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A Study on the Oil Price Cointegration Dynamic Process: Evidence From the Shanghai Crude Oil Futures

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This work studies the integration process of the Shanghai crude oil futures market in pricing discovery mechanism of global crude oil markets by conducting cointegration analysis and lead–lag causality tests. Using the representative samples of several futures contracts covering different listing periods, we conclude a significant and gradual change of the relations between the Shanghai crude oil futures market and international benchmarks, from unidirectional Granger causality to bidirectional Granger causality. The cointegration relationships become stable after about 2 years' market development. Moreover, the Shanghai crude oil futures market always leads domestic (Daqing) crude oil spot market since 2019. Our evidences support that it has the increasing influence on domestic crude oil market and international benchmarks.

Keywords: shanghai crude oil futures, granger causality, spot market, price discovery, price cointegration

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1 INTRODUCTION

On 26 March 2018, the first RMB-denominated crude oil futures contract was launched in the Shanghai International Exchange. Since 2019, in terms of the trading volume, the Shanghai crude oil futures market (for short, SIE) has grown into the third largest oil futures market behind West Texas Intermediate (WTI) and Brent, which is building the regional pricing benchmark in Asia-Pacific crude oil market. However, it is expected that SIE needs take some time to play its pricing function in the global market. In other words, as the practical experience of foreign futures markets in the past shows, it needs go through a gradual process from the listing to maturity. In order to investigate the market efficiency of SIE, our work tries to study the cointegration process between it and other representative crude oil markets (Chinese Daqing crude oil spot, US WTI crude oil futures and spot, UK Brent crude oil futures and spot), which contributes to the study of crude oil market efficiency in emerging and developing countries.

There are a few studies on whether crude oil spot and futures prices are integrated well or not by adopting WTI and Brent as the representative markets. For example, Maslyuk and Smyth (2009) study the cointegration relationship between well-established WTI and Brent oil spot and future markets via Gregory and Hansen's (1996) residual-based cointegration test. Chen and Zeng (2011) argue that the Brent futures prices are always integrated well with spot prices during financial crisis from July 2007 to June 2009. Inci and Seyhun (2018) focus on the Brent crude oil spot and futures markets, and find they are well-integrated by using Granger Causality test. In addition, Lean et al. (2010, 2015) investigate the efficiency of crude oil futures markets by adopting stochastic dominance test and mean-variance approach. Related literature also provides different arguments about the lead–lag relationship between WTI and Brent. Elder et al. (2014) demonstrate that Brent is

dominated by WTI in price discovery during the period from 2007 to 2012. But, Ji and Fan (2015) argue that Brent plays a leading role since 2011. Klein (2018) uses Engle and Kroner's (1995) BEKK-MGARCH model to reexamine the leading and lagging effects by considering the impact of OPEC meetings. Certainly, there are plenty of recent works, e.g., Liu et al. (2020), Neves et al. (2021), Ye et al. (2021), Martínez-Cañete et al. (2022), exploring other different issues about oil market, such as the relation between oil and stock market or the forecasting of oil prices.

Above work focuses on the WTI and Brent markets, while studies have begun to examine stylized facts of SIE and its pricing efficiency. Based on data from the launch period of SIE, Ji and Zhang (2019) explore price volatilities of SIE and give a Granger causality test between return and trading volume; Yang et al. (2019) argue that SIE is less efficient relative to both WTI and Brent since the spot prices of the later play a unidirectional Granger causality role on SIE; but from the perspective of price discovery in the Asia-Pacific region, SIE is efficient.

It is worth noting that Lee and Zeng (2011) demonstrate that the cointegration degree between spot and futures prices (WTI) is affected by the length of futures contracts, revealing different market efficiency for different futures contracts; Zhang et al. (2019) find that the integration degree of global crude oil market varies over time. We expect that the listing date and contract length may affect the integration progress between SIE and other markets. We therefore select different futures contracts, including SC 2001, SC 2003, and SC2007 with different listing periods and different lengths, to investigate the change in cointegration degree and Granger causality relationships between SIE and other crude oil markets. Specifically, we employ popular test methods to provide a comprehensive comparison of the cointegration relationships in different periods in order to evaluate recent development and improvement of SIE. Compared with the existing literature (e.g., Ji and Zhang 2019; Yang et al., 2019), our empirical results support a significant and gradual change from unidirectional Granger causality to bidirectional Granger causality between SIE and international benchmarks; meanwhile; SIE always leads the Daqing spot market, which supports that SIE is an efficient regional pricing benchmark.

