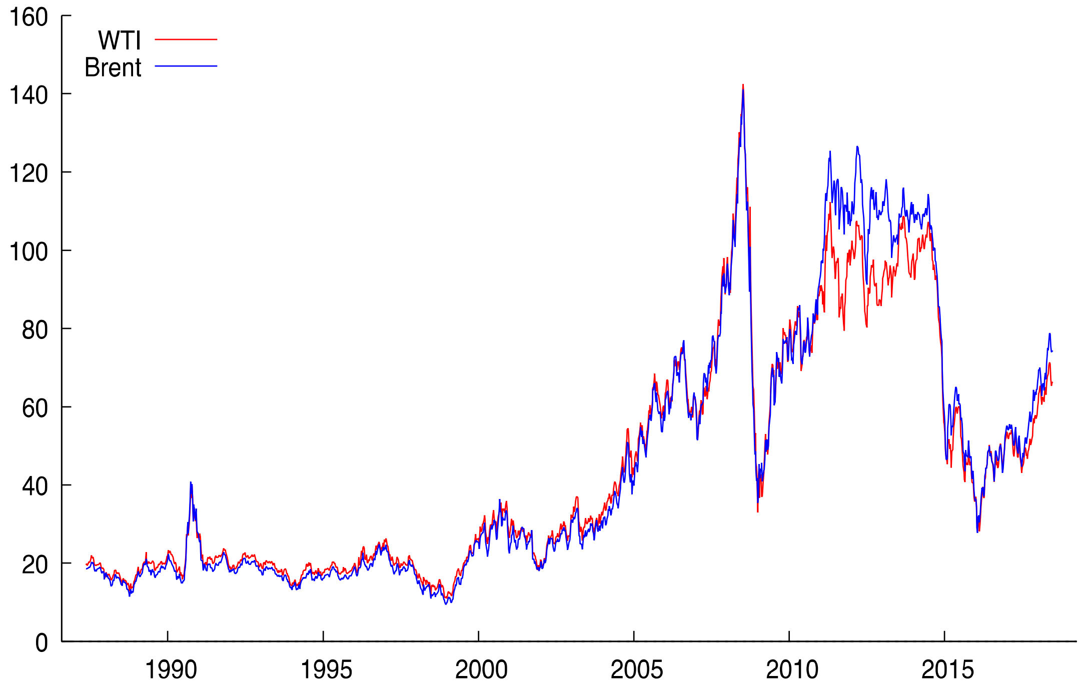

Table 2 shows several descriptive statistics for the two crude oil prices. These statistics corroborate the tendencies observed in Figure 1. A similar variation in sample mean, standard deviation, asymmetry, and kurtosis is found, which suggests that these commodities can offer investors quite different risk-return trade-offs when considered from an investment portfolio point of view.

Table 2.
Descriptive statistics for the data

	Mean	Median	Max	Min	St. Dev	Asym.	Kurtosis
WTI	45.105	31.820	142.52	11	29.455	0.846	-0.441
Brent	46.167	30.530	141.07	9.44	32.973	0.900	-0.429

Notes: The data spans from 15th May 1987 to 19th April 2019

3.2. Methodology

Our empirical procedure consists of several steps. First, we apply the fractionally cointegrated vector autoregressive (FCVAR) model proposed by Johansen and Nielsen (2012) in order to contrast the possible existence of the spread's persistence. Then, we study the permanent-transitory decomposition (Gonzalo and Granger, 1995; and Figuerola-Ferretti and Gonzalo, 2010) in order to determine which crude oil drives the common trend. Thus, in the context of cointegration theory, the commonly linear model is as follows:

$$B_t = c + \beta W_t + \varepsilon_t \tag{1}$$

According to this expression, B_t are the weekly spot prices of Brent at time *t,* and W_t represent the weekly spot prices of WTI. Both spot prices should be nonstationary and related through a cointegration relationship with the parameters (1, - β). Following the work of Growitsch *et al.* (2015), the coefficient $\square_t$ represents the strength of price globalization. If $\square_t = 0$, it implies that there is no relation between the markets and that they are completely decoupled. If prices have globalized and markets are perfectly integrated and competitive, $\square_t$ should be equal to 1. If this difference is stationary, Brent and West Texas Intermediate are driven by a common stochastic trend and do not allow for arbitrage opportunities because the market forces adjust to correct any temporary disequilibrium.

