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Study on the impacts of Shanghai crude oil futures on global oil market and oil industry based on VECM and DAG models

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Abstract

In the present study, the daily settlement data of Shanghai crude oil futures and world's major crude oils are selected. The role of Shanghai crude oil futures is studied regarding its pricing power and hedging risk. The dynamic relation analysis between Shanghai crude oil futures and international oil market is conducted by using rolling window causality test. The vector error correction model (VECM) and directed acyclic graph (DAG) are used to explore the long-term relationship and identify the contemporaneous causality structure respectively. Then Shanghai crude oil futures' impacts on other oil price fluctuations are analyzed by using variance decomposition method. The obtained analysis results show that the pricing power of Shanghai crude oil futures is limited compared with the international benchmark oil price, but it has begun to have a contemporaneous influence in the Asian oil market price transmission and better reflect oil supply and demand. Moreover, Shengli crude oil has stronger impact on the pricing mechanism after the listing of Shanghai crude oil futures. Furthermore, it also establishes an effective hedging tool for oil importers and refineries. Therefore, although the Shanghai crude oil futures is still in its initial development stage at present, it provides an important basis for becoming a regional benchmark in Asia and a useful instrument for energy market participants, influencing China's oil industry in import price and consumption.

Keywords: Shanghai crude oil futures; price transmission; vector error correction model; directed acyclic graph; hedging risk

1 Introduction

As an important energy resource for industrial production, national defense and transportation, crude oil is a valuable raw material to a country's economic development. According to the Energy Information Administration [1], China is the largest importer in the world. And large quantities of oil imported from Middle East with high dependence above 70%. Therefore, it is an emergency issue to set up its own pricing system to eliminate the economic loss of "Asian Premium". Many scholars [2,3] have put forward their studies to help Chinese government build a complete and competitive oil market. They believe that China should introduce its own crude oil futures market to compete with others.

With the process of market-oriented reform, China's oil price has been more and more affected by international oil prices. Some studies [4,5] investigate the price transmission and spillover effect cross different international oil markets and most studies show that Chinese oil market is a price taker. On March 26, 2018, China's first crude oil futures contract was officially listed in the Shanghai International Exchange (INE) in order to build up a benchmark for medium sour crude oil and hedge investment risks. Its characteristics and functions have been studied recently [6-8]. They found that the contracts have volatility jump and it is more sensitive to the downside risk shocks of international benchmark oils. Although it truly has some influences to open China's oil market furtherly [9,10], the development of China's crude oil futures market is still in its initial stage [8] and a number of questions are proposed. Firstly, whether the crude oil futures have integrated into the global oil markets or not. Secondly, if it is a part of international market, how its price affects other market prices or affected by others, meaning that how the global oil prices transmit. Thirdly, whether it becomes the benchmark of medium sour crude in a regional or global view or not. And last is it an efficient tool for risk hedging. Identifying the price transmission is the key step to analyze and answer the questions.

There are some existing studies focusing on the basic functions of Shanghai crude oil futures. The stylized characteristic of China crude oil futures has been discussed in [6-8], which investigate the price efficiency and information spillover effect between Shanghai crude oil futures and international oil markets. Ji and Zhang [6] analyze Shanghai crude oil futures from its volatility, return and trading volume. They find that there is an obvious volatility jump in the initial crude oil futures contracts and there exists a negative relationship between trading volume and return.

Yang and Zhou [7] use a cointegration approach and multivariate volatility model to analyze the information spillover effect of Shanghai crude oil futures market and find that it has a strong linkage with benchmark oils. Yang et al. [9] evaluate its price efficiency by examining co-integration and Granger causality test. And Shanghai crude oil futures can reflect the oil demand and supply effectively. Few literatures focus on the hedge performance of China crude oil futures. By employing a copula-based GARCH model, Wu et al. [8] find that financial participants can utilize it to hedge risks. There are still some questions to be answered. Firstly, does it outperform international oil futures in regard with hedge effectiveness? Secondly, what kind of spot crude it hedges better since it is an efficient tool for risk minimizing? The hedge ratios are calculated in the present study to get the results.

Further, few studies focus on the function and mechanism of Shanghai crude oil futures from dynamic evolution. Although there are still some literatures that try to build up an econometric or systemic model, insufficient data may make the model biased and inaccurate. Furthermore, the causality relationship between different oil markets by proposing a series of robust tests may be not sufficient to describe the complexity of this system. Therefore, it still needs further study on the price transmission and volatility contribution of each oil market. In the present study, a wider range of dataset and multi-time dimension point of view are adopted to eliminate the possible bias caused by the limited sample size and a model is developed to reflect the relationship between Shanghai crude oil futures and others. Moreover, from different time horizon, long-term and short-term studies are conducted respectively on oil prices transmission path and volatility contribution by using Granger causality test and vector error correction model (VECM), which are effective for the financial market and systemic modeling. Furthermore, the price flows in the simultaneous period is shown directly by using the directed acyclic graph (DAG) and then the contemporaneous order of variables is obtained to conduct the variance decomposition (FEVD). Finally, the Dynamic Conditional Correlation - Generalized Autoregressive Conditional Heteroscedasticity (DCC-GARCH) is constructed to calculate the dynamic hedge ratios and we select Shengli and OPEC crude to represent the Chinese spot market instead of Daqing crude as previous study, because Shengli is the only deliverable underlying asset among Chinese oil varieties and OPEC is the main imported source in China. These are the innovation and contribution of the present study. The paper will expand the existing literature in applied energy and energy finance field.

The paper structure is as follows. Section 2 reviews previous studies. Section 3 briefly introduces the method. Section 4 presents the data and its summary statistics. Section 5 shows the empirical results. And the last section draws some conclusions and policy implications.

2 Literature Review

2.1 The lead-lag relationship among different oil markets

As an important part of the world oil market, the energy policy formulated by the Chinese government and the domestic energy consumption and supply will have a certain impact on the world oil price. Therefore, in the study on the integration of the world crude oil market, some scholars [11-13] have also involved the Chinese market to better reflect the overall changes of the world crude oil market. Specifically, Li and Leung [14] and Chan et al. [15] explore the influence of China's oil market on the world oil market by introducing Daqing crude oil spot. All these studies show that China has become a member of the "Great Pool". Since oil prices are linked to each other, it is important to explore the oil price fluctuations transmission to better understand how the prices operate. The existing studies can be divided into three categories: the price transmission mechanism between WTI and Brent international benchmark; the price lead-lag relationship of major international oil markets; the price relationship between China's oil market and other international markets.

Most scholars [16-18] believe that oil prices flow from WTI to Brent market. Lin and Tamvakis [16] chose the daily price and it is not a good reflection to the inter-day trading, so their research only takes into account part of the impact. On this basis, they selected the high frequency every 3 minutes trading data to confirm the leading effect of WTI on Brent again [17]. Some researchers [19-20] claim that although there is a price spillover relationship between WTI and Brent, the price leadership role of WTI in Brent is limited. For example, Lu et al. [19] find that WTI has only a slight dominant effect on Brent. And Zhang and Zhang [21] find that the WTI and Brent are not always moving together.

As for the price transmission relationship in the international oil market, studies show that WTI and Brent dominate the global crude oil price [19,22,23]. Ji and Fan [4] use 23 countries data and divide the research range before and after the global financial crisis. They find that the United States was the center of the world oil market before and after the crisis, but weakened after the crisis. Sahel et al. [24] divide the

global market into OPEC member markets and non-OPEC member markets. With the high integration of the world oil market, other oil markets, except for the international benchmark oil markets, have also become a new price “transmission source” and even Bentzen [25] thinks that the influence of WTI and Brent is gradually weakening. Besides, Wlazlowski et al. [22] find that Urals crude also plays an important role in price setting and can make global oil prices up.

The relationship between the Chinese market and the world market was investigated. The early researches on China’s oil market mainly focus on crude oil spot [2-3]. Chen et al. [11,12] find that although China is an important part of the world oil market, it is still the price taker. Ji and Fan [26] also agree that the China’s oil market is still the price receiver and is greatly affected by the fluctuation of international oil prices. However, some scholars believe that China’s oil market has certain effects on the world oil market. For example, Zhang and Wang [27] investigate the return and volatility spillover effects between China and the world oil market. They find that the Chinese market had a limited impact on the world crude oil market, both in terms of return and risk spillover. By comparing the risk reduction of the WTI and Brent with the underlying assets of Oman and OPEC, Li et al. [28] find that Shanghai crude oil futures market has significant hedge effectiveness. Peng et al. [29] consider the reform of China’s refined oil pricing to explore the impact of the Chinese market on the world oil market. After the establishment of Shanghai crude oil futures market in China, there are still few studies to explore its lead-lag relationship with other oil markets.