This work is organized as follows. In the following **Section 2**, we first introduce the test methodology and then analyze stationarity of data. The main empirical results are presented in **Section 3**. **Section 4** gives a simple conclusion.

2 METHODOLOGY AND DATA

2.1 Methodology

Our study employs the popular Johansen (1988, 1991) cointegration test for the existence of cointegration and Granger causality test for lead–lag casual relationships. We use the notations sc, dq, wti, bre, $xwti$, and $xbre$ to represent the daily closing prices of SIE, Daqing spot, WTI and Brent futures, WTI and Brent crude oil spot, respectively. Considering that different listing date of futures contract may bring different pricing efficiency, in order to illustrate the gradual changes of the cointegration process, we perform the corresponding tests for different contract periods.

2.1.1 Johansen Cointegration Test

Following the widely popular test, i.e., the Johansen cointegration test based on the VAR model (Sims, 1980) and the maximum likelihood estimation method, we construct the VAR models to test the existence of cointegration relationship as follows:

$$sc_t = c_1 + \alpha_1 sc_{t-1} + \mathrm{L} + \alpha_p sc_{t-p} + \beta_1 z_{t-1} + \mathrm{L} + \beta_p z_{t-p} + v_t^{sc} \quad (1)$$

$$z_t = c_2 + \lambda_1 z_{t-1} + \mathrm{L} + \lambda_p z_{t-p} + \theta_1 sc_{t-1} + \mathrm{L} + \theta_p sc_{t-p} + v_t^{z} \quad (2)$$

where, $z_i = dq, wti, bre, xwti, xbre, \quad i = t-1, \cdots, t-p, t$ respectively. $c_i\,(i = 1, 2)$ is a constant, $v_t^{sc}(v_t^{z})$ is the residual term and p denotes the lag periods. Besides, $\alpha_i, \beta_i, \lambda_i, \theta_i\,(i = 1, 2, \cdots, p)$ denote the estimated coefficients.

Based the above VAR models, we here check whether there is a cointegration relationship between SIE and other markets by applying both the traditional characteristic root trace test and the classical maximum eigenvalue test. Formally, the null hypothesis for the test of each pair of crude oil prices is that the cointegration relationship between two market does not exist; alternative hypothesis is that the cointegration relationship between two market exists.

2.1.2 Granger Causality Test

In order to clarify that the leading and lagging role of SIE relative to other markets, we employ the following Granger causality test model:

$$sc_t = \varphi_1 + \sum_{i=1}^{k} \alpha_i sc_{t-i} + \sum_{i=1}^{k} \beta_i z_{t-i} + u_{1t} \quad (3)$$

$$z_t = \varphi_2 + \sum_{i=1}^{k} \lambda_i z_{t-i} + \sum_{i=1}^{k} \delta_i sc_{t-i} + u_{2t} \quad (4)$$

Where, $sc_{t-i}\,(i = 1, \cdots, k)$ denotes the SIE prices, $z_{t-i}\,(i = 1, \cdots, k)$ denotes the prices of $z = dq, wti, xwti, bre, xbre$, respectively, and $\varphi_i\,(i = 1, 2)$ is a constant. $\alpha_i, \beta_i, \lambda_i, \delta_i\,(i = 1, 2, \cdots, p)$ denote the corresponding coefficients. Based on the above models **Eqs. 3**, **4**, one may judge the Granger causal linkages (bidirectional, unidirectional or no causality linkage) between given two crude oil markets by looking at whether the corresponding coefficients are zero.

2.2 Data

2.2.1 Data Description

To explore the change in the cointegration relationships, we select three main SIE crude oil futures contracts with different listing time and maturities, including SC 2003 (2018.03.26-2020.02.28), SC 2001 (2019.01.02-2019.12.20) and SC 2007 (2019.07.01-2020.06.30). The data cover about two and a half years, consisting of three periods, 2018, 2019 and the first half of 2020. Roughly speaking, they can be treated as a turbulent, stable and mature relatively period of SIE respectively, which may be used to analyze the market efficiency under different periods.

