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Cointegration and causality in capital markets

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Abstract

Purpose – The purpose of this paper is to study the efficiency of different oil and gas markets. Most previous studies examined the issue using low frequency date sampled at monthly, weekly, or daily frequencies. In this study, 30-minute intraday data are used to explore efficiency in energy markets.

Design/methodology/approach – Sophisticated statistical analysis techniques such as Granger-causality regressions, augmented Dickey-Fuller tests, cointegration tests, vector autoregressions are used to explore the transmission of information between oil and gas energy markets.

Findings – This study provides evidence for efficiency in energy markets. The new information that arrives either to futures markets or spot markets is digested correctly, completely, and in a fast manner, and is propagated to the other market. The evidence indicates high efficiency.

Originality/value – This study is one of the first papers that uses 30-minute interval intraday data to investigate efficiency in oil and gas commodity markets.

Keywords Cointegration, Energy, Commodity markets, Oil and gas markets

Paper type Research paper

1. Introduction

Capital markets enable the trade of innumerable tangible and intangible items, including financial and commodity products. Oil markets have been the primary medium of energy exchange for the governments, all major industries, companies, geographical regions, and most countries all around the world for more than a century. One can certainly admit that in recent decades, there is a growing effort toward finding, harnessing, and utilizing alternative energy sources. There are several reasons for this effort. First, oil provides power to a certain number of countries, which possess surplus resources of this energy source. Second, these countries can act unilaterally to control the supply and therefore, the price of this energy source. The well-known group of the Organization of Petroleum Exporting Countries is claimed to have acted as a cartel in the past in order to influence the price of oil. Third, gasoline use has increased at an enormous rate over the last century as the primary source of fuel in internal combustion engines. This in turn has had a significant negative impact on the environment. The health hazards to humans and to other living organisms due to the pure quality of air, potential leaks and the consequences of these natural disasters, the benzene and other carcinogens that exist in the composition of oil have enormous real and potential costs. All these factors have nudged researchers and governments to find alternative energy sources, and several potential replacements have emerged in recent years.

Even with all the recent alternatives that have been introduced as potential replacements, oil continues to be the primary source of energy for the majority of industries. Oil industry and all the sub-industries, along with all the by-products continue to

JEL Classification — G13, G14, Q32, Q35, Q41

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be the primary drivers of many economies all around the world. Oil continues to be traded non-stop at spot markets and futures markets 24 hours and seven days a week.

In this paper, the focus is on the efficiency of oil markets and on the determination of how quickly and completely new information is incorporated into these markets. The paper also explores how information propagates from one market to another. Is there symmetry or asymmetry in the propagation of information? How fast does information travel from one market to the other? Again, is the speed synchronous, or is the speed of propagation asymmetric? The majority of papers, which examine these issues in oil markets, have used data samples and sample periods with low sampling frequencies, ranging from quarterly, to monthly, weekly, or, daily. In recent years, there is a trend to apply intraday prices. One such example is Inci and Seyhun (2018). This current paper is a continuation of that study with further analysis using intraday data.

The primary innovation in this paper is the utilization of intraday oil prices. The paper explores oil spot and oil futures markets focusing on the Brent Index spot and futures markets. Daily and 30-minute intraday data are used for the investigation. All these are unique characteristics of this paper. The study shows that oil spot and oil futures markets are quite attractive for numerous different types of investors. The markets exhibit high degrees of efficiency. Institutional investors, pension funds, mutual funds, insurance company funds, endowments, investment companies, professional investors, international and domestic investors, individual investors can all participate in these markets – for numerous different investment objectives.

The rest of the paper is organized as follows. The next section presents an overview of the previous literature on oil markets. Section 3 is about the data used in the study. Section 4 presents the results, along with the interpretation and discussion. The last section follows the conclusion.

2. Literature review

Well-connected oil markets are attractive to producers and consumers of oil. These markets are also very attractive for investors who are not necessarily interested in producing or consumer oil, but are more interested in the dynamics of oil process. These investors are primarily interested in enhancing their wealth through trading contracts on oil either in real time or through futures. For these professional, investors and financial institutions, efficiency and effectiveness of these markets, as well as the connection between different kinds of oil markets and oil contracts are of enormous interest. The risk management strategies and profit generation strategies are all influenced heavily by whether the markets exhibit efficiency.

The research on oil in the literature goes back a long time. One of the early studies in the area by Garbade and Silber (1983) concluded that oil markets are integrated and that risk management tools can be applied in these markets. Schwarz and Szakmary (1994) focus on futures markets on oil and document that oil futures markets achieve risk transfer and accurately price oil. Silvapulle and Moosa (1999) examine the reaction of oil markets to the arrival of new information. They document that the price reaction to new information is typical of those in efficient markets. Moosa (2002) utilizes sophisticated statistical estimation techniques and the analyses through the empirical systems of equations method confirm the results and conclusions of earlier studies. In a similar vein, Bekiros and Diks (2008) use sophisticated dynamic linear and non-linear models to determine the impact of the interaction between oil spot and oil futures markets. They find the necessity and the usefulness of both of these types of markets in trading oil for producers, consumers, and investors – both of these markets are found to be essential in the price discovery process of oil.