2.2 The relationship between futures and spots prices

Some researchers analyzed the relationship between oil futures and spots among world main oil markets by using mixed markets data. Some studies focused on the classical theory, mainly investigating futures price discovery function [30-35] and the market efficiency theory [36,37]. The others concentrated on the integration of world crude oil market especially the price co-movement [9,18,23,38], lead-lag effect [39-41] and risk spillover [19,42-44] phenomenon.

Ozdemir et al. [45] evaluate the prices co-movement between Brent futures and its spot by adopting an econometric approach. Jia et al. [40] propose the wavelet analysis from the perspective of grey correlation to research oil prices co-move and pointed out that benchmark oil price plays a leading role in the fluctuation process of Daqing oil price. Furtherly, on the basis of wavelet analysis, Jiang et al. [39] used

Dubai, Oman, Minas, Cint, Widurie, Tapis and Daqing spot oil as well as WTI and Brent oil futures prices. After the Bayesian network analysis, they find that between different factors influencing benchmark oil prices show a multi-period evolution phenomenon. Furthermore, by selecting trading data of nearly ten months (2018.03-2019.01), Wu et al. [8] quantitatively analyze the dynamic hedge ratios between Shanghai crude oil futures and its spot. It is found that the Shanghai crude oil futures truly have a relation with spot price and can effectively reduce its spot price fluctuation. After that, Yang and Zhou [7] studied the risk spillover relationship between China's crude oil futures and international benchmark futures, concluding that Shanghai crude oil futures have stronger relations with benchmark oils.

In all, the previous studies testified the strong relationship between crude oil futures and spots prices in the range of world oil markets by imposing econometric or system modelling methods and they also provided a theoretical basis for future studies.

2.3 Price transmission modeling

In 20th century, oil economist Adelman [46] proposed “The world oil market, like the world ocean, is one great pool”. And many literatures about globalization and regionalization of oil markets have been put forward. In the early studies on the causality effect among different oil markets, researchers [14,34] used Granger causality test. After that, researchers begin to focus on price transmission among world oil markets. Cointegration analysis has been commonly used in the discovery of prices co-movement [12,31,32]. And there are mainly two branches in the study of price transmission, one is econometric modeling and another is systemic modeling.

For the econometric modeling, some studies [47,48] introduce Markov-switching regime in the VECM model to evaluate the time-varying adjustment among the oil prices. Although it is a flexible way to express the dynamic system behavior, there are still some limitations for application. It requires a large number of states so as to estimate too much coefficients which can shrink the degree of freedom sharply. And the Markov property assumption is restrictive and may not suitable for the price transmission process. Researchers [2,15,49] also use threshold analysis to describe asymmetric price adjustments with considering the arbitrage opportunity and transaction costs in the economic system. The method does not include contemporary effects among variables and results are usually shown in pairwise which evaluate the relationship indirectly. Others [5,19,50] propose VECM combined with dynamic conditional correlation (DCC) to model fluctuations and dynamic relationship, but

even if the conditional correlations happen to be constant, the conditional covariance across the standardized residuals may appear to the dynamic because of misspecification [51].

For the systemic modeling, some studies [32,38-40] apply the wavelet-based model for detecting the properties of dynamic coherence and quick variation of the various variables in different time horizons. The discrete wavelet transform (DWT) is mostly used when considering the price data is discrete. However, the discretization is less efficient and natural. Besides, the use of kernel may bias the signal and make it be similar to a pre-selected shape, which is different from the econometric modeling by only using the past behavior to model the signal and its distribution. Others also use graph theory [26] or networks [52] to explore the relationship among the world oil markets. It truly shows the long trend evolution between regional markets by imposing minimal spanning tree, but it does not consider the short-term adjustment and contemporary effects of information transmission. In the present study, the VECM combined with a DAG is adopted to investigate the Shanghai crude oil futures prices transmission from a multi-time dimension point of view.

3 Methodology

3.1 Vector Error Correction Model

The vector error correction model (VECM) was proposed by Davidson et al. [53]. The basic form of the model, VECM (p-1), set by Johansen [54] is as follows:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \quad (1)$$

where

$$\Pi = \sum_{i=1}^p A_i - I \quad (2)$$

$$\Gamma_i = -\sum_{j=i+1}^p A_j \quad (3)$$

Y_t is a $K \times 1$ vector of variables, A_i is a $K \times K$ matrix of parameters and ε_t is a $K \times 1$ vector of disturbances. ε_t has zero mean, covariance matrix Σ , and is i.i.d. normal over time. If Y_t has co-integration relationship, then $\Pi Y_{t-1} \sim I(0)$ and VECM can be written as follows:

$$\Delta Y_t = \alpha \beta' Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \quad (4)$$

where $\alpha_{K \times r}$ is the long-term adjustment parameter, K is the number of variables in the model, r is the number of co-integration equations and (p-1) is the lag order of the

model. $\beta_{K \times r}$ is the co-integration parameter in the co-integration equation which represents the long-term relationship between variables and $\Gamma_{K \times K}$ is the short-term parameter matrix in the model. ε_t is the innovation term of the model. $\beta'Y_{t-1}$ is the error correction term in VECM which makes the model different from VAR (p). In this paper, equation $\Pi = \alpha\beta'$ is made and $\Pi_{K \times K}$ is called impact factor matrix.

The parameters to be determined in the model are p and r, which are usually determined according to the corresponding VAR (p) model, because the lag order of VECM model is one less than that of VAR model. The lag order of VAR model is usually determined by AIC, SBIC, HQIC test, likelihood ratio (LR) test and final prediction error test (FPE). For the number of co-integration in the model, the trace statistic and the maximum eigenvalue statistic proposed by Johansen [55] are usually used. The trace statistic is as follows:

$$-T \sum_{i=r+1}^K \ln(1 - \hat{\lambda}_i) \quad (5)$$

where T is the sample size, $\hat{\lambda}_i$ is the estimated eigenvalue, r is the co-integration number. The original hypothesis of the test is that there are at most r co-integration vectors in the model.

3.2 Directed Acyclic Graph

The directed acyclic graph was first introduced into the VAR model by Sprites et al. [56] to identify the simultaneous causality between variables and to apply it to the fields of social science and medical diagnosis. This method has since been applied by more and more scholars in the field of energy economics and finance [26,57-59]. With the development of financial market and the continuous improvement of trading mechanism among markets, investors often use multiple markets to engage in arbitrage activities or avoid risks. Price volatility in one market may soon be transmitted to other associated markets, causing prices in other markets to fluctuate to varying degrees. In particular, the oil market is a global market and the simultaneous information transmission will be more obvious. Therefore, the simultaneous causality can be well identified by constructing directed acyclic graphs.

In this paper, the correlation coefficient matrix of innovation terms in VECM is used and PC algorithm [56] is selected to determine the simultaneous causality among variables. The basic idea [56] is as follows:

(1) First, a complete undirected graph is constructed, meaning that there is a correlation between the residues of each two variables and the relation has no direction. Then through the unconditional correlation test of each edge, the edge with

no significant relationship is removed.

(2) Then the conditional correlation test is carried out. When any third variable is given, the partial correlation coefficient of the two variables is tested and the non-significant edges are removed again until all the edges pass the significance test.

(3) Then for three given variables X, Y and Z. X & Y and Y & Z are adjacent and X and Z are not adjacent, then the relationship between XYZ is $X \rightarrow Y \leftarrow Z$ (if and only if Y is not a separated set of X and Z). If $X \rightarrow Y$ and Y & Z are adjacent, X and Z are not adjacent and then there exists $Y \rightarrow Z$. If there is a significant edge between X and Y and there is a causality between X and Y, then there must be $X \rightarrow Y$. Repeat until all edges can point from one variable to another.

The Fisher's z statistic is usually used to test whether the correlation coefficient ($\rho_{XY.C}$) between each group of variables is significant from 0 and the statistic is as follows:

$$z(\rho_{XY.C}, n) = \left(\frac{1}{2}\sqrt{n - |C| - 3}\right) \ln \left[\frac{(1 + \rho_{XY.C})}{(1 - \rho_{XY.C})} \right] \quad (6)$$

Where $\rho_{XY.C}$ represents the total partial correlation coefficient between X and Y based on sequence C, $|C|$ is the number of variables in C. If X, Y and C are subject to normal distribution and $r_{XY.C}$ is the partial correlation coefficient of samples, then $z(\rho_{XY.C}, n) - z(r_{XY.C}, n)$ obeys standard normal distribution [60].

4 Data and summary statistics

In this paper, the world oil markets are geographically divided into five parts [4]: American, European, African, Middle East and Asia-Pacific market, which are represented by WTI, Brent, OPEC basket, Dubai, Tapis and Minas. Specifically, Daqing and Shengli spot and Shanghai crude oil futures (SC) are selected in China's oil market [9] since Shengli spot is the only delivery variety as mentioned. In addition to WTI, Brent and Dubai, Tapis and Minas are usually the reference prices in Asia and Australia, which are active traded products [39]. The OPEC basket oil price is composed of the weighted price of its member countries and it is chosen as the underlying spot of Shanghai crude oil futures [28].