Moving on to the empirical procedure, the next application of the model is a generalization of Johansen's (1995) cointegrated vector autoregressive (CVAR) model to allow the fractional processes of order d that cointegrate to order $d - b$. The fractional cointegrated vector autoregressive (FCVAR) model has the power to be used for stationary and nonstationary time series and is settled in Johansen and Nielsen (2012) and Nielsen and Popiel (2016). To introduce the FCVAR model, first, we must refer to the CVAR model. Letting Y_t, t = 1, …., T be an $I(1)$ time series, the CVAR model is

$$\Delta Y_t = \alpha\beta' L Y_t + \sum_{i=1}^{k} \Gamma_i \Delta L^i Y_t + \varepsilon_t. \tag{2}$$

To derive the FCVAR model, we begin by introducing the fractional difference operator to the CVAR model, $\square$, which inserts persistence in the model, and the fractional lag operator is $L = (1 - \Delta)$. Replacing the lag operators with their fractional counterparts Δ^b and $L_b = (1 - \Delta^b)$, respectively, we obtain

$$\Delta^b Y_t = \alpha\beta' L_b Y_t + \sum_{i=1}^{k} \Gamma_i \Delta^b L_b^i Y_t + \varepsilon_t. \tag{3}$$

Applying $Y_t = \Delta^{d-b} X_t$, we obtain the following FCVAR model:

$$\Delta^d X_t = \alpha\beta' L_b \Delta^{d-b} X_t + \sum_{i=1}^{k} \Gamma_i \Delta^d L_b^i X_t + \varepsilon_t. \tag{4}$$

As usual, ε_t is a p-dimensional i.i.d. variable with mean zero and covariance matrix . The parameters α and β are p x r matrices, where $0 \leq r \leq p$. The columns in matrix β are the cointegrating vectors, and $\beta' X_t$ assumes the existence of a common stochastic trend, which is integrated to order d, and the short-term parts from the long-run equilibrium are integrated to order $d - b$. The speed of the adjustment to the equilibrium coefficients is reflected in α. Thus, $\alpha\beta'$ is the long-run adjustment, and Γ_i represents the short-run dynamics of the variables.

There are two additional parameters in the FCVAR model compared with the CVAR model. The parameter d represents the order of fractional integration of the observable time series. The parameter b determines the degree of fractional cointegration, that is, the reduction in fractional integration order of $\beta' X_t$ compared to X_t itself. The relevant ranges for *b* are (0, 1/2), in which case the equilibrium errors are fractional of order greater than 1/2 and are therefore non-stationary although mean reverting, and (1/2, 1], in which case the equilibrium errors are fractional of order less than 1/2 and are stationary (Dolatabadi *et al.*, 2015). Note that for $d = b = 1$, the FCVAR model is reduced to the CVAR model, which is thus nested in the FCVAR model as a special case. Johansen and Nielsen (2012) show that the maximum likelihood estimators $(b, \alpha, \Gamma_i, \ldots, \Gamma_k)$ are asymptotically normal and that the maximum likelihood estimator of (β, ρ) is asymptotically mixed normal when $b > 1/2$ and asymptotically normal when $b < 1/2$. The important implication is that the standard asymptotic inference can be applied to all these parameters.

We now determine the number of stationary cointegrating relations following the hypotheses of the rank test based on a series of LR tests. In the FCVAR model, we test the hypothesis $H_0\colon rank(\Pi) = r$ against the alternative $H_1\colon rank(\Pi) = p$ for $r = 0, 1, \ldots$. "estimated" rank is then the first non-rejected value in the sequence of tests. Being $L(d, b, r)$ is the profile likelihood function given a rank *r*, where (α, β, Γ) have been reduced by rank regression (see Johansen and Nielsen, 2012). The asymptotic distributions of these LR test statistics are non-standard and are derived in Johansen and Nielsen (2012). We use the *P*-values obtained from computer programs made available by MacKinnon and Nielsen (2014) based on their numerical distribution. Maximizing the profile likelihood distribution under both hypotheses, the LR test statistics are now $LR_t(q)$. The asymptotic distribution of $LR_t(q)$ depends on the parameter *b* and on $q = n - r$. MacKinnon and Nielsen (2014) based on their numerical distribution functions, provide asymptotic critical values of the LR rank test. In the case of "weak cointegration", i.e., $0 < b < 1/2$, $LR_t(q)$ has a standard asymptotic distribution $LR_t(q) \xrightarrow{D} \chi^2(q^2)$.