One primary deficiency of previous research in this area has to do with the sampling of the data used in the empirical studies. The statistical tests, causality analyses, theoretical models, and their application to real life empirical data all use low frequency sampling of the data. Sampling frequency is as low as quarterly or monthly in some studies. Recent papers mainly use daily sampling of the prices and returns, however, in today's world of optical cables, ultra-high frequency trading, daily updates or portfolios, minimized financial frictions, ease of capital mobility across borders and markets necessitate the use of higher frequency data. Only that way, the statistical causality analyses can be properly conducted, and market efficiency explorations can be correctly concluded. When new information arrives, the prices react fast. To see that reaction and to determine how completely and correctly process respond to information requires the use of intraday data. The propagation of price and return adjustments from one market to the other can only be investigated using intraday data.

The purpose of this paper is to utilize intraday data to better address the effectiveness and efficiency of information reaction, and the oil spot and the oil futures markets' connections. The statistical causality and the lead or lag relationships between spot prices and between futures prices of different contract maturities can be more correctly analyzed only with intraday data. From these perspectives, this paper furthers the conjectures of the Inci and Seyhun (2018). That study utilizes ultra-high frequency tick data. The synchronized two-minute returns in the futures contracts are examined in that paper to answer efficiency concerns in oil markets. In this study, 30-minute prices and returns are used, where the information reaction can be better informed. The arrival of new information can be interpreted differently by markets participants. Positive or negative interpretations, the intensity of the news varies among market participants. The wide geographic dispersion of oil markets around the globe, non-stop continual trading 24 hours a day and seven days a week, lead to a critical limitation in the interpretation of new information. This leads to heightened volatility around the immediate arrival of new information.

Many structural factors unique to oil spot and oil futures markets contribute to accentuated volatility in the very short term. For example, West Texas Intermediate oil prices are recorded at the Dubai oil price benchmarks with a delay of one day. Second, there exist nonsynchronous trading periods, such as the closure of the New York Mercantile Exchange oil trading pit trading 2.30 p.m. eastern US time, with the simultaneous non-stop continuation of electronic trading in systems such as Globex. Geographically, there are other trading platforms such as the Intercontinental Exchange (ICE) in London where electronic trading continues electronically for more than 22 hours a day from 12.55 a.m. to 11 p.m. London time.

The trading ecosystem of accentuated volatility in the very short term would see the heightened instability subside somewhat in a half-hour time segment, after the interpretations of new information become more meaningful, structured, and objective. Therefore, the focus of intraday sampling in this paper is the 30-minute sampling period to investigate the efficiency of oil spot and oil futures markets.

3. Data and sample characteristics

3.1 Connection between spot and futures markets

The fundamental relationship between oil spot prices and oil futures prices is based on the cost-of-carry relation. The future delivery price of an existing quantity of oil depends on the purchase spot price of the same quality and same quantity oil and the physical cost of storing that amount of oil until the future delivery date. Furthermore, any additional advantages of having possession of that amount of time between the spot and future dates, known as the convenience yield, must be taken into account. Finally, the prevailing interest rate throughout the spot and future data must also be considered. All these components are combined together under the umbrella of the cost-of-carry relationship. The resulting connection from the cost-of-carry relationship indicates the interchangeable nature of the oil spot and oil futures contracts. This fundamental cost-of-carry relationship between the oil spot and oil futures prices has been investigated theoretically and empirically, and has been document in numerous academic articles in the literature. Examples of some recent research in this area can be summarized with Quan (1992), Huang *et al.* (2009), Lee and Zeng (2011), Jin *et al.* (2012), Lu *et al.* (2014), and Alzahrani *et al.* (2014). The empirical investigation in this current paper naturally starts from this well-established theoretical setting. The empirical analyses also start from the fundamental connection, but consider and test various expansions of the original setting.

The summary of the data variables is presented in Table I. The table provides the summary statistics for the intraday 30-minute ICE Brent Futures prices and returns. ICE Brent Futures average prices, as well as the minimum and maximum price levels track the corresponding prices for the spot quite closely. Overall, a comparison of the minimum, average, and maximum prices for the spot and futures contacts with different maturities indicate that there are both backwardation (the futures price lower than the spot price) and contango (the spot price lower than the futures price) periods.

Formal empirical investigation of spot and futures prices must start with the exploration of the potential presence of non-stationary components. This set of analyses is conducted with augmented Dickey-Fuller (ADF) tests and the results are reported in Table II. Panel A is about the daily time series for spot prices and returns, as well as the daily prices and returns for futures with one-month, two-month, and three-month maturities. Panel B presents the 30-minute intraday ICE Brent Futures prices and returns. As generally anticipated with time series data, the table indicates the presence of unit roots (UR) in level data variables without much ambiguity. The level price series for all the variables contain UR according to every version of the Dickey-Fuller tests. On the other hand, when first differenced, the return series of every variable is free from UR at the 1 percent significance level.