The data selected includes 461 trading days from March 26, 2018, the date of listing the Shanghai crude oil futures, to December 31, 2019, which are daily settlement prices in US dollars. The Shanghai crude oil futures are settled in RMB and the daily exchange rate is used to convert. The data come from the Wind terminal,

the Energy Information Agency and the Federal Reserve. Because trading times vary from market to market, there may be a missing of market data on some trading days. In practice, the observations of the previous trading days are used to replace missing observations to ensure consistent and continuous data [61].

First, the changes of crude oil prices in the selected time period are drawn as shown in Fig.1. The fluctuation characteristics of all prices are basically the same in terms of direction and degree. Among them, Daqing, Shengli crude and Shanghai crude oil futures have also shown similar changes, so it can be preliminarily considered that the Chinese oil market has been integrated into the world oil market. Then the descriptive statistics is calculated as shown in Table 1. From the results, it can be found that in the selected sample range, Dubai crude has positive mean value and its volatility is lower as well as OPEC basket and Shanghai crude oil futures, which indicates that the prices are more stable. The fluctuation of Daqing and Shengli crude oil price may be affected by the downward trend of international oil price at the end of 2018 and the upward pressure in early 2019. The augmented Dicky-Fuller unit root test verifies the series is stationary. Through Jarque-Bera test, all the returns show the characteristics of non-normal distribution. Furtherly, the correlation coefficient of each oil market is obtained, from 0.751 to 0.992, which indicates that oil returns have high correlation and the world oil market is highly integrated.

Table 1 The descriptive statistics of rate of return

	Mean	Max	Min	S.D.	Kurt.	Skew.	JB	ADF
Brent	-0.011	13.303	-7.251	1.958	6.147	-0.021	0.918**	-6.812**
WTI	-0.015	13.694	-8.234	2.077	5.535	0.065	0.933**	-6.666**
Daqing	0.009	8.617	-9.939	2.076	2.436	-0.303	0.972**	-6.375**
Dubai	0.006	9.062	-7.801	1.875	2.476	-0.237	0.968**	-6.581**
Tapis	0.008	7.075	-7.728	1.755	1.817	-0.282	0.979**	-6.359**
Minas	0.010	8.250	-9.582	2.021	2.285	-0.257	0.974**	-6.585**
OPEC	0.004	10.147	-4.999	1.504	4.553	0.336	0.959**	-6.245**
SC	0.003	7.161	-5.249	1.471	1.907	-0.041	0.974**	-7.088**
Shengli	0.032	8.401	-9.887	2.064	2.091	-0.366	0.977**	-6.187**

Note: rate of return = $100 \times \ln(\frac{p_t}{p_{t-1}})$, * and ** denote significant in 5% and 1% levels respectively

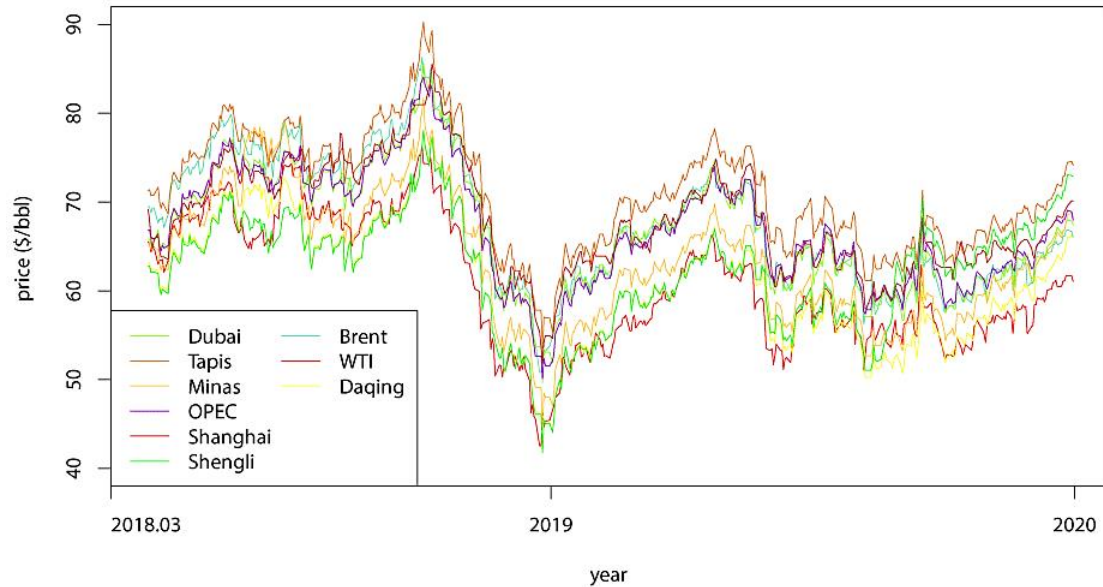


Fig.1 The price trend of different crude oil (2018.3.26-2019.12.31)

5 Empirical results

5.1 Lead-lag relationship in oil prices

Table 2 shows the Granger causality test in full sample between China's oil market and other oil markets. Of the 72 pairs of relationships examined, only 38 pairs have Granger causality. Specifically, it is noted that Shanghai crude oil futures (SC) has a bicornelation with Daqing spot while has a single relationship with Shengli spot, where Shengli→SC and Daqing→Shengli. And the results are different from Yang et al. [9], putting the results that the crude oil futures has a bi-directional leading relationship with the Daqing and Shengli spot prices. Besides, the Shanghai crude oil futures have a pairwise Granger causality with Dubai crude, indicating that they can affect each other. Also, the Shanghai crude oil futures have causal effects with Tapis and Minas crude. Similar with most researches, Brent and WTI lead the global oil market price and Shanghai crude oil futures do not Granger-cause them.

Furtherly, in order to investigate the dynamic relationship among different oil market prices, rolling window method is applied to conduct the time-varying Granger causality test. 25, 30 and 35 are used as the window sizes, mainly focus on 25 window and the results are shown in Table 3. From the results, it can be seen that Shanghai crude oil futures truly have two-way relation with Daqing and Shengli spot from the dynamic view, but the numbers are quite smaller (33 for Daqing and 37 for Shengli)

compared with the others (167 and 150 for SC respectively). Obviously, Dubai crude has a stronger impact on Shanghai crude oil futures. Moreover, Brent and WTI are the price settler among all other oil markets, while the Chinese oil market is more often the receiver of the price. This may be related to the immaturity development of China's crude oil futures market. It will still take some time to implement the long-term impact of Shanghai crude oil futures.

Table 2 Full sample Granger causality test

$\begin{matrix} i & j \end{matrix}$	Brent	WTI	Daqing	Dubai	Tapis	Minas	OPEC	SC	Shengli
Brent	-	4.07	188.72	218.71	198.89	216.09	111.88	154.73	184.01
WTI	2.63	-	203.28	240.51	216.08	164.39	94.938	199.91	211.41
Daqing	3.46	3.29	-	2.37	0.84	0.36	35.369	16.17	3.48
Dubai	1.62	1.59	4.10	-	3.89	0.79	36.377	19.38	2.43
Tapis	3.68	3.81	0.60	0.29	-	0.14	53.357	16.63	0.09
Minas	2.43	2.37	1.36	0.86	0.37	-	37.697	11.75	0.02
OPEC	0.85	1.09	105.86	101.63	115.01	135.72	-	76.12	94.59
SC	0.37	0.71	4.17	4.25	5.02	2.21	5.46	-	2.97
Shengli	3.03	2.78	0.33	3.22	0.56	2.09	30.82	14.55	-

Notes: H_0 : i does not Granger cause j; numbers in bold means significant at least 5% level

Table 3 Rolling window Granger causality test (p-value=0.05)

$\begin{matrix} i & j \end{matrix}$	Brent	WTI	Daqing	Dubai	Tapis	Minas	OPEC	SC	Shengli
Brent	-	52	426	420	420	430	363	396	422
WTI	73	-	419	428	428	403	324	403	431
Daqing	54	51	-	25	17	61	193	167	35
Dubai	51	47	19	-	29	39	194	244	28
Tapis	49	43	17	8	-	16	237	163	28
Minas	33	35	48	34	26	-	177	134	25
OPEC	23	17	380	391	379	364	-	352	394
SC	5	17	33	28	35	29	52	-	37
Shengli	41	35	13	25	27	23	196	150	-

Notes: numbers above denote the reject times of null hypothesis: i does not Granger cause j

5.2 The price spillover in long and short term

Through Granger causality test, the lead-lag relationship between China's crude oil futures price and other crude oil prices can be preliminarily explored. Furthermore, the long-term structure and adjustments are identified. Firstly, the optimal lag order of

VAR model is determined. Then optimal lag order of VAR is selected from different criteria as shown in Table 4. Finally, the VAR with 4 lags is established according to Lagrange Multiplier (LM) diagnose. The Johansen co-integration test is to determine the number of co-integration equations in the VEC model and trace statistics show that there are two co-integration relationships among the 9 variables selected.