The specification in (4) is the so-called restricted constant version of the model by Johansen and Nielsen (2012), which is also used by Dolatabadi *et al.* (2016). Deterministic trends may be assumed in the FCVAR model in several ways. Johansen and Nielsen (2012) considered the insertion of the restricted constant term ρ in the long-run cointegrating relation. Dolatabadi *et al.* (2016) suggested an unrestricted constant ξ as the linear trend of the fractionally integrated processes. The following specification shows a more general form:

$$\Delta^d X_t = \alpha L_b \Delta^{d-b}(\beta' X_t + \rho') + \sum_{i=1}^{k} \Gamma_i \Delta^d L_b^i X_t + \xi + \varepsilon_t, \quad (5)$$

where ρ is denoted as the restricted constant term, i.e., the mean level of equilibrium relation, and ξ is the unrestricted constant term that generates a deterministic trend in the levels of the variables (Dolatabadi *et al.*, 2016).

Therefore, the FCVAR model allows simultaneous modelling of the long-run equilibria, the adjustment reactions to deviations from the equilibria and the short-run dynamics of the system. Johansen and Nielsen (2012) and Nielsen and Popiel (2016) provide estimation and inference explanations for the model, and the latter study specifies MATLAB computer programs for the calculation of estimators and test statistics.

When the VAR model encounters the case of $d = b = 1$ (CVAR), the error correction term is integrated of order $(d - b)$, which is $I(0)$ in this case. However, in the fractional cointegration, these axioms are relaxed because $(d - b) = 0$, which means that the error correction term shows short-run stationary behaviour, or $(d - b) > 0$, which in turn means that there is a long memory process and that the error correction term will revert in the long run.

Connecting with the previous idea explained in subsection 2.3 and according to Table 1 in Tkacz (2001), when (d – b) = 0, the error correction term follows a stationary process, and the shock duration is short-lived. If 0 < (d – b) < 0.5, there is a stationary process, and the shock duration is long-lived. Then, if 0.5 < (d – b) < 1, the error correction term follows a nonstationary process, although it is mean-reverting, and the shock duration is long-lived. Finally, when *(d – b) = 1*, the error correction term follows a unit root process. These new scenarios derived from the degree of integration of the spread are represented in Table 3.

Table 3.
Degree of globalization of the *Brent-WTI* price differential by applying the FCVAR

Order of integration of the error correction term (ECT)	**Long-run relationship (Value of *β*)**	
	$\beta = 1$	**$0 < \beta < 1$**
$I(d-b) = I(0)$	**Strong globalization** and the shock duration is **short-lived**.	**Weak globalization** and the shock duration is **short-lived.**
$I(0) < I(d-b) < I(0.5)$	**Strong globalization** and the shock duration is **long-lived**.	**Weak globalization** and the shock duration is **long-lived**.
$I(0.5) < I(d-b) < I(1)$	**Strong globalization** and the ECT follows a **nonstationary** process, although mean-reverting and the shock duration is **long-lived**.	**Weak globalization** and the ECT follows a **nonstationary** process, although mean-reverting and the shock duration is **long-lived**.

Notes: The first row corresponds to the two traditional cases of the standard approaches. If $\beta = 1$, the error correction term could be interpreted as the *Brent-WTI* price spread/differential.

Maximizing the profile likelihood distribution under both hypotheses, the LR test statistic is now $LR_t(q)$. The asymptotic distribution of $LR_t(q)$ depends on the parameter b and on $q = n - r$. MacKinnon and Nielsen (2014) was based on these numerical distribution functions and provided asymptotic critical values of the LR rank test. According to the existence literature, cointegration implies a fractionally vector error correction model (FVECM) such as the following:

$$\begin{pmatrix} \Delta B_t \\ \Delta W_t \end{pmatrix} = \begin{pmatrix} \alpha_B \\ \alpha_W \end{pmatrix} (B_{t-1} - \beta W_{t-1} - c) + \sum_{i=1}^{n} \Gamma_i \begin{pmatrix} \Delta B_{t-i} \\ \Delta W_{t-i} \end{pmatrix} + \begin{pmatrix} u_{1t} \\ u_{2t} \end{pmatrix} \quad (4)$$

This model includes the adjustment parameters □, the cointegration coefficient □, the restricted constant (*c*), the lag length (*n*) and the errors u. Γ_i are 2 x 2 parameter matrices in the short-run dynamics. The adjustment coefficients α_B and α_W capture the speed of the adjustment of the Brent (B_t) and West Texas Intermediate (W_t) towards the equilibrium.