For the return series in Table II, very high ρ values are estimated in the ADF tests that also lead to consequent τ values. In these cases, the ρ values all converge together for each of the three versions of the ADF tests. That is why similar/same values appear for some of the return series in the ADF tests. Consequently, the τ values are also very close to each other in these three versions of the ADF tests for the return series. The results indicate clearly that the return series exhibit no evidence of UR.

3.2 Oil prices and returns

The oil spot price index used in the paper is the Brent Index. Brent Index is the closing price, more specifically, the last price of a trade before the closure of the market for the day. This settlement index price from the ICE for Brent in London is calculated as the average of the trading prices in the 25-day Brent-Forties-Oseberg-Ekofisk (BFOE) market in the related

	30-minute intraday data				
ICE Brent Crude Futures (CO)	n	Mean	SD	Min.	Max.
1-month Futures prices	45,648	103.4969	13.93815	68.31357	127.3761
2-month Futures prices	41,346	103.1628	13.45866	69.20139	126.46
3-month Futures prices	33,301	103.3742	12.80124	69.79	125.8933
1-month Futures returns	45,647	0.00001	0.0023	−0.03088	0.02606
2-month Futures returns	41,345	0.00001	0.00237	−0.03008	0.02627
3-month Futures returns	33,300	0.00001	0.00261	−0.02904	0.02753
Brent Index Spot	1,066	103.1509	14.22045	69.07	126.14
Brent Index Spot Return	1,065	0.0003	0.01227	−0.04918	0.04322

Notes: Raw price values and raw return values are used for the statistical calculations in the table. The sample period is from January 2010 to March 2014

Table I.
Summary statistics

	Type	ρ	Pr < ρ	τ	Pr < τ	
Panel A: daily data						
Brent Index	Zero mean	0.12	0.7115	0.26	0.7608	UR
	Single mean	−7.27	0.2581	−2.09	0.2473	UR
	Trend	−9.67	0.459	−2.16	0.51	UR
Brent Index Return	Zero mean	−965.22	0.0001	−21.95	< 0.0001	No UR
	Single mean	−966.49	0.0001	−21.95	< 0.0001	No UR
	Trend	−967.81	0.0001	−21.95	< 0.0001	No UR
ICE Brent Crude Futures (CO)						
1-month Futures prices	Zero mean	0.12	0.7111	0.26	0.7606	UR
	Single mean	−7.24	0.26	−2.1	0.2455	UR
	Trend	−9.32	0.4842	−2.12	0.5318	UR
2-month Futures prices	Zero mean	0.12	0.7109	0.26	0.7612	UR
	Single mean	−7.29	0.2569	−2.1	0.2464	UR
	Trend	−9.36	0.481	−2.13	0.5267	UR
3-month Futures prices	Zero mean	0.11	0.7096	0.25	0.7587	UR
	Single mean	−7.44	0.248	−2.11	0.2423	UR
	Trend	−9.51	0.4701	−2.15	0.5158	UR
1-month Futures returns	Zero mean	−911.14	0.0001	−21.32	< 0.0001	No UR
	Single mean	−911.14	0.0001	−21.31	< 0.0001	No UR
	Trend	−911.4	0.0001	−21.3	< 0.0001	No UR
2-month Futures returns	Zero mean	−915.97	0.0001	−21.38	< 0.0001	No UR
	Single mean	−916.79	0.0001	−21.38	< 0.0001	No UR
	Trend	−916.98	0.0001	−21.37	< 0.0001	No UR
3-month Futures returns	Zero mean	−915.58	0.0001	−21.38	< 0.0001	No UR
	Single mean	−916.15	0.0001	−21.38	< 0.0001	No UR
	Trend	−916.65	0.0001	−21.37	< 0.0001	No UR
Panel B: 30-minute intraday data						
1-month Futures prices	Zero mean	0.13	0.7127	0.26	0.7631	UR
	Single mean	−7.92	0.2225	−2.22	0.1972	UR
	Trend	−9.83	0.4498	−2.21	0.4847	UR
2-month Futures prices	Zero mean	0.12	0.7122	0.27	0.7634	UR
	Single mean	−8	0.2182	−2.22	0.1974	UR
	Trend	−9.89	0.4462	−2.22	0.4792	UR
3-month Futures prices	Zero mean	0.12	0.7108	0.26	0.761	UR
	Single mean	−8.53	0.1924	−2.3	0.1732	UR
	Trend	−10.11	0.4305	−2.26	0.4557	UR
1-month Futures returns	Zero mean	−46,937	0.0001	−153.19	0.0001	No UR
	Single mean	−46,940	0.0001	−153.19	0.0001	No UR
	Trend	−46,942	0.0001	−153.2	0.0001	No UR
2-month Futures returns	Zero mean	−42,206	0.0001	−145.27	0.0001	No UR
	Single mean	−42,208	0.0001	−145.27	0.0001	No UR
	Trend	−42,210	0.0001	−145.27	0.0001	No UR
3-month Futures returns	Zero mean	−34,247	0.0001	−130.85	0.0001	No UR
	Single mean	−34,249	0.0001	−130.85	0.0001	No UR
	Trend	−34,251	0.0001	−130.86	0.0001	No UR