Table 4 Selection of optimal lag order

Lags	LR	FPE	AIC	HQIC	SBIC
0		0.0000026	12.698	12.730	12.780
1	902.47	0.00000052	11.074	11.395*	11.888*
2	256.94	0.00000042*	10.866*	11.475	12.412
3	141.71	0.00000044	10.911	11.808	13.189
4	167.03*	0.00000044	10.900	12.086	13.910

Notes: * denotes the optimal lag order different choose

Then check each variable to determine whether it is included in the co-integration equation before establishing VECM. The model is re-estimated by limiting the coefficient $\beta = 0$ (in eq.4) before each variable in the co-integration vector. Table 5 shows that only Shengli crude oil is not significant and it should be excluded from co-integration vector. Both Shanghai crude oil futures and Daqing crude reject the null hypothesis, showing that Shanghai crude oil futures have a long-term equilibrium relationship with the prices of other oil markets in the world.

Similarly, it needs furtherly exploring whether each variable responds to the adjustment of co-integration variables. That is whether the variables will be adjusted in face of the impact of other variables in the model. At this time, the adjustment coefficient of each variable is limited so that $\alpha = 0$ (in eq.4). If the test is not passed, it is shown that the variable cannot adjust the impact, indicating that the variable is weakly exogenous and slightly determined by factors outside the system. The results are shown in Table 6. It shows that OPEC, Shanghai crude oil futures and Shengli spot are not significant and the other variables will respond to the impact. It indicates that these three have weak externality in the long run adjustments.

In order to verify the robustness of the above constraints, the joint significant test is carried out. By limiting the β coefficient of Shengli crude oil to 0 and the α coefficient of OPEC, Shanghai crude oil futures and Shengli spot to 0, the model is re-estimated. The joint test statistic is 10.353 and the corresponding p-value is 0.241. Thus, the constraints set previously cannot be rejected.

Table 5 The covariate exclusion test (the test for each $\beta = 0$)

Coint.	Brent	WTI	Daqing	Dubai	Tapis
1	34.433**	20.903**	11.538**	22.075**	7.554**
2	36.753**	23.324**	11.546**	25.455**	19.131*
Coint.	Minas	OPEC	SC	Shengli	
1	15.979**	11.217**	10.504**	1.993	
2	17.083**	22.286**	11.632**	2.527	

Notes: * and ** denote significant in 5% and 1% levels respectively

Table 6 Variable weak externality test (the test for each $\alpha = 0$)

Coint.	Brent	WTI	Daqing	Dubai	Tapis
1	5.452*	4.400*	6.933**	14.397**	7.614**
2	5.461*	5.875*	6.962*	14.476**	9.574**
Coint.	Minas	OPEC	SC	Shengli	
1	14.226**	1.064	1.087	2.430	
2	14.968**	1.334	1.220	2.785	

Notes: * and ** denote significant in 5% and 1% levels respectively

After limiting each co-integration vector and adjustment coefficient, the VECM is established as shown in Table 7. And two co-integration equations are written as below.

$$\begin{aligned} Brent_{t-1} = & 21.594 - 0.456Daqing_{t-1} + 1.818Dubai_{t-1} - 2.046Tapis_{t-1} \\ & + 1.006Minas_{t-1} + 1.010OPEC_{t-1} - 0.498SC_{t-1} \end{aligned} \quad (7)$$

$$\begin{aligned} WTI_{t-1} = & 62.112 + 1.547Daqing_{t-1} + 0.973Dubai_{t-1} - 6.938Tapis_{t-1} \\ & + 0.745Minas_{t-1} + 4.637OPEC_{t-1} - 0.365SC_{t-1} \end{aligned} \quad (8)$$

The co-integration equations reflect the long-term relationship between variables. There is a positive long-term relationship between Shanghai crude oil futures and Tapis crude oil, but a negative long-term relationship with Brent, WTI, OPEC basket, Dubai and Minas crude oil. From the adjustment coefficients (Appendix), the Brent, WTI and Dubai crude have the larger number in absolute value, indicating that the benchmark oils can response quickly when its prices are deviated from the long run equilibrium and they are more efficient in the global oil markets. By contrast, Shanghai crude oil futures have no adjustment effects as discussed above. It is less efficient in oil pricing and market operation mechanism. This is consistent with the

results obtained from full sample and rolling window Granger causality tests.

Table 7 The impact factor matrix (Π)

	B_{t-1}	W_{t-1}	DQ_{t-1}	DB_{t-1}	TP_{t-1}	MN_{t-1}	OP_{t-1}	SC_{t-1}	SL_{t-1}
ΔB_t	-0.215**	0.074**	-0.213**	0.319**	0.073	0.162**	-0.126**	-0.080**	-
ΔW_t	-0.196**	0.047**	-0.162**	0.310**	-0.073	0.162**	-0.022	-0.080**	-
ΔDQ_t	0.055**	-0.017**	0.051**	-0.084**	-0.003	-0.043**	0.022	0.021**	-
ΔDB_t	0.127**	-0.045**	0.128**	-0.187**	-0.054*	-0.094**	0.081**	0.047**	-
ΔTP_t	0.064**	-0.034**	0.082**	-0.084**	-0.103**	-0.040*	0.092**	0.020**	-
ΔMN_t	0.123**	-0.048**	0.131**	-0.177**	-0.084**	-0.088**	0.100**	0.044**	-
ΔOP_t	-	-	-	-	-	-	-	-	-
ΔSC_t	-	-	-	-	-	-	-	-	-
ΔSL_t	-	-	-	-	-	-	-	-	-

Notes: * and ** denote significant at 5% and 1% levels respectively, ΔB_t denotes the first order different of Brent, W =WTI, DQ =Daqing, DB =Dubai, TP =Tapis, MN =Minas, OP =OPEC, SL =Shengli

It can be seen from Table 7 that the coefficient of OPEC, Shanghai crude oil futures and Shengli spot are missing due to the restrictions put on the β and α , the co-integrative vectors and long-term adjustments. However, Shanghai crude oil futures do have a statistically significant effect on other crude oil prices fluctuations based on their historical prices. The results show that Shanghai crude oil futures have a long-run equilibrium with other global oil markets and especially a negative adjustment with Brent and WTI crude futures as well as a positive adjustment with Daqing spot, Dubai, Tapis and Minas crude. In details, a unit increase of Shanghai crude oil futures price will lead the WTI and Brent prices fluctuations decrease 0.08 units, indicating that it will shrink the gap between their future and historical prices. The Dubai crude price changes drop 0.47 units with the decline of one unit of Shanghai crude oil futures price. However, this price adjustment effect is still limited comparing with other crude oils like WTI and Brent, which pose a more efficient way in the long run price equilibrium mechanism. Finally, the robustness of VECM is tested as shown in Table 8.

Table 8 Robust test of VECM

Methods	Condition/Statistic	Results/p-value
Eigenvalue condition	(T-k) of eig. are 1	7 eig. are 1
LM test	86.177	0.326
Normal test	11000	0.000

Notes: T is the number of variables, k is the number of co-integration equations, LM

stands for Lagrange Multiplier test

5.3 Contemporaneous causal flows

The predicted correlation coefficient of VECM residuals can be used to construct the contemporaneous causal flows by using the directed acyclic graph technic. The results are shown in Fig.2. By contrast, the dataset is selected from 13th January, 2016, which is the latest refined oil price reform and it denoted that the China's crude oil price is linked to global oil prices furtherly, to 23rd March, 2018, the last trading day before the Shanghai crude oil futures listed. Follow the above tests and steps, the VECM with 4 lags and 1 co-integration equation is established. The corresponding DAG is shown in Fig.2 sub-period 1. Given that only 461 daily observations are used in this study, the p-value tends to choose higher significant level [56]. In the present study, 10% level is used to construct the acyclic graph model. And these constraints pass the likelihood ratio test for model over-identification proposed by Sims [62].

Obviously, the China's oil price fluctuation is transmitted from Shengli crude to Daqing crude before introducing the Shanghai crude oil futures. And there also exists $\text{Minas} \rightarrow \text{Shengli}$, $\text{Tapis} \rightarrow \text{Shengli}$, $\text{Minas} \rightarrow \text{Daqing}$ and $\text{Tapis} \rightarrow \text{Daqing}$, indicating that Chinese oil market always plays a role in price taker in the global markets. Furtherly, in the Asia-Pacific region, the oil price is mainly affected by Dubai crude which is the pricing reference. Among the international benchmarks, it shows that the WTI leads Brent and Dubai, which is consistent with [16-18], but the OPEC basket is the price receiver in the contemporaneous transmission.