We collect the daily closing prices from the Shanghai International Energy Exchange. The missing data which arise from slightly different trading times different markets are addressed via an interpolation method. **Supplementary Appendix Tables S1–3** give the summary statistics. **Supplementary Appendix Tables S4–6** present the matrix of the correlation coefficients as follows.

Supplementary Appendix Tables S1–3 show that there is a big change in variance from SC 2003, SC2001 to SC 2007. Specifically, SC2003 has a bigger variance than SC 2001. This may because the SIE market is unstable in the initial stage (i.e. SC2003 sample period), but relatively stable after about 1 year's development. Moreover, from the three tables, we know that the variance of SC2007 is significantly larger than SC2003 and SC 2001. There are two possible reasons to explain this phenomenon. On the one hand, the extreme event that crude oil futures prices fall sharply in April 2020 enhances greatly the market volatility. On the one hand, the COVID-2019 affects global economy and increases the uncertainty of crude oil prices.

Supplementary Appendix Tables S4–6 tell the differences and changes in correlation coefficient between two markets. Specifically, from **Supplementary Appenedix Table S4**, we know that SIE is more correlated to the Brent futures market in the SIE launching period; **Supplementary Appendix Table S5** means the correlation coefficient between SIE and the Daqing spot market is biggest, but **Supplementary Appendix Table S6** shows there is not much difference in correlation coefficients. Thus, based on these results about correlation coefficients, we infer that it is possible that the price movement of SIE has a closer relationship to the Brent futures market than other markets; the Daqing spot market is closely correlated to SIE in during the SC2001 and SC2007 sample periods. Especially, in the relatively recent SC2007 sample period, there are much stable relationships between SIE and other five markets. This provides some interesting implication in terms of development of SIE.

2.2.2 Preliminary Analysis of Stationarity

Let $\ln sc$ be the logarithmic data series of SIE; similarly, let $\ln dq$, $\ln wti$, $\ln bre$, $\ln xwti$, and $\ln xbre$ represent logarithmic data series of corresponding futures or spot prices respectively. After taking such logarithm transformation of the prices data, we achieve the stationarity by applying the augmented Dickey-Fuller (ADF) test. **Supplementary Appendix Tables S7–9** present the stationarity results for the logarithmic data or the first-order difference data, suggesting that they are stationary since, given the significance level of 1%, the ADF test values are smaller than the critical value. Thus, in following work, in order to assure the stationarity of the data, we adopt such transformation without changing the data structure.

3 EMPIRICAL RESULTS

This section presents the results with different futures contracts or different periods respectively, which show the changes of cointegration relationships between SIE and other markets.

3.1 Results of SC2003 Futures Coving an Earlier Study Period (From the Launch of the Shanghai Market in 2018)

The contract SC2003 covers an earlier contract period starting from the listing date of SIE. As previous works, e.g., Ji and Zhang (2019) show, high volatility of SIE was maintained in the initial stage after its launching. This indicates data in the first few months may affect the significance of test results for SIE. In other words, cointegration relationship may be absent if our test includes the data in the first few months; whereas it may be shown if we do not consider the first few months. Thus, for our purposes, by removing the data of first several months, we conduct the test (from 26 March 2018; 26 June 2018; 26 July 2018; 26 September 2018; 26 December 2018 respectively) to examine the cointegration process. The results of VAR models, Johansen cointegration test, and Granger causality analysis for testing the leading and lagging relationships are presented in **Supplementary Appendix Table 10** in detail.

It is straightforward to note that the cointegration test results in **Supplementary Appendix Table 10** are not consistent throughout the five study periods. In some degree, it confirms that SIE is unstable relatively in the early stage. Specifically, there exists no any long-term equilibrium relationship between SIE and other markets until 26 December 2018 (the first day after Christmas Day). This reflects that the SIE is linked weakly to other domestic and foreign crude oil markets before 26 December 2018. It is worth noting that with the removal of the first 3 months data, SIE starts to show a long-term equilibrium relationship to Brent spot or futures prices. It is concluded that SIE reaches an earlier relationship to Brent relative to WTI in a statistical sense.