Notes: Three different Dickey-Fuller test results are presented in the table. The last column summarizes whether there are unit roots (UR) or not (No UR) based on 5 percent statistical significance

Table II. Augmented Dickey-Fuller tests for unit roots

delivery month reported by the industry media. Only the published cargo size trades and assessments are considered in the calculations.

More explicitly, the index is the average of three parts: First part is the weighted average of the cargo trades of the first month in the 25-day BFOE market. The second part is the weighted average of the cargo trades of the second month in the 25-day BFOE market augmented with a straight average of the spread trades between the first and second months. The third part is the average of designated assessments printed in the conventional media reports.

As explained further at the ICE resources, the first part weighted average is the average of the cargo trade prices reported that are weighted by the volume in order to include multiple trades at any one price level. If conventional media sources do not agree on the number of trades at a given price, then the ICE Futures attempts to clarify the actual number and amount of trades – with the condition and flexibility of omitting unsubstantiated trades that do not meet the satisfaction of the ICE London Exchange. The second part averages produce an inferred price for the first month of the 25-day market. This is accomplished by averaging the second month traded cargo prices and by using the averages of the spreads of the first month trades and the second month trades. The average spread value is determined using the standard average price of spread trades documented by conventional media sources. The average spread is then added to the weighted average trade price representing the second month in order to build the implied first month price level. Trades in the second month of the 25-day market are naturally taken into consideration in this second part calculation as well, after they are adjusted for the size of the differential between the first 25-day month and the second 25-day month. The third part of the Brent Price Index is acquired from the conventional industry media publications of 25-day BFOE market price assessments throughout the trading day. The mid-point of each quote is utilized to calculate an average value representing the whole trading day.

The second group of data is the futures prices obtained from the ICE Brent Futures contracts based on Brent Crude Oil. The intraday sample period for these futures prices and trading volume is from January 2010 to March 2014. ICE futures contracts are applied as a chief trading classification tool for oil and these futures contracts serve as fundamental benchmark prices for the purchases and the sales of oil all around the world. These oil futures contacts' prices are extracted from the North Sea and they include Brent Blend, Forties Blend, Oseberg, and Ekofisk crude oil elements and markets, known shortly as the BFOE. The oil futures markers at trading markets are also known under alternative names, such as the Brent Blend, the London Brent, or the Brent Petroleum. These futures contracts were originally traded through the traditional open outcry system of the International Petroleum Exchange in London, but since 2005 the futures contracts are traded at the electronic ICE – the ICE in London. The size of one futures contract constitutes 1,000 barrels of oil. The currency of quotation of these oil futures contracts is in term of US dollars. Each positive (up) or negative (down) tick is a $10 amount[1].

The trading medium for the ICE oil futures contracts and the ICE oil option contracts is the ICE Futures Europe Exchange. Trades are given and executed at the web-ICE trading platform, which has a distribution and maintenance presence in more than 70 countries around the world. ICE Brent Futures became the world's largest crude oil futures contracts in 2012 in terms of volume. The ICE Brent Futures market share has more than doubled since 2008. The largest group of trading participants in the ICE Brent Futures contracts and the ICE Brent options contracts is commercial hedgers in the form of oil producers, oil consumers, oil processors, and oil merchants. These participants demonstrate ICE futures importance as a risk-reduction tool for these tangible market participants. With a strong and dispersed market, and an easily accessible worldwide trading platform, ICE oil futures exemplify a reachable hedging tool and symbolize a useful indicator of global, regional, and domestic fundamentals. Other fundamental global commodity indices have been resorting to the use of ICE oil futures more frequently and have been increasing the representation of ICE oil futures within the indices because of the growing popularity and importance in the pricing of crude oil.

The summary of the data variables is presented in Table I. The table provides the summary statistics for the intraday 30-minute ICE Brent Futures prices and returns[2].

ICE Brent Futures average prices, as well as the minimum and maximum price levels track the corresponding prices for the spot quite closely. Overall, a comparison of the minimum, average, and maximum prices for the spot and futures contacts with different maturities indicate that there are both backwardation (the futures price lower than the spot price) and contango (the spot price lower than the futures price) periods.