Permanent-Transitory (PT) decomposition in the FCVAR model

According to the Gonzalo and Granger (1995) and Figuerola-Ferretti and Gonzalo (2010) PT decomposition, we let $X_t = (B_t, W_t)'$, where B_t and W_t denote Brent crude oil and West Texas Intermediate crude oil, respectively. In the PT decomposition, X_t can be decomposed into a transitory (stationary) part $\beta' X_t$ and a permanent part $Z_t = \alpha'_\perp X_t$, where $\alpha'_\perp \alpha = \alpha' \alpha_\perp = 0$. Z_t is the common permanent component of X_t, and it is interpreted as the dominant crude oil, where the information that does not affect Z_t will not have a permanent effect on X_t. To know which parameter contributes to each market (Brent or WTI), we attend to the key parameter $\alpha_\perp$. Following the mirror hypothesis, the linear hypothesis on $\alpha_\perp$ can also be tested directly on $\alpha_\perp$or alternatively on □ using the values of the LR tests in each hypothesis, and the critical values can be taken from the χ^2 distribution for testing. For example, to test the hypothesis that the dominant crude oil is the Brent, which means that $\alpha_\perp = (0, a)'$, we can equivalently test the mirror hypothesis $H_0: \alpha = (\gamma, 0)'$. Similarly, to test the hypothesis that the dominant rate is WTI, which means that $\alpha_\perp = (a, 0)'$, we test the mirror hypothesis $H_1: \alpha = (0, \gamma)'$ (see Dolatabadi *et al.* (2018) that first combined the FCVAR with PT decomposition in the commodity market).

An interpretation of the coefficient □ is that it is an adjustment coefficient that measures how disequilibrium errors could be affected by the current changes in X_t. Under this interpretation, we wonder whether any coefficients in □ are zero, which means that the variable in question is weakly exogenous. For example, under hypothesis H_1, the parameter □ = 0 such that the WTI does not react to the disequilibrium error and it is the transitory component, thus implying that the WTI is the main contributor to the common trend.

To determine the magnitude of each variable in the long-run, we use the component share (CS). As Baillie *et al.* (2002) notes, since $\alpha' \alpha_\perp = 0$, it may also be expressed in terms of the elements of the error correction vector □. To interpret this, we let $\alpha = (\alpha_b, \alpha_w)'$ and $\alpha_\perp \alpha = (\alpha_{\perp,b}, \alpha_{\perp,w})'$. Afterwards, $\alpha'_\perp \alpha = \alpha_{\perp,b} \alpha_b + \alpha_{\perp,w} \alpha_w = 0$ implies that $\alpha_{\perp,b} = -\alpha_{\perp,w} \alpha_w / \alpha_b$. Therefore, the component share (CS) may be expressed as

$$CS_B = \frac{\alpha_w}{\alpha_w - \alpha_b}, CS_W = \frac{-\alpha_b}{\alpha_w - \alpha_b} \quad (5)$$

where B and b and W and w corresponds to Brent and WTI crude oil, respectively.

3.3 Model specification

According to Dolatabadi *et al.* (2016), we have followed the model specification proposed by them. In this respect, before estimating the FCVAR model and the hypotheses of interest, there are three additional elements in the specification of the FCVAR model: the lag length (k), the deterministic components, and the cointegration rank (r).

First, regarding the selection of the lag length, we meticulously apply some sources of information, including the Bayesian information criterion (BIC), the *LR* test statistics for significance of Γ_k, and the tests for serial correlation in the residuals. In each case, that are based on the model that includes all the deterministic components considered and has full rank $r = p$. Indeed, for our series, we first use the BIC as a starting point for the lag length, and from there we find the nearest lag length that satisfies the criteria. Second, we check whether Γ_k is significant based on the *LR* test. Third, we check that the tests for serial correlation in the residuals do not show signs of misspecification.