After the official listing of Shanghai crude oil futures, some changes appear in the simultaneous causal flows. Fig.2 sub-period 2 reveals that the Shanghai crude oil futures have a direct impact on Dubai crude and lead Shengli and Daqing spot through the transmission from Dubai crude and finally to OPEC basket. Furthermore, the relation between Shengli and Tapis crude now becomes $\text{Shengli} \rightarrow \text{Tapis}$, meaning that China's oil may affect other crudes and become more important in price transmission during the contemporary period. This is mainly because that the underlying asset Shanghai crude oil futures traded is medium sour crude and it is different from the WTI and Brent futures traded. Besides, the Shanghai crude oil futures can delivery seven kinds of crude physically which include Dubai and Shengli crude. The information can swiftly transmit from the futures to the spots due to large amounts of trades and other financial activities such as hedging and speculation. Compared with the market in sub-period 1, the Chinese market with Shanghai crude

oil futures are more efficient in pricing especially in the Asia area.

The variance decomposition results are shown in Table 9 and the variable order is according to the DAG's contemporaneous relations. Here only the results contributing to the volatility of 1 day, 15 and 30 days are listed.

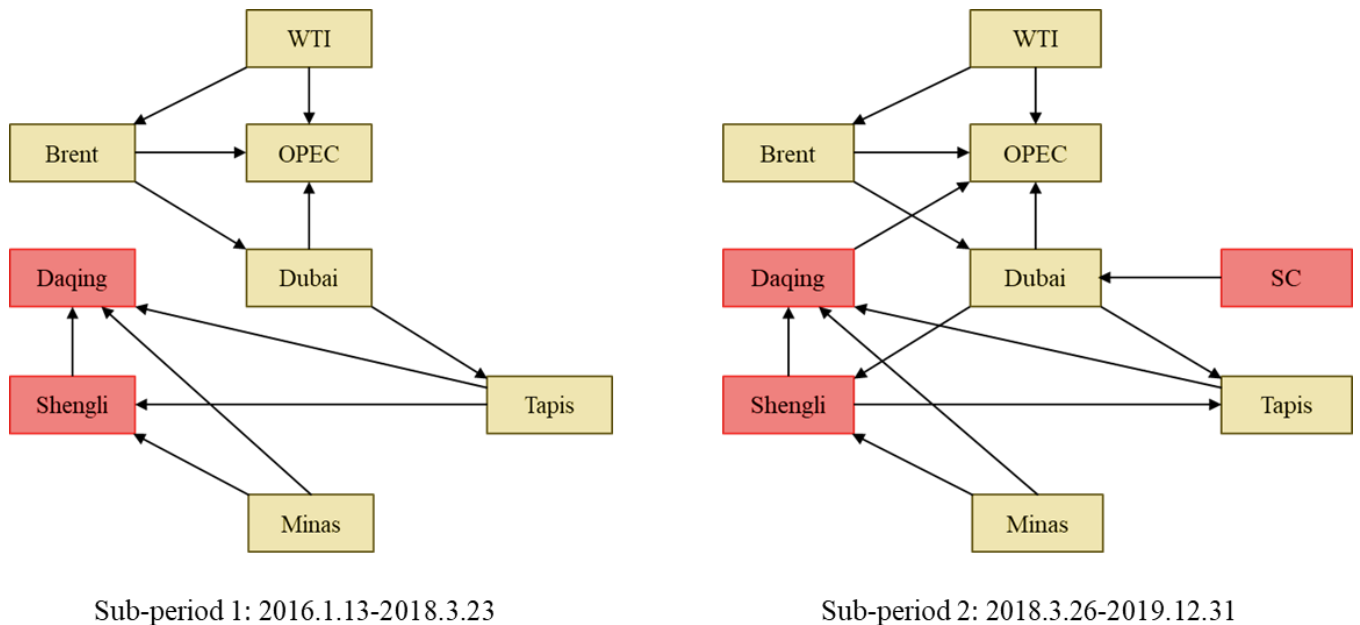


Fig.2 Contemporary causality flows of oil markets

First of all, Shanghai crude oil futures prices have impact on Daqing, Dubai, Tapis, OPEC basket and Shengli spot in the contemporary period. And this is consistent with the directed acyclic graph results. Take Dubai crude for an example, Shanghai crude oil futures can explain 5.24% of its price fluctuation one day later and it becomes 1.94% within two weeks. Finally the impact takes up 1.88% after one month, indicating that the effect of Shanghai crude oil futures declines at a diminishing rate. By contrast, the Shanghai crude oil futures affect Brent and WTI increasingly at a quite low pace in 30 days. Secondly, the ability of Shanghai crude oil futures to explain its own price fluctuation is stronger, which still has 16.49% in one month. In comparison, Daqing and Shengli have a weak ability to explain themselves. This shows that Daqing and Shengli crude oil are greatly affected by other international crude oil prices, but Shanghai crude oil futures can have certain pricing power reflecting demand and supply in the short run and thus weakening the influence of other crudes to defense the price risks.

From the international crude oil market point of view, WTI and Brent crude oil have the greatest impact on Shanghai crude oil futures. Furthermore, five kinds of

crude oil in the Asia-Pacific market (Tapis, Minas, Daqing, Shengli and Shanghai crude oil futures) are compared and Shanghai crude oil futures has significant effects on Tapis and Shengli in the contemporaneous causal relation, which is consistent with the conclusion obtained from the DAGs, while it has weak impact on Minas. These show that Shanghai crude oil futures are posing a limited impact on the Asia-Pacific crude oil market, indicating it only has a contemporaneous impact on a part of spot oil but it has not yet reached the same influence as an international benchmark. Shanghai crude oil futures may make a difference in oil futures markets and may contribute to becoming the Asian crude oil market benchmark in the future.

Table 9 Forecasted error variance decomposition (%)

	t	Brent	WTI	Daqing	Dubai	Tapis	Minas	OPEC	SC	Shengli
Brent	1	11.31	88.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	5.07	86.48	0.34	0.23	0.35	1.90	0.97	0.95	3.70
	30	4.64	84.39	0.22	0.12	0.18	2.93	1.23	1.21	5.09
WTI	1	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	6.08	82.07	0.09	0.15	1.26	1.33	2.40	1.49	5.13
	30	10.15	70.99	0.08	0.58	3.62	1.25	3.73	2.00	7.59
Daqing	1	0.21	2.01	7.95	10.91	0.37	69.82	0.00	1.35	7.38
	15	4.79	64.83	1.07	1.23	0.12	25.30	1.03	0.35	1.28
	30	4.89	64.14	1.19	1.32	0.07	25.54	1.11	0.33	1.42
Dubai	1	1.27	9.41	0.00	65.00	0.00	19.08	0.00	5.24	0.00
	15	4.67	83.93	0.14	5.43	0.20	1.11	0.26	1.94	2.31
	30	4.86	84.89	0.09	4.63	0.30	0.71	0.26	1.88	2.38
Tapis	1	1.36	10.60	0.00	42.49	31.20	0.00	0.00	5.60	8.75
	15	5.85	81.21	0.15	4.54	3.39	1.37	2.32	0.27	0.90
	30	6.14	82.16	0.08	3.06	2.05	2.14	3.15	0.16	1.07
Minas	1	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
	15	4.50	34.09	0.06	10.21	1.00	43.76	1.15	0.78	4.45
	30	4.96	34.80	0.05	10.93	0.82	42.17	1.13	0.65	4.48
OPEC	1	3.61	52.50	0.63	21.25	0.13	3.52	15.70	2.22	0.44
	15	3.50	83.56	0.08	2.88	0.07	1.33	6.79	0.25	1.54
	30	3.47	83.89	0.05	2.45	0.03	1.33	6.65	0.30	1.82
SC	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
	15	2.13	70.52	0.04	3.26	0.16	0.71	1.33	19.30	2.55
	30	1.97	71.17	0.04	2.69	0.10	1.63	1.78	16.49	4.14
Shengli	1	0.41	4.08	0.00	23.55	0.00	40.68	0.00	2.19	29.09
	15	3.72	66.26	3.96	1.71	1.67	18.21	1.27	0.68	2.52
	30	3.06	58.83	3.82	0.94	3.92	25.00	2.04	1.20	1.20

Notes: t is the lasting days

Finally, Shengli, Daqing spot and Dubai crude have changes on global pricing transmission after the listing of Shanghai crude oil futures as shown in Fig.3, in which the dotted line is in the period without Shanghai crude oil futures. Take Brent and WTI for an example, Shengli spot significantly increases its impact on benchmark oil prices in the forecasted period. By comparison, Dubai crude accounts for fewer fluctuations in the prices transmission after the introduction of Shanghai crude oil futures especially during the first two weeks. The newly listed Shanghai crude oil futures improve the transactions of Shengli spot and make it more efficient and competitive in the global oil markets due to its large quantities of trades.