4. Empirical results

The initial investigation of UR clearly reveals that level series – prices – do have UR, while the differenced series – returns – are free from UR. For completeness and for the potential interactions between futures contracts of different maturities, cointegration tests are conducted in order to determine whether the spot and futures prices share a common, non-stationary component. Table III presents these cointegration and rank tests of the interactions between futures prices of different maturities. Panel A presents the results for daily futures prices, while Panel B presents the results for intraday 30-minute price ticks. The cointegration rank test result for each pair of futures price series provides evidence of the rank being equal to one. Therefore, spot prices and futures prices share a common, non-stationary component. These results point out that one can investigate the relations between spot and futures markets either using price levels or returns. Returns are used in this paper because using returns leads to more robust results and conclusions[3].

The interaction of the futures contracts with different maturities between each other, as well as their interactions with the spot index series require the implementation of Granger-causality tests. While Granger-causality tests are not helpful in providing the economic intuition or the tests of economic causality, they are useful in describing the characteristics of the raw data, indicating the presence or absence of lead-lag relations. Consequently, in order to find out any discernible patterns of the interaction between the data series, Granger-causality tests are conducted next.

In the next set of statistical analyses, vector autoregressive technique is employed in order to examine further the integration of oil markets. The statistical models in Table IV use the contemporaneous return along with six lagged values of the independent variable and six lagged values of the dependent variable as the explanatory variables. The order of the lags is determined by using several information criteria, such as the Akaike Information Criterion, Schwarz Bayesian Information Criterion, Hannan-Quinn Information Criterion, and the Final Prediction Error Criterion. One cannot detect a pattern of significance emerging from the causality regressions for the lagged variables. The contemporaneous return is the only explanatory variable that is consistently significant at the 1 percent significance level in every regression with a highly significant *t*-statistics value of at least 190. In the rare situations when the lagged variables have some sort of statistical meaningfulness, they are significant barely at 5 percent level. Therefore, only the contemporaneous explanatory variable and its statistical characteristics are reported in the table.

The regressions in Table IV use the order of six as the order for the autoregressive and moving average components. The results of the Granger-causality regressions between the ICE Brent Futures contracts with different maturities are provided. The table focuses on reporting the estimate and the relevant statistics of the contemporaneous explanatory variable. The first two columns report the Granger-causality regression results of the daily futures results. The last two columns are about the 30-minute returns.

For the causality regressions using daily returns, 1-m to/from 2-m only has the first two lags of the independent coefficient significant in both directions. 3-m on 1-m exhibits an ARMA (1,4) model, while in the reverse direction the fifth lag of the dependent variable and the first two lags of the independent variable are significant. In the 3-m on 2-m regression, the first two independent variables are significant, while in the reverse direction the second lag of the dependent and the first two lags of the independent are significant.

Table III.
Cointegration tests of ICE Brent Crude Futures contracts

Panel A: daily futures prices					
ICE Brent Crude Futures prices: 1-month vs 2-months					
H_0: rank = r	$H1$: rank > r	Eigenvalue	Trace	5% crit. val.	
0	0	0.0324	40.7115	19.99	
1	1	0.0046	5.0373	9.13	
Hypothesis test of the H_0: restriction					
Rank	E-value	Rest. E-value	df	χ^2	Pr > χ^2
0	0.0324	0.0324	2	0.30	0.8608
1	0.0044	0.0046	1	0.28	0.5950
ICE Brent Crude Futures prices: 1-month vs 3-months					
H_0: rank = r	$H1$: rank > r	Eigenvalue	Trace	5% crit. val.	
0	0	0.0251	32.569	19.99	
1	1	0.0047	5.1139	9.13	
Hypothesis test of the H_0: restriction					
Rank	E-value	Rest E-value	df	χ^2	Pr > χ^2
0	0.025	0.0251	2	0.31	0.8557
1	0.0044	0.0047	1	0.3	0.5833
ICE Brent Crude Futures prices: 2-month vs 3-months					
H_0: rank = r	$H1$: rank > r	Eigenvalue	Trace	5% crit. val.	
0	0	0.0198	26.7586	19.99	
1	1	0.0047	5.1174	9.13	
Hypothesis test of the H_0: restriction					
Rank	E-value	Rest. E-value	df	χ^2	Pr > χ^2
0	0.0198	0.0198	2	0.37	0.8325
1	0.0198	0.0198	2	0.37	0.8325
Panel B: 30-minute intraday futures prices					
ICE Brent Crude Futures prices: 1-month vs 2-months					
H_0: rank = r	$H1$: rank > r	Eigenvalue	Trace	5% crit. val.	
0	0	0.0024	101.728	19.99	
1	1	0.0001	5.4757	9.13	
Hypothesis test of the H_0: restriction					
Rank	E-value	Rest. E-value	df	χ^2	Pr > χ^2
0	0.0024	0.0024	2	0.32	0.8529
1	0.0001	0.0001	1	0.31	0.5807
ICE Brent Crude Futures prices: 1-month vs 3-months					
H_0: rank = r	$H1$: rank > r	Eigenvalue	Trace	5% crit. val.	
0	0	0.0016	58.5668	19.99	
1	1	0.0002	5.7255	9.13	
Hypothesis test of the H_0: restriction					
Rank	E-value	Rest. E-value	df	χ^2	Pr > χ^2
0	0.0016	0.0016	2	0.32	0.854
1	0.0002	0.0002	1	0.29	0.5873
ICE Brent Crude Futures prices: 2-month vs 3-months					
H_0: rank = r	$H1$: rank > r	Eigenvalue	Trace	5% crit. val.	
0	0	0.0026	91.751	19.99	
1	1	0.0002	5.855	9.13	
Hypothesis test of the H_0: restriction					
Rank	E-value	Rest. E-value	df	χ^2	Pr > χ^2
0	0.0026	0.0026	2	0.32	0.854
1	0.0002	0.0002	1	0.31	0.5781