After selecting the lag length, we need to select the deterministic components and the cointegrating rank (r). For the former, this work considers that the restricted constant, $\rho\pi_t$, is present following the methodology framework. Otherwise, the selection of deterministic components is concentrated into the absence or presence of the unrestricted constant[4], that is, the trend component. As Dolatabadi et al. (2016) state, because the limit distribution of the cointegration rank test depends on the actual cointegration rank and the presence or absence of the trend, we must simultaneously decide the cointegration rank and whether the trend is included. The testing of both hypotheses jointly is discussed in depth in Johansen (1995).

4. Results

This section shows the results of applying a FCVAR model to simultaneously assess the long run and the persistence of the relationship between the Brent-WTI price spread. That is, the model allows us to discriminate if the markets are globalized or regionalized, which would allow us to study a scenario not contemplated until now. The application of the FCVAR model, which is a new procedure to accomplish this goal, is summarized in Table 3. We start our econometric exercise by studying the possibility that the fractional cointegration would be more appropriate than the standard one. Once this step is done, we test the degree of the Brent-WTI spread persistence. Then, under this estimation, we examine if the error term shows a long memory process in step 2 and 3. Finally, in step 4, using the FVECM and, subsequently, the permanent–transitory decomposition, we assess which of our variables has a permanent behavior in the common trend, which allows us to know which variable is the price setter.

Table 4.
Strategy of Empirical Research

	Procedure	**Hypotheses**
Step 1	Standard Cointegration vs. Fractional Cointegration	H_1^d: Is the fractional cointegration more appropriate than traditional cointegration?
Step 2	*Cointegrating vector (1, -1)*	H_1^β: Strong or weak globalization?
Step 3	Degree of Brent-WTI spread persistence, i.e., order of integration ($d – b$)	H_1^{d-b}: How long is the duration of the shock (short-lived or long-lived)?

[4] We have specified the model with and without the presence of the unrestricted constant. The achieved results are practically identical regardless of the presence or absence of the unrestricted constant. The results are available upon request.

Step 4	Permanent-Transitory decomposition	$\boldsymbol{H_1^{\beta}} \cap \boldsymbol{H_{1\perp}^{\alpha_{B/W}}} \equiv \boldsymbol{H_1^{\beta}} \cap \boldsymbol{H_1^{\alpha_{W/B}}}$(mirror): What drives the Brent-WTI price structure?

Before testing the possible long-run relationship in the Brent-WTI crude oil price spread and aiming to decide if the FCVAR model is suitable to the main purpose, each of the series is examined singly before driving the multivariate analysis. Broadly, if both stationary tests and unit root tests of a time series are rejected, which suggests that the time series is likely a fractional time series, despite the fact that there are considerable procedures for estimating the fractional differencing parameter in a semiparametric context. Though the semiparametric log-periodogram regression recommended by Geweke and Porter-Hudak (1983) is the most used, this method was varied and deeper developed by Robinson (1995) and has been analyzed by Velasco (1999) and Shimotsu and Phillips (2002), among others. Then, the estimation of the fractional parameter *d* is determined for each univariate series, with the results presented in Table 5. The first three columns correspond to the semiparametric log-periodogram regression estimates from Geweke and Porter-Hudak (1983), which are labeled here as GPH[5] and are computed with the bandwidths $m = T^{0.4}$, $m = T^{0.5}$, and $m = T^{0.6}$, respectively. The remaining columns in Table 5 present the FAR (*k*) estimates with r = 0 and the *k* lags, such as in Johansen and Nielsen (2010). The results are shown for *k* = 0, *k* = 1 and *k* = 2, and the associated Ljung-Box Q-test statistics, which are labeled as $Q_{\hat{\varepsilon}}$, for the serial correlation up to a lag of 12 in the residuals are also given. In this sense, by conducting the univariate analysis, the GPH estimates support the idea that the fractional cointegration could be appropriate for this issue. The FAR (*k*) models show that the residuals are well behaved and that the estimates of *d* are in line with or similar to those for the GPH estimates, although their standard errors are lower.