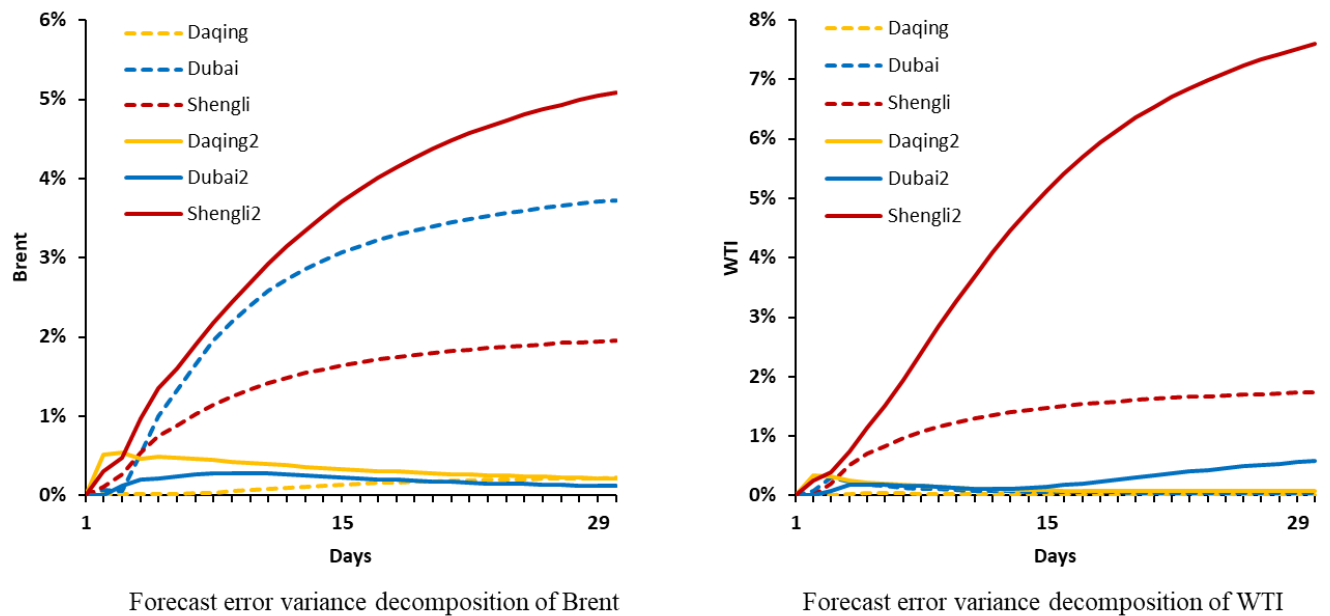


Fig.3 Forecast error variance decomposition during two periods

5.4 Hedging

Hedging risk is an important characteristic of commodity futures to spot price [63,64]. It can help the physical participants such as oil refiners, petrochemical producers and even airline companies to minimize the total non-systemic risks from their operating cost. It is also a useful instrument for financial entities to better manage their asset portfolios. Therefore, it is necessary to investigate the role of Shanghai crude oil futures markets in risk management. The dynamic conditional correlation (DCC) method with the multivariate generalized autoregressive conditional heteroscedasticity (GARCH) model [65,66] are applied to construct the hedging ratios and evaluate the hedge performance as eq.9 and eq.10.

$$H_t|I_{t-1} = \frac{Cov(R_{s,t}, R_{f,t}|I_{t-1})}{Var(R_{f,t}|I_{t-1})} \quad (9)$$

$$HE_t = \frac{Var(R_{s,t}) - Var(R'_{s,t})}{Var(R_{s,t})} \quad (10)$$

$H_t|I_{t-1}$ means the hedge ratio given the previous information set. $R_{s,t}$ and $R_{f,t}$ denote the unhedged spot price returns and futures price returns at time t, while $R'_{s,t}$ denotes the hedged spot price returns at time t. The hedge ratios between Shanghai crude oil futures and Shengli spot, OPEC are calculated where the former is the underlying asset as mentioned and the latter is the main imported source in China [28]. By comparison, the hedging ratios between WTI, Brent futures and Shengli spot, OPEC are obtained respectively as shown in Table 10.

The summary statistics of hedging ratios indicate that Shanghai crude oil futures present higher hedge performance than Brent and WTI. Indeed, it is an effective tool for risk management activities in regard of Shengli crude oil and OPEC reference basket. Furthermore, it proves that Shanghai crude oil futures have visible pricing power in the Asian region. Overall, Chinese oil importers, refiners and traders can only use international crude oils to hedge risks before the listing of Shanghai crude oil futures, but the newly introduced instrument may provide them potential opportunity against their operating costs and extreme risks in applied energy field.

Table 10 Hedge ratios summary statistics and hedge effectiveness (HE)

	mean	min	max	HE
SC/Shengli	0.702	0.639	0.846	0.359
Brent/Shengli	0.163	0.011	0.418	0.109
WTI/Shengli	0.144	0.011	0.388	0.090
SC/OPEC	0.527	0.032	0.550	0.280
Brent/OPEC	0.405	0.026	0.534	0.270
WTI/OPEC	0.364	0.020	0.525	0.113

5.5 The impact on China's oil industry

After the study of Shanghai crude oil futures pricing power and hedging effectiveness, the results show that it poses a contemporaneous impact on international price transmission and the volatility information spillover can hedge oil price fluctuation efficiently, which may have an influence on China's oil industry.

The crude oil futures market has developed stably in more than two-year operation, with the growing participation of diversified entities all over the world.

Among them, first is that the futures price is highly linked to international oil prices and it can reflect domestic supply and demand. Since 2019, the international crude oil prices have been volatile with the situation of geopolitical outbreaks and in 2020, with the global epidemic of Covid-19, oil price volatility will be even more intense, facing tremendous downward pressure. However, Shanghai crude oil futures, WTI and Brent prices can maintain a high degree of correlation. At the same time, it objectively reflects the relative changes in the supply and demand relationship between China and other regions in terms of the spot futures spread, which can effectively guide the direction of asset allocation. Second, the trading volume has been steadily increasing, with some trading days in Asia exceeding Brent. After the Spring Festival in 2020, although the global oil markets were affected by the outbreak of Covid-19 epidemic, its average daily trading volume in some trading days still exceeded Brent crude oil futures [67]. Third, the price discovery and hedging function have been further developed. China National Petroleum Corporation (CNPC) had been actively involved in Shanghai crude oil futures trading, successfully completed the market's first trade on the listing day of Shanghai crude oil futures. More oil-related companies have since participated in the trading of crude oil futures, with Chambroad Petrochemical using Shanghai crude oil futures prices as benchmark prices. After the sharp fall in international oil prices because of the Covid-19, energy giant Freepoint Commodities used crude oil futures to lock down oil price in Asian markets. In addition, as aviation kerosene prices are highly correlated with crude oil prices, China Airlines used Shanghai crude oil futures to make long hedge strategy against the risks associated with the rising of aviation kerosene prices.

In short, Shanghai crude oil futures effectively reflect the supply and demand in the Asia-Pacific market, fill the gap in the Asia-Pacific crude oil market price and may further improve the international energy pricing system. As China's futures market continues to open up, the Shanghai crude oil futures market should further reduce transaction costs to improve its liquidity and become the powerful hedging tools to form an international benchmark in the Asia-Pacific region.

6 Conclusions

This study investigates global oil prices transmission after the listing of Shanghai crude oil futures during the period 2018.3.26-2019.12.31, and the impacts of Shanghai

crude oil futures on oil markets are analyzed from a multi-time structure by using the rolling window Granger causality tests, VECM, DAG, innovation accounting and DCC-GARCH methods. In comparison, the analysis is conducted based on the data of period (2016.1.13-2018.3.23) without Shanghai crude oil futures.

Firstly, the summary statistics show that Shanghai crude oil futures have lower volatility in the selected period. Then the full sample Granger test reveals that it has a co-moved casual effect and it has been affected by the benchmark crude oils in the long time. But different from Yang et al. [9] research, a single relation in Shengli → SC and Daqing → Shengli is found. Chinese oil market takes the role of price taker and has been integrated into the world oil market while WTI and Brent lead the global oil markets. It is a good proof of the "one great pool" hypothesis [46]. Secondly, the VECM is established by selecting the optimal lags and conducting a series of robust checks. Furtherly, the quantitative analysis of price fluctuation is explored. The Shanghai crude oil futures show no adjustment effects, meaning that it is less efficient in oil pricing and market operation mechanism in the long run. Thirdly, in the simultaneous period, comparing with the period without Shanghai crude oil futures, WTI and Brent still lead the global oil price fluctuations and Shanghai crude oil futures have certain impacts on Dubai, so its pricing power is limited to the Asian region and Shengli crude starts to take its role in pricing after the listing of Shanghai crude oil futures. Furtherly, it has been taken the calculation of hedging ratios and evaluation of its hedge effectiveness. And it proves that Shanghai crude oil futures have better performance than WTI and Brent against the price of Shengli and OPEC basket.