After noting the long-term equilibrium relationship exists when we do not consider the SC2003 prices for the first 6 months, we further analyze the lead-lag relationship by using sample data (1848 observations) after 26 December 2018. The empirical results in the last two columns in **Supplementary Appendix Table 10** show that a bidirectional Granger causality relationship between SIE and the Daqing spot prices exists. That is, SIE can effectively reflect the movement of domestic crude oil prices and vice versa. However, **Supplementary Appendix Table 10** also demonstrates unidirectional causal relationships from Brent, WTI to SIE. This means that SIE is affected by the market information of Brent, WTI, since its pricing function may not work effectively in the launching period. That is, the international benchmarks lead the newly emerged SIE. In other words, the price discovery of SIE follows the international benchmarks in the given sample period, but the former's influence on the latter is quite weak. Thus, in some degree, arbitrage opportunity can be found by comparing SIE and international benchmarks, but it does hold between SIE and the Daqing spot prices.

3.2 Results of SC2001 and SC2007 Futures Covering a Later Sample Period (From 2019)

The listing date and maturity date may impact the cointegration relationship. In this section, we redo the whole analysis by using

different representative contracts SC2001 and SC2007 with later listing dates than SC 2003.

3.2.1 SC2001 Crude Oil Futures Contract

The listing time of SC2001 is about the ninth month after the launching of SIE. In the sample period of SC 2001, the market may become more active and stable relative to the launching period after experiencing rapid development. Besides the test for the whole sample period, we also attempt to do similar work by removing the first month and the first 40 days (the data before the Chinese New Year holiday, i.e. 12 February 2019) data respectively. The results are reported in **Supplementary Appendix Table S11**.

It is shown that, starting from the first day after the Chinese New Year holiday (1,350 observations), the cointegration relationships are present between SIE and other five markets; and thus, there is a long-term equilibrium relationship. Furthermore, the Granger causality test results in **Supplementary Appendix Table S11** are consistent with those of SC 2003. This further confirms that SIE becomes relatively efficient after going through the development of almost 1 year. Although a bidirectional Granger causality between SIE and the Daqing holds, we cannot infer statistically that whether SIE is efficient or not. Since a unidirectional causal relationship from Brent, WTI to SIE in **Supplementary Appendix Table S11** means that, unlike Brent and WTI, SIE does not perform well in global crude oil price discovery system. In other words, one can find arbitrage opportunity in SIE by catching available crude oil prices information from WTI and Brent. For example, when SIE discovers a different and low price from WTI and Brent, one can buy and sell position in SIE to get a positive return since the rational investor believes that the SIE price will become the same to WTI and Brent under market equilibrium. We conclude that SIE does not become mature as international benchmarks in the sample period of SC 2001.

3.2.2 SC2007 Crude Oil Futures Contract

When SC2007 is listed and traded, SIE has been established for around 15 months. As SIE becomes more and more active in the global crude oil market, it is expected that a long-term equilibrium relationship exists. We do the whole analysis by keeping the all data (1,260 observations) of the SC2007 futures contract. **Supplementary Appendix Table S12** presents the results of the contract SC 2007.

It is observed that prices of SC2007 is closely related to the other five crude oil prices, i.e., the long-term equilibrium holds. Different from SC2001 and SC2003 that only record unidirectional Granger causal relations, the empirical findings of SC2007 in **Supplementary Appendix Table S12** show that the Granger causality between SIE and foreign crude oil prices becomes bidirectional, revealing the increasing influence of SIE on the global market after about 1 year' development. It means that SIE in the sample period of SC2007 becomes as effective as the WTI or Brent in price discovery. Thus, there is the same speed of the response to the new market information for SIE and international benchmarks. Theoretically speaking, it is unavailable to find arbitrage opportunity in SE only by catching the market information from international benchmarks. In additional, we find that the Daqing market is not a good predictor of SIE prices movement; that is, we get a unidirectional Granger causal relation from SIE to Daqing. Conversely, SIE may cause spot prices change of the Daqing market. By comparing our finding with Yang et al. (2019), we also know the Granger causal relation between SIE and international benchmarks (the WTI and Brent spot prices) changes from unidirectional Granger causality to bidirectional one as the development of SIE.