Table 5.
Univariate analysis

	GPH estimates			FAR(k) estimates					
	$m = T^{0.4}$	$m = T^{0.5}$	$m = T^{0.6}$	$k = 0$		$k = 1$		$k = 2$	
	$\hat{d}$	$\hat{d}$	$\hat{d}$	$\hat{d}$	$Q_{\hat{\varepsilon}}$	$\hat{d}$	$Q_{\hat{\varepsilon}}$	$\hat{d}$	$Q_{\hat{\varepsilon}}$
WTI	0.699	0.763	1.062	1.086	25.464	1.009	22.839	1.119	14.580
	(0.204)	(0.125)	(0.079)	(0.021)	(0.013)	(0.037)	(0.029)	(0.035)	(0.265)
Brent	0.847	0.814	1.043	1.139	17.092	0.652	14.631	0.538	13.892
	(0.160)	(0.094)	(0.069)	(0.022)	(0.146)	(0.035)	(0.262)	(0.101)	(0.308)

Notes: GPH denotes the Geweke-Porter-Hudak semiparametric log-periodogram regression estimator, and FAR(*k*) denotes the fractional AR model with r = 0 and k lags. $Q_{\hat{\varepsilon}}$ denotes the Ljung-Box Q-test statistic for the residuals computed with 12 lags because monthly data are used. The standard errors are given in parentheses beneath the estimates of *d*, and the *P* values are in parentheses beneath the $Q_{\hat{\varepsilon}}$ tests. The sample size is T = 1667.

In this section, we have shown the procedure that we will perform for a battery of results shown below. Following the model specification proposed by Dolatabadi *et al.* (2016), we follow a path to determine the optimal specification of our model and we chose one lag (see appendix). In this respect, although De Jong et al. (1992) have shown that both the BIC and AIC criteria and their estimates notably differ, we must consider that too long of a lag length would distort the data and lead to a decrease in the estimation power. Additionally, Mackinnon and Nielsen (2014) reveal that one lag is sufficient to whiten the residuals in the FCVAR model. Then, once the lag length is selected, we

[5] For testing the presence of unit roots, the estimates were obtained using first-differenced data because the original series may be above 0.5. This test expects that the results are limited to the interval -0.5 < *d* < 0.5, and then, 1 is added to obtain the appropriate estimates of *d*.

determine if there is a long-run relationship between the variables that are chosen. For this reason, we test the cointegration rank before testing the hypothesis of the fractional parameter and evidence that the number of cointegrating vectors is one in our case (Table A2 in the appendix). Once the rank cointegration test is established, we test the hypothesis H_1^d, which tests whether the fractional cointegration is more appropriate than standard cointegration is. Table 6 shows that, in our case, we reject the null hypothesis of $d = 1$, and its rejection implies that the FCVAR model is more suitable than a traditional cointegration therefore, fractional cointegration is appropriate for this study. The next issue consists of estimating the long-run relationship between Brent and WTI (see equation 1). As it can be observed, the parameter □ is close to 1, which will be crucial for our purpose. For this reason, we test the hypothesis H_1^{β}, and with a *p-value* of 0.207, it supports the existence of a long-run relationship, thus implying that both crude oils are strongly globalized. In summation, step 1 and step 2 under our empirical proposal reveal that fractional cointegration is more appropriate than standard cointegration, while also showing that Brent-WTI are strongly globalized.

Table 6
Fractional cointegration test and results

Hypothesis tests:				
		$H_1^d: d = b = 1$		$H_1^{\beta}: \beta = (1, -1)$
	LR	2.565		2.280
	pvalue	0.109		0.131
Cointegration vector :		$\beta = (1, -1.098)$		
$\hat{d} = 1.034$ (0.049)	$\hat{b} = 0.796$ (0.097)	$Q_{\hat{\varepsilon}}(10) = 0.466$	$Q_{\hat{\varepsilon}^2}(10) = 0.277$	$\text{Log}(\mathcal{L}) = -5827.33$
Restricted cointegration vector:		$\beta = (1, -1)$		
$\hat{d} = 1.060$ (0.061)	$\hat{b} = 0.649$ (0.092)	$Q_{\hat{\varepsilon}}(10) = 0.481$	$Q_{\hat{\varepsilon}^2}(10) = 0.316$	$\text{Log}(\mathcal{L}) = -5828.97$

Notes: Standard errors are in parenthesis below the values of $\hat{d}$ and $\hat{b}$. The sample size is 1667.