In summary, this paper explores the role of Shanghai crude oil futures after two-years trading and shows that it truly has an impact on the crude oil price transmission in Asia during the contemporary period and better reflects oil supply and demand. Shengli crude gradually takes its role in regional pricing with large transactions of Shanghai crude oil futures. Moreover, it is an efficient instrument for Chinese oil importers and refiners to guide their productive activity and minimize operating risks. However, it does not become the regional benchmark. Governments should improve the financial market environment and simplify the trading process so that the price mechanism works better. Investors should have better access to professional training to avoid the risks associated with high oil price volatility. And for oil-related company, the exchange rate risk and global systemic shocks must be carefully considered when applying Shanghai crude oil futures in the energy market.

At the end it should be emphasized that there are some limitations in this study. First, the dynamic impacts of Shanghai crude oil futures on hedging crude oil markets risk have not been studied. Second, how to use the newly-listed crude oil futures for asset allocation does not investigate. These shall be taken into account and overcome in the future research.

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Appendix

Table 1 The estimations of adjustment parameters

	co-integration 1	co-integration 2
ΔB_t	-0.215	0.074
ΔW_t	-0.196	0.047
ΔDQ_t	0.055	-0.017
ΔDB_t	0.127	-0.045
ΔTP_t	0.064	-0.034
ΔMN_t	0.123	-0.048
ΔOP_t	-	-
ΔSC_t	-	-
ΔSL_t	-	-

Notes: * and ** denote significant at 5% and 1% levels respectively, ΔB_t denotes the first order different of Brent, W=WTI, DQ=Daqing, DB=Dubai, TP=Tapis, MN=Minas, OP=OPEC, SL=Shengli

References

- [1] U.S. Energy Information Administration, 2017. International energy data and analysis for China. <https://www.eia.gov/international/overview/country/CHN> [Accessed 12 December 2019]
- [2] Liu, L., Chen, C.C., Wan, J.Q., 2013. Is world oil market ‘one great pool’?: an example from China’s and international oil markets. *Econ. Model*, 35, 364-373. <http://dx.doi.org/10.1016/j.econmod.2013.07.027>
- [3] Song, C.M., Li, C.G., 2015. Relationship between Chinese and international crude oil prices: A VEC-TARCH approach. *Mathematical Problems in Engineering*, 1-10. <https://doi.org/10.1155/2015/842406>
- [4] Ji, Q., Fan, Y., 2016. Evolution of the world crude oil market integration: a graph theory analysis. *Energy Economics*, 53, 90-100. <https://doi.org/10.1016/j.eneco.2014.12.003>
- [5] Song, M.L., Fang, K.N., Zhang, J., Wu, J.B., 2016. The Co-movement Between Chinese Oil Market and Other Main International Oil Markets: A DCC-MGARCH Approach. *Computational Economics*, 54, 1303–1318. <https://doi.org/10.1007/s10614-016-9564-5>
- [6] Ji, Q., Zhang, D.Y., 2018. China’s crude oil futures: introduction and some stylized facts. *Finance Research Letters*, 28, 376-380. <https://doi.org/10.1016/j.frl.2018.06.005>
- [7] Yang, J., Zhou, Y., 2020. Return and volatility transmission between China’s and international crude oil futures markets: A first look. *Journal of Futures Markets*. doi:10.1002/fut.22103
- [8] Wu, X., Miao, H., Zhu, S., Li, X., 2020. Study on the optimal hedging ratio of Shanghai crude oil futures based on Copula models. *Asia-Pacific Journal of Accounting & Economics*, 1–14. doi:10.1080/16081625.2020.1754251
- [9] Yang, C., Lv, F., Fang, L.B., Shang, X.X., 2019. The pricing efficiency of crude oil futures in the Shanghai International Exchange. *Finance Research Letters*. <https://doi.org/10.1016/j.frl.2019.101329>
- [10] Wang, F., Ye, X., Wu, C.X., 2019. Multifractal characteristics analysis of crude oil futures prices fluctuation in China. *Physical A*, 533. <https://doi.org/10.1016/j.physa.2019.122021>
- [11] Chen, H.T, Cao, H.H. Zhou, D.Q., 2007. The research on the time difference between Chinese and international oil futures price based on grey incidence theory. *Proceedings of 2007 IEEE International Conference on Grey Systems*

- and Intelligent Services, GSIS, 100-104.
<https://doi.org/10.1109/GSIS.2007.4443245>
- [12] Chen, K.C., Chen, S., Wu, L., 2009. Price Causal Relations between China and the World Oil Markets. *Global Finance Journal*, 20, 107 – 118.
<https://doi.org/10.1016/j.gfj.2008.11.001>
- [13] Meng, J., Nie, H., Mo, B., Jiang, Y., 2020. Risk spillover effects from global crude oil market to China's commodity sectors, *Energy*.
<https://doi.org/10.1016/j.energy.2020.117208>
- [14] Li, R., Leung, G.C.K., 2011. The integration of China into the world crude oil market since 1998. *Energy Policy*, 39, 5159-5166.
<https://doi.org/10.1016/j.enpol.2011.05.048>
- [15] Chan, H.L., Woo, K.Y., 2016. An investigation into the dynamic relationship between international and China's crude oil prices. *Applied Economics*, 48(24), 2215-2224. <http://dx.doi.org/10.1080/00036846.2015.1117046>
- [16] Lin, S.X., Tamvakis, M.N., 2001. Spillover effects in energy futures markets. *Energy Economics*, 23(1), 43-56.
[https://doi.org/10.1016/S0140-9883\(00\)00051-7](https://doi.org/10.1016/S0140-9883(00)00051-7)
- [17] Lin, S.X., Tamvakis, M.N., 2004. Effects of NYMEX trading on IPE Brent Crude futures markets: a duration analysis. *Energy Policy*, 32, 77-82.
[https://doi.org/10.1016/S0301-4215\(02\)00259-8](https://doi.org/10.1016/S0301-4215(02)00259-8)
- [18] Klein, T., 2018. Trends and contagion in wti and brent crude oil spot and futures markets - the role of opec in the last decade. *Energy Economics*, 75, 636-646.
<https://doi.org/10.1016/j.eneco.2018.09.013>
- [19] Lu, F.B., Hong, Y.M., Wang, S.Y., Lai, K.K., Liu, J., 2014. Time-varying granger causality tests for applications in global crude oil markets. *Energy Economics*, 42, 289-298. <https://doi.org/10.1016/j.eneco.2014.01.002>
- [20] Xiao, X.Y., Huang, J., 2018. Dynamic Connectedness of International Crude Oil Prices: The Diebold – Yilmaz Approach. *Sustainability*, 10, 3298.
<https://doi.org/10.3390/su10093298>
- [21] Zhang, Y.J., Zhang, L., 2015. Interpreting the crude oil price movements: Evidence from the Markov regime switching model. *Applied Energy*, 143, 96-109. <https://doi.org/10.1016/j.apenergy.2015.01.005>
- [22] Wlazlowski, S.S., Hagstromer, B., Giulietti, M., 2011. Causality in crude oil prices. *Applied Economics*, 43(24), 3337-3347.
<https://doi.org/10.1080/00036841003636250>

- [23] Ji, Q., Fan, Y., 2015. Dynamic integration of world oil prices: A reinvestigation of globalisation vs. regionalization. *Applied Energy*, 155, 171-180. <https://doi.org/10.1016/j.apenergy.2015.05.117>
- [24] Sahel, A.R., Rashid, S., Onur, T.B.K., 2018. A dynamic network analysis of the world oil market: analysis of opec and non-opec members. *Energy Economics*, 75, 28-41. <https://doi.org/10.1016/j.eneco.2018.07.032>
- [25] Bentzen, J., 2007. Does OPEC influence crude oil prices? Testing for co-movements and causality between regional crude oil prices. *Applied Economics*, 39:11, 1375-1385. <http://dx.doi.org/10.1080/00036840600606344>
- [26] Ji, Q., Fan, Y., 2016. How do China's oil markets affect other commodity markets both domestically and internationally? *Finance Research Letters*, 19, 247 - 254. <https://doi.org/10.1016/j.frl.2016.08.009>
- [27] Zhang B., Wang, P.J., 2014. Return and volatility spillovers between china and world oil markets. *Economic Modelling*, 42, 413-420. <https://doi.org/10.1016/j.econmod.2014.07.013>
- [28] Li, J, Huang, L.X., Li, P., 2020. Are Chinese crude oil futures good hedging tools? *Finance Research Letters*. <https://doi.org/10.1016/j.frl.2020.101514>
- [29] Peng, C., Zhu, H., Guo, Y., Chen, X., 2018. Risk spillover of international crude oil to china's firms: evidence from granger causality across quantile. *Energy Economics*, 72, 188-199. <https://doi.org/10.1016/j.eneco.2018.04.007>
- [30] Jena, S. K., Tiwari, A. K., Hammoudeh, S., Roubaud, D., 2018. Distributional predictability between commodity spot and futures: evidence from nonparametric causality -in- quantiles tests. *Energy Economics*. <https://doi.org/10.1016/j.eneco.2018.11.013>
- [31] Holmes, M. J., Otero, J., 2017. Re-examining the movements of crude oil spot and futures prices over time. *Energy Economics*, S0140988317303018. <https://doi.org/10.1016/j.eneco.2017.08.034>
- [32] Chang, C.P., Lee, C.C., 2015. Do oil spot and futures prices move together? *Energy Economics*, 50, 379-390. <https://doi.org/10.1016/j.eneco.2015.02.014>
- [33] Elder, J., Miao, H., Ramchander, S., 2014. Price discovery in crude oil futures. *Energy Economics*, 46(S1), S18-S27. <https://doi.org/10.1016/j.eneco.2014.09.012>
- [34] Chen, P.F., Lee, C.C., Zeng, J.H., 2014. The relationship between spot and futures oil prices: do structural breaks matter? *Energy Economics*, 43, 206-217. <https://doi.org/10.1016/j.eneco.2014.03.006>