3.3 Comparison of Results and the Dynamic Changes of Cointegration Relationships

Supplementary Appendix Table S13 shows a comparison of the results of SC 2003, SC 2001, and SC2007 crude oil futures contracts. From the perspective of the listing dates of contracts, the SC2003 is first listed when SIE is launched; SC2001 and SC2007 are listed after 9 and 15months respectively. Based on the different listing periods, we may find the dynamic changes by comparing the cointegration relationships. The cointegration relationship is ambiguous and unstable in the first few months in 2018 since the launch of the market. In 2019, SIE shows a constant cointegration relationship with the other five crude oil markets, along with a stable long-term equilibrium relationship. The results in **Supplementary Appendix Table S13** indicate that, after 2 years, SIE has become more mature. In short, some discrepancies appear in the cointegration pattern, which reveal the change of pricing discovery function of SIE as its development.

Specifically, the last column of **Supplementary Appendix Table S13** presents that the lead-lag causality between SIE and the Daqing crude oil spot prices has changed from bidirectional causality (SC2003 and SC 2001) to unidirectional causality (SC 2007), since the Granger causality from the Daqing market to SIE disappears for the newest contact SC2007 in our samples after more than 1 year's development of SIE. In other words, SIE has always been the Granger cause of the Daqing crude oil spot prices movement but not vice versa, indicating the leading role of SIE on the domestic crude oil spot market. This result confirms the previous findings that the futures market appears to dominate spot prices in price discovery process (e.g., Schwartz and Szakmary, 1994) in terms of SIE and Daqing spot prices. Moreover, based on **Supplementary Appendix Table S13**, we show that the causal relationship between SIE and international benchmarks has changed from a unidirectional causal relationship to a bidirectional causal relationship. Thus, our result gives evidence that, as the development of SIE, it has significant cointegration relationships to major international markets and domestic crude oil spot market, but also performs increasing impact on the system of global crude oil prices.

We Conclude the Following Findings

Result 1. The cointegration process between SIE and other markets changes significantly. The influence of SIE on global crude oil market becomes significant after the development of about 2 years.

Result 2. There exist constant long-term relationships between SIE and Daqing, WTI, Brent. The bidirectional causal relationships between SIE and the major international markets are established, suggesting that SIE becomes efficient as international benchmarks and can react simultaneously to new market information.

Result 3. In terms of the price discovery function, SIE persists a leading role on the domestic crude oil spot market.

Although this section uses popular models to report the price integration process between SIE and major domestic and international crude oil markets by considering several representative contracts with different listing period, it is certain that several issues can be further explored as the influence of SIE on energy market increases. For example, one can use various methods, e.g., Bayesian semiparametric quantile model (Jiang et al., 2020; Liu et al., 2021 etc.), to study relevant risk management problems in the SIE market; it is also interesting to further study that how price fluctuations in the SIE market affect energy efficiency (e.g., Sun et al., 2021), green investment (e.g., Sun et al., 2020; Dai et al., 2021) or spillover effects (e.g., Škrinjarić and Sego, 2020; Zhang et al., 2021) between the SIE market and stock market, bond market and so on.

4 CONCLUSION

In this work, we discover that the Granger Causality between SIE and international crude oil markets (futures and spot markets of WTI and Brent) changes from unidirectional to bidirectional. Besides, the empirical results indicate that long-term equilibrium relationships have been established between SIE and other five crude oil markets. The influence of SIE on global crude oil market gradually increases during the whole sample period. After about 2 years' development, the market forms a more stable relationship with the other markets, affecting the international pricing benchmarks (WTI and Brent) and dominating domestic crude oil prices (Daqing). Our findings provide important implications for understanding the development of SIE.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HW: Methodology, Formal analysis, Writing—review and editing. SQ: Writing—review and editing, Funding acquisition. HY: Writing—review and editing. YD: Conceptualization, Writing—original draft.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.901236/full#supplementary-material

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