Following our application, in order to complete the third step, by assuming that the cointegrating vector is (1, -1), we can interpret the difference *(d – b)* as the order of integration of the Brent–WTI price spread, which is the degree of persistence (H_1^{d-b}).[6] In this case, this hypothesis receives a value of 0.411 $(\hat{d} - \hat{b})$, thus implying that the Brent–WTI price spread follows a long memory process, which suggests potential forecasting power at longer horizons (Baillie and Bollerslev, 1994). This implication may be important to the design of investment or hedging strategies in the futures market. Therefore, this value also implies that the duration of the shock is long-lived. Taking into account that shocks are long-lived, one difference between globalized markets and regionalized markets is that there are more players involved in a globalized market, so it is natural for a globalized market to take longer to respond to shocks than regionalized markets. Moreover, regulations could indirectly affect the transmission mechanism in both markets and also it is a possible clue about how a shock is spread and how it affects the concerned parties, including producers, suppliers and investors.

[6] According to our methodology, d and b represent the fractional order of integration of the explanatory variables and the cointegrating error, respectively.

Brent crude oil is the benchmark oil for the European market and for 65% of global crude oil types that are referenced, whose prices are expressed as a premium or a discount against Brent. Several factors differentiate Brent from other crude oils, including its representative quality standard, which facilitates the appraisal process of other grades; the proximity of the North Sea to an important region of oil consumption and the main refining centres of Europe and the USA; and stable and favourable fiscal regulation (from the perspective of the producers), a solid legal regime and relatively low political risk in the United Kingdom, whose government supervises the benchmark index. The status of Brent crude has also been driven by the diverse ownership of production. Diverse ownership greatly reduces the likelihood of market interference and price manipulation compared to a monopolistic structure. This feature has greatly facilitated the willingness of market participants to adopt Brent as a point of reference. From a geopolitical point of view, due to the 'Arab spring' and Libyan crisis, which have decreased the supply of light, sweet crude in the European region, the prices of both crude oils began to mirror each other (see Difiglio, 2014; or Baumeister and Kilian, 2016), although Brent kept its hefty premium. Finally, another reason emerging to explain why Brent is driving the oil price formation is the supply glut at the main storage facility of WTI in Oklahoma; the premium/discount situation has flipped and now Brent is more expensive than WTI.

At last, Table 7 shows the FVECM and, subsequently, the permanent–transitory decomposition. Regarding the price adjustments to the short-run disequilibrium, attending to the joint hypothesis, we find that the Brent index is weakly exogenous (*p*-value 0.728), which further corroborates the evidence that this market is the driver in global oil markets. To check this premise, we apply PT decomposition, which also suggests that the Brent crude oil is dominant in the common trend and drives the Brent-WTI price structure. This finding is partially confirmed by the estimates of the component shares of the Brent and WTI prices, which show that the Brent price constitutes almost 90% of the price structure. For example, as Brent is the dominant crude oil in the common trend and drives the price structure between Brent and WTI, the stakeholders must consider that when a shock occurs, it primarily and directly affects Brent crude oil instead of WTI; that is, any change would affect Brent itself and the Brent – WTI relationship. Otherwise, if the shock occurs over WTI, the shock would only affect WTI and Brent would remain inherent; that is, Brent could be assumed a leading indicator ahead of WTI, i.e., what happens to Brent will also happen to WTI. In this regard, the stakeholders must design strategies in order to take advantage of this situation. Additionally, diverse events (such as institutional forces, market demand and supply, price volatilities or exogenous shocks) are absorbed differently into crude oil markets.

Table 7
FVECM results under constrained parameters (1, -1)

Hypothesis tests:			
		$\boldsymbol{H_1^{\beta} \cap H_1^{\alpha_{Brent}} \equiv H_1^{\beta} \cap H_1^{\alpha_{\perp WTI}}}$	$\boldsymbol{H_1^{\beta} \cap H_1^{\alpha_{WTI}} \equiv H_1^{\beta} \cap H_1^{\alpha_{\perp Brent}}}$
	LR	0.121	7.276
	pvalue	0.728	0.007
Speed of adjustment:			
		$\alpha_{Brent} = -0.017$	$\alpha_{WTI} = 0.144$
Component share:			
		$\mathrm{CS_{Brent}}$ =0.894	$\mathrm{CS_{WTI}}$ =0.106

Notes: With respect to the hypothesis, we reference the mirror hypothesis. The sample size is 1667. CS_{Brent} and CS_{WTI} denote the component shares of Brent and WTI, respectively, and both are normalized such that the two elements add to one.