- [35] Zhang, Y.J., Wang, Z.Y., 2013. Investigating the price discovery and risk transfer functions in the crude oil and gasoline futures markets: Some empirical evidence. *Applied Energy*, 104, 220–228. doi:10.1016/j.apenergy.2012.10.066
- [36] Narayan, P. K., Narayan, S., Popp, S., 2011. Investigating price clustering in the oil futures market. *Applied Energy*, 88(1), 397–402. doi:10.1016/j.apenergy.2010.07.034
- [37] Shao, Y.H., Yang, Y.H., Shao, H.L., Stanley, H.E., 2019. Time-varying lead–lag structure between the crude oil spot and futures markets. *Physica A: Statistical Mechanics and its Applications*. 523, 723–733. <https://doi.org/10.1016/j.physa.2019.03.002>
- [38] Jia, X.L., An, H.Z., Sun, X.Q., Huang, X., Wang, L., 2017. Evolution of world crude oil market integration and diversification: a wavelet-based complex network perspective. *Applied Energy*, 185, 1788–1798. <https://doi.org/10.1016/j.apenergy.2015.11.007>
- [39] Jiang, M., An, H., Jia, X., Sun, X., 2017. The influence of global benchmark oil prices on the regional oil spot market in multi-period evolution. *Energy*, 118, 742–752. <http://dx.doi.org/10.1016/j.energy.2016.10.104>
- [40] Jia, X.L., An, H.Z., Fang, W., Sun, X.Q., Huang, X., 2015. How do correlations of crude oil prices co-move? A grey correlation-based wavelet perspective. *Energy Economics*, 49, 588–598. <https://doi.org/10.1016/j.eneco.2015.03.008>
- [41] Balcilar, M., Gungor, H., Hammoudeh, S., 2015. The time-varying causality between spot and futures crude oil prices: A regime switching approach, *International Review of Economics and Finance*, 40, 51–71. <https://doi.org/10.1016/j.iref.2015.02.008>
- [42] Ghassan, H.B., Alhajhoj, H.R., 2016. Long run dynamic volatilities between opec and non-opec crude oil prices. *Applied Energy*, 169, 384–394. <http://dx.doi.org/10.1016/j.apenergy.2016.02.057>
- [43] An, S., Gao, X., An, H., An, F., Sun, Q., Liu, S., 2020. Windowed volatility spillover effects among crude oil prices, *Energy*. <https://doi.org/10.1016/j.energy.2020.117521>
- [44] Zhang, D.Y., Ji, Q., Kutan, A.M., 2019. Dynamic transmission mechanisms in global crude oil prices: estimation and implications. *Energy*, 175, 1181–1193. <https://doi.org/10.1016/j.energy.2019.03.162>
- [45] Ozdemir, Z. A., Gokmenoglu, K., Ekinici, C. 2013. Persistence in crude oil spot and futures prices. *Energy*, 59, 29–37. doi:10.1016/j.energy.2013.06.008

- [46] Adelman, M.A., 1984. International Oil Agreements. *The Energy Journal*, 5(3):1-10. <https://www.jstor.org/stable/41321691>
- [47] Kuck, K., Schweikert, K., 2017. A Markov regime-switching model of crude oil market integration. *Journal of Commodity Markets*, 6, 16-31. <http://dx.doi.org/10.1016/j.jcomm.2017.03.001>
- [48] Serletis, A., Xu, L.B., 2019. Markov Switching Oil Price Uncertainty. *Oxford Bulletin of Economics and Statistics*, 81, 1045-1064. <https://doi.org/10.1111/obes.12300>
- [49] Hammoudeh, S., Thompson, M., Ewing, B., 2008. Threshold cointegration analysis of crude oil benchmarks. *Energy J*, 29, 79–95. <https://www.jstor.org/stable/41323182>
- [50] Li, P., Zhang, Z.Y., Yang, T.N., Zeng, Q.C., 2018. The relationship among China's fuel oil spot, futures and stock markets. *Financial Research Letters*, 24, 151-162. <http://dx.doi.org/10.1016/j.frl.2017.09.001>
- [51] Caporin, M., McAleer, M., 2013. Ten Things You Should Know About the Dynamic Conditional Correlation Representation. *Econometrics*, 1, 115-126. <https://doi.org/10.3390/econometrics1010115>
- [52] Gao, X., Fang, W., An, F., & Wang, Y., 2017. Detecting method for crude oil price fluctuation mechanism under different periodic time series. *Applied Energy*, 192, 201–212. doi:10.1016/j.apenergy.2017.02.014
- [53] Davidson, J.E.H, Hendry, D.F, Srba, F, Yeo, J.S., 1978. Econometric modelling of the aggregate time-series relationship between consumers' expenditure and income in the United Kingdom. *Economic Journal*, 88 (352): 661–692. <https://doi.org/10.2307/2231972>
- [54] Johansen, S., 1988. Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control*, 12, 231-254. [https://doi.org/10.1016/0165-1889\(88\)90041-3](https://doi.org/10.1016/0165-1889(88)90041-3)
- [55] Johansen, S., Juselius, K., 1990. Maximum Likelihood Estimation and Inference on Cointegration – with Applications to the Demand for Money. *Oxford Bulletin of Economics and Statistics*, 52, 2, 169–210. <https://doi.org/10.1111/j.1468-0084.1990.mp52002003.x>
- [56] Sprites, P., Glymour, C., Scheines, R., 2000. *Causation, Prediction, and Search*. Cambridge: MIT Press.
- [57] Ji, Q., 2012. System analysis approach for the identification of factors driving crude oil prices. *Comput. Ind. Eng.* 63 (3), 615–625.

<https://doi.org/10.1016/j.cie.2011.07.021>

- [58] Yang, Z., Zhao, Y., 2014. Energy consumption, carbon emissions, and economic growth in India: evidence from directed acyclic graphs. *Economic Model*, 38, 533–540. <http://dx.doi.org/10.1016/j.econmod.2014.01.030>
- [59] Ji, Q., Zhang, H.Y, Geng, J.B., 2017. What drives natural gas prices in the United States? - A directed acyclic graph approach. *Energy Economics*, 69, 79-88. <https://doi.org/10.1016/j.eneco.2017.11.002>
- [60] Anderson, T., 1984. *An Introduction to Multivariate Statistical Analysis*. Wiley: New York.
- [61] Savva, C.S., Osborn, D.R., Gill, L., 2009. Spillovers and correlations between US and major European stock markets: the role of the euro. *Applied Finance Economics*. 19 (19), 1595-1604. <https://doi.org/10.1080/09603100802599563>
- [62] Sims, C., 1986. Are forecasting models usable for policy analysis? *Quarterly Review*, Federal Reserve Bank of Minneapolis 10, 2–16. <https://doi.org/10.21034/qv.1011>
- [63] Wang, Y., Geng, Q., Meng, F., 2019. Futures hedging in crude oil markets: A comparison between minimum-variance and minimum-risk frameworks. *Energy*, 181, 815–826. <https://doi.org/10.1016/j.energy.2019.05.226>
- [64] Hung, J.C., Yi-Hsien Wang, Chang, M.C., Shih, K.-H., Hsiu-Hsueh Kao., 2011. Minimum variance hedging with bivariate regime-switching model for WTI crude oil. *Energy*, 36(5), 3050–3057. <https://doi.org/10.1016/j.energy.2011.02.049>
- [65] Engle, R.F. 2002. Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroscedasticity models. *Journal of Business & Economic Statistics* 20: 339–350. <https://www.jstor.org/stable/1392121>
- [66] Jiang, Y.H., Jiang, C., Nie, H., Mo, B., 2018. The time-varying linkages between global oil market and China's commodity sectors: Evidence from DCC-GJRGARCH analyses, *Energy*. doi: 10.1016/j.energy.2018.10.116
- [67] Shanghai International Energy Exchange, 2020. Shanghai crude oil futures market development report. <http://www.ine.cn/upload/20200331/1585628522650.pdf> [Accessed 10 November 2020]