Notes: Cointegration test results are presented in the table. Panel A presents the results for daily data and Panel B presents the results for the 30-minute intraday frequency data

Daily		30-minute	
2-month on 1-month ICE Futures		*2-month on 1-month ICE Futures*	
Variable	Rco1(*t*)	Variable	Rco1(*t*)
Estimate	0.96429	Estimate	0.96174
SD	0.00361	SD	0.0013
t-value	266.89	*t*-value	742.05
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
1-month on 2-month ICE Futures		*1-month on 2-month ICE Futures*	
Variable	Rco2(*t*)	Variable	Rco2(*t*)
Estimate	1.02433	Estimate	0.96918
SD	0.00384	SD	0.00131
t-value	266.95	*t*-value	739.73
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
3-month on 1-month ICE Futures		*3-month on 1-month ICE Futures*	
Variable	Rco1(*t*)	Variable	Rco1(*t*)
Estimate	0.94412	Estimate	0.94544
SD	0.00486	SD	0.00218
t-value	194.27	*t*-value	433.19
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
1-month on 3-month ICE Futures		*1-month on 3-month ICE Futures*	
Variable	Rco3(*t*)	Variable	Rco3(*t*)
Estimate	1.03491	Estimate	0.90207
SD	0.00533	SD	0.00208
t-value	194.27	*t*-value	433.57
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
3-month on 2-month ICE Futures		*3-month on 2-month ICE Futures*	
Variable	Rco2(*t*)	Variable	Rco2(*t*)
Estimate	0.98368	Estimate	0.96985
SD	0.0018	SD	0.00191
t-value	547.43	*t*-value	506.94
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
2-month on 3-month ICE Futures		*2-month on 3-month ICE Futures*	
Variable	Rco3(*t*)	Variable	Rco3(*t*)
Estimate	1.01353	Estimate	0.91364
SD	0.00185	SD	0.0018
t-value	548.55	*t*-value	507.14
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001

Notes: The contemporaneous explanatory variable is reported in the table. The lags of the returns are not reported because there is no uniform pattern of significance in the regressions; rather the significance of the lagged explanatory variables is spurious and when significant, it is generally barely borderline significant at the 5 percent significance level

Table IV.
Granger-causality regressions

For the 30-minute intraday return regressions, when there is evidence of Granger causality, the 2-m on 1-m regression has the first lags of the dependent and the independent variable as statistically significant. The 3-m to 1-m regression has the first two lags of the dependent and the first lag of the independent variable significant. Finally, in the 3-m to 2-m regression, the second lag of the dependent variable and the first lag of the independent variable are significant.

One can see from the table that the slope coefficient, as the interaction term, is highly statistically significant and very close to unity in nearly all of the Granger-causality regressions. This is evidence for high interaction between futures returns with different maturities independent of the frequency of the return. Overall, the evidence in Table IV indicates that oil markets are strongly connected in terms of information flow. Any shock to any one contract is transmitted to the other contracts very quickly and almost fully.

The lead-lag relationships between oil spot prices and oil futures prices are explored next. The analyses results are reported in Table V. For oil futures prices, one-month, two-month, and three-month to maturity ICE Brent Futures contracts are used, where the prices are recorded at 4:30 p.m. local London time. For the oil spot prices, Brent Index is employed and the lead-lag relationships between spot and futures markets are examined. Contemporaneous relationships between the spot and the futures prices are strong and dominant. One-day lagged values of the ICE Brent Futures predict the next day's Brent Index spot change. The magnitude of the predictive coefficient is small though, resulting in about 0.17. This finding is quite interesting and is consistent with the exposition that the futures markets, in a general sense, tend to anticipate the developments and the dynamics in spot markets and tend to react in advance of the changes in spot prices. The remainder of the statistical models in Table V also exhibit similar relationships and linkages between the two-month to maturity ICE Brent Futures and the spot Brent Index, as well as between the three-month to maturity ICE Brent Futures and the spot Brent Index[4].