Finally, next Table 8 summarizes the set of results showed by our empirical application. This table shows the main information derived of the application of the FCVAR model and the PT decomposition to the Brent-WTI price spread.

Table 8.
Summary of results

Steps	**Hypotheses**
Step 1	$\boldsymbol{H_1^d}$: The fractional cointegration is more appropriate than traditional cointegration
Step 2	$\boldsymbol{H_1^\beta}$: The Brent-WTI market is strongly globalized
Step 3	$\boldsymbol{H_1^{d-b}}$: The Brent–WTI price spread follows a long memory process (long-lived shocks),
Step 4	$\boldsymbol{H_1^\beta} \cap \boldsymbol{H_{1\perp}^{\alpha_{B/W}}} \equiv \boldsymbol{H_1^\beta} \cap \boldsymbol{H_1^{\alpha_{W/B}}}$(mirror): Brent drives the Brent-WTI price structure.

5. Conclusions

In this paper, we have studied the possible relationship between two of the main indicators of the oil market, the Brent and WTI crude oil prices, using the FCVAR model. Despite the controversy in the existing literature concerning the treatment of this topic, the fractional cointegration model voids most of the problems raised in this literature. In particular, in this article, we propose to measure the cointegration and the stationary simultaneously, which would allow us to study new scenarios in which both prices could be cointegrated but the spread could be nonstationary. Additionally, this model allows us to identify other points of interest, such as the price structure and the persistence of the spread between each one.

The application of the FCVAR allows us analyze the order of integration of the error correction term, thereby revealing several important results. Firstly, important considerations can be taken into account in relation to the evidence held so far since although the series do have a long-term relationship, the spread shows a long memory process, and consequently, the shocks are long-lived. This result is novel in the literature, since until now, the globalization or regionalization of markets has been defined from these perspectives individually. In addition, the results confirm that Brent drives the price structure. Although the FCVAR shows that these markets are strongly globalized, attending to the stationary of the spread, we reveal that this spread shows a long memory process.

These results support several implications for business operators, arbitrageurs, economic agents and policy makers. First, a globalized market determines the price configuration of the Brent and WTI oil markets. This concept assumes that oil markets have linked prices moving closely together. However, as we reveal that the spread is a long memory process, this scenario is not acceptable, given that price adjustments will not be immediate. Our finding indicates that arbitrage opportunities are increased, which implies that the oil market and the energy futures markets, due to their high liquidity, have increased the ability of market agents to arbitrage immediately. The results also have implications for other stakeholders. On one hand, business operators in their hedging strategies need to take into account the persistence of the spread when considering the adjustment period for investment provisions. On the other hand, government policies will have a long-lived effect, and the effect will not be immediate. A high degree of persistence is likely to send erroneous signals to the monetary policy authority, which could feel the need to affect interest rates to mitigate the impact of oil prices on the economy, thinking that the effect of oil prices will last longer than in fact they do (Gil-Alana and Gupta, 2014).

Finally, focusing on the driver in global oil markets also yields interesting results. The central banks closely monitor the oil price for CPI calculations and global growth projections (Mann and Sephton, 2016). In this context, the decision between using Brent or WTI prices is not insignificant. In this paper, we demonstrate that the Brent is the benchmark price, so banks should incorporate it into their forecasts. Indeed, the price of oil is believed to be a leading indicator of growth and inflation in the economy (Stock and Watson, 2003). Additionally, if policy makers seek to guarantee the symmetry of information in these markets in order to evade the risky markets, it would be advisable to avoid the intervention via taxes, imports or exports, the environment, or changing the quantity of production.

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APPENDIX

Table A1.
Lag length selection

Lags	AIC	BIC
1	11670.02	**11745.77**
2	11676.83	11774.23
3	11668.05	11787.09
4	11652.83	11793.51
5	11638.82	11801.14
6	11650.54	11834.52

Notes: Bold indicates the lag length order that was selected. The sample size is 1667.

Table A2.
Cointegration Rank Test

Rank Test	Log-likelihood	LR statistics
0	-5835.768	29.519
1	-5827.833	**13.650**
2	-5821.008	

Note: In bold the number of cointegration relations