关于中国原油期货的一些实证研究

学生姓名：黄力新

学校名称：普林斯顿数理学校

学校地址: **19 Lambert Drive, Princeton, NJ, USA**

指导老师: **Mr. Xiang Gong**

2018S.-T. Yau High School Science Award

Some Empirical Studies on Chinese Crude Oil Futures

Student Name: Lixin HUANG

School name: Princeton International School of Mathematics and Science

School Address: 19 Lambert Drive, Princeton, New Jersey, USA

Mentor: Mr. Xiang Gong

2018S.-T. Yau High School Science Award

Contents:

2018S. -T. Yau High School Science Award

Some Empirical Studies on Chinese Crude Oil Futures

Lixin HUANG

Princeton International School of Mathematics and Science

Princeton, NJ 08540, USA

Abstract: Chinese crude oil futures market was launched on March 26, 2018 and has been the third largest crude oil futures market in the world. In this paper, we do some empirical studies on this new comer. We first employ DCC-GARCH model to investigate the dynamic correlation between Chinese crude oil futures and spot markets. For comparison, we also analyze the correlation between Chinese crude oil spot and WTI crude oil futures, Brent crude oil futures and Chinese energy stock index. Empirical results show that the correlation between Chinese crude oil spot and futures markets is the strongest, while the correlation between Chinese crude oil spot and Brent crude oil futures is stronger than that with WTI crude oil futures. In addition, we investigate the optimal hedge ratio and hedging effectiveness of Chinese crude oil futures against the risk of Chinese crude oil spot. Comparing with the other three markets we consider, Chinese crude oil futures is the most effective hedging instrument. Also, we find that all of the correlation, optimal hedge ratio, and hedging effectiveness have the same ranking that Chinese crude oil futures is the best, then Chinese energy stock index, then Brent crude oil futures, and finally WTI crude oil futures