Sensitivity analysis and robustness tests are reported in Table VI. The sample period is divided into two parts. When futures contract prices are higher than spot prices, the dynamics for the commodity is named contango. One other hand, when the spot prices are higher than futures contract prices, the dynamics of the commodity is known as backwardation. The sample period in this paper is roughly split between these two dynamics. From January 2010 to mid-March 2011, the dynamics for oil markets indicate contango. The second half of the sample period exhibits backwardation from mid-March 2011 through to the end of the sample period. The purpose of the sensitivity

Panel A: R(1-m Brent Futures)$_t$ = R(1-m Brent Futures)$_{t-1}$+R(BI)$_t$+R(BI)$_{t-1}$												
Model	Intercept	*t*-stat	R(1-m BF)$_{t-1}$	*t*-stat	R(BI)$_t$	*t*-stat	R(BI)$_{t-1}$	*t*-stat	R^2	EM	$\chi^2(6)$	$p(\chi^2)$
(1)	0.00002802	1.69	−0.12055	−3.69	1.13313	92.1	−0.006	−0.2	84.7%	MA(1)	4.19	0.522
R(BI)t = R(1-m BF)t+R(1-m BF)$t-1$+R(BI)$t-1$												
Model	Intercept	*t*-stat	R(1-m BF)$_t$	*t*-stat	R(1-m BF)$_{t-1}$	*t*-stat	R(BI)$_{t-1}$	*t*-stat	R^2	EM	$\chi^2(6)$	$p(\chi^2)$
(2)	−0.0000201	−1.38	0.78328	92.07	0.16819	6.34	0.032	1.180	85.5%	MA(1)	3.57	0.613
R(2-m BF)t = R(2-m BF)$t-1$+R(BI)t+R(BI)$t-1$												
Model	Intercept	*t*-stat	R(2-m BF)$_{t-1}$	*t*-stat	R(BI)t	*t*-stat	R(BI)$_{t-1}$	*t*-stat	R^2	EM	$\chi^2(6)$	$p(\chi^2)$
(3)	0.00001983	0.68	−0.07091	−1.96	1.07465	81.3	−0.025	−0.7	82.9%	MA(1)	8.29	0.141
Panel B: R(BI)t = R(2-m BF)t+R(2-m BF)$t-1$+R(BI)$t-1$												
Model	Intercept	*t*-stat	R(2-m BF)$_t$	*t*-stat	R(2-m BF)$_{t-1}$	*t*-stat	R(BI)$_{t-1}$	*t*-stat	R^2	EM	$\chi^2(6)$	$p(\chi^2)$
(4)	−9.84E-06	−0.33	0.79943	81.13	0.15156	5.0	0.044	1.4	83.8%	MA(1)	7.66	0.176
R(3-m BF)t = R(3-m BF)$t-1$+R(BI)t+R(BI)$t-1$												
Model	Intercept	*t*-stat	R(3-m BF)$_{t-1}$	*t*-stat	R(BI)t	*t*-stat	R(BI)$_{t-1}$	*t*-stat	R^2	EM	$\chi^2(6)$	$p(\chi^2)$
(5)	−0.00003	−0.35	−0.32448	−5.66	1.03859	68.7	0.240	4.2	81.0%	ARMA (1,1)	7.13	0.129
R(BI)t = R(3-m BF)t+R(3-m BF)$t-1$+R(BI)$t-1$												
Model	Intercept	*t*-stat	R(3-m BF)$_t$	*t*-stat	R(3-m BF)$_{t-1}$	*t*-stat	R(BI)$_{t-1}$	*t*-stat	R^2	EM	$\chi^2(6)$	$p(\chi^2)$
(6)	0.000057	0.7	0.78653	68.61	0.29173	6.52	−0.124	−2.43	81.7%	ARMA (1, 1)	4.70	0.32

Notes: Lead-lag regression results with Brent Index (BI) and ICE Brent Futures (BF) daily returns are reported in the table. R^2 excludes the explanatory power of the error models (EM). χ^2 statistic tests for the autocorrelation of residuals for the first six lags. $p(\chi^2)$ indicates the p-value or the significance level of the χ^2 statistic

Table V. Oil spot vs Oil futures: lead-lag relationships

Panel A: contango Granger-causality regressions					
2-m on 1-m ICE Futures		3-m on 1-m ICE Futures		3-m on 2-m ICE Futures	
Variable	Rco1(*t*)	Variable	Rco1(*t*)	Variable	Rco2(*t*)
Estimate	0.96805	Estimate	0.95459	Estimate	0.98546
SD	0.00614	SD	0.00832	SD	0.00308
t-value	157.67	*t*-value	114.75	*t*-value	320.35
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
1-m on 2-m ICE Futures		1-m on 3-m ICE Futures		2-m on 3-m ICE Futures	
Variable	Rco2(*t*)	Variable	Rco3(*t*)	Variable	Rco3(*t*)
Estimate	1.02268	Estimate	1.02767	Estimate	1.01209
SD	0.00649	SD	0.00896	SD	0.00316
t-value	157.62	*t*-value	114.75	*t*-value	320.45
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
Panel B: backwardation Granger-causality regressions					
2-m on 1-m ICE Futures		3-m on 1-m ICE Futures		3-m on 2-m ICE Futures	
Variable	Rco1(*t*)	Variable	Rco1(*t*)	Variable	Rco2(*t*)
Estimate	0.96221	Estimate	0.93835	Estimate	0.98182
SD	0.0045	SD	0.00603	SD	0.00219
t-value	213.81	*t*-value	155.54	*t*-value	447.35
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001	Pr > |*t*|	0.0001
1-m on 2-m ICE Futures		1-m on 3-m ICE Futures		2-m on 3-m ICE Futures	
Variable	Rco2(*t*)	Variable	Rco3(*t*)	Variable	Rco3(*t*)
Estimate	1.02509	Estimate	1.03868	Estimate	1.01522
SD	0.00479	SD	0.00668	SD	0.00227
t-value	213.81	*t*-value	155.46	*t*-value	447.08
Pr > |*t*|	0.0001	Pr > |*t*|	0.0001	Pr > |*t*|	0.0001

Notes: Causality evidence, causality regressions, and the joint VAR estimation results (30-minute intraday data) are reported for the contango and backwardation periods. From January 2010 to mid-March 2011 is predominantly contango. From mid-March 2011 to end of the sample is predominantly backwardation period. In Panel E, AIC is the Akeike Information Criterion, SBC is the Schwarz Bayesian Criterion, and the HQC is the Hannan-Quinn Criterion

Table VI. Sensitivity tests: contango vs backwardation periods

and robustness tests is to find out whether the prior conclusions of the paper continue to hold in these two sub-samples representing quite different dynamics.

Granger-causality regression test results using 30-minute intraday returns for each sub-sample are provided in Table VI. Panel A is for the dynamics when oil futures prices are higher than oil spot prices – contango. Panel B represents the dynamics when oil futures prices are less than oil spot prices – backwardation. Regardless of the different dynamics, the results depict the tight connection between futures contracts with different maturities – the slope coefficients of the regressions are consistently very close to one. These findings, as before, point out that an innovation in one futures contract with a specific maturity will propagate to other futures contracts of various maturities. This propagation will experience very little attenuation regardless of whether the financial ecology exhibits contango dynamics or backwardation dynamics. These results again exhibit the tight connection in oil markets.

5. Conclusions

This paper builds on the oil commodity literature explores further whether oil markets are efficient and whether the oil spot and oil futures markets are effectively connected. This is an important issue for a wide spectrum of market participants ranging from producers and consumers of oil, to speculators, arbitragers, risk-reducing hedgers, professional and individual investors, traders, and policy makers.

Efficiently connected oil spot and oil futures markets are indicative of well-functioning oil markets. These markets discover new, important, and relevant information quickly. Such new information, innovations, and positive or negative shocks are priced correctly and then transmitted to all related markets, quickly and completely.

Using accurate 30-minute intraday return data, the study extends the literature further and builds on Inci and Seyhun (2018). The evidence confirms that oil spot and oil futures markets are tightly linked. Economic shocks, news, innovations that arise in spot markets quickly and fully conveyed to the futures markets. The evidence shows that most of the reaction is completed within at most half an hour. Similarly, positive or negative shocks, news, innovations arriving in futures markets are transmitted to spot markets quickly and fully. The transmissions amongst futures contacts with different maturities are also fast and comprehensive, though the direction of transmission seems to be stronger from the liquid and actively traded shorter-maturity futures contracts to longer-maturity futures contracts. These conclusions are in line with efficient markets. Overall, oil spot and oil futures markets are tightly connected and innovations are communicated quickly and completely.

Notes

1. More details on the futures contracts about their construction, introduction, marketing, trading statistics, trading parties, major buyers and sellers, the number of different contracts, the maturity dates and the related processes are provided in ICE Brent Crude oil facts and summary documentation. Brent Index data are publicly available at the ICE exchange and website. Additional feature are provided at the www.theice.com/products/219/Brent-Crude-Futures
2. The 30-minute prices are volume-weighted averages of all the trading prices recorded during that relevant half-hour interval.
3. The unrestricted trace hypothesis tests were not conclusive, while the trace hypothesis test with restrictions showed that the cointegration rank was 1. In circumstances such as these, one can either utilize co-integrating regressions focusing on price series, or alternatively, one can resort to using returns series in the investigation. Since numerous different empirical issues are explored in the paper such as the Granger causality, the joint VAR analysis, and the interactions between futures series and spot series, returns of the time series variables are used in the paper.
4. Employing higher lags of both the dependent as well as the independent variables in the regressions did not produce statistically significant results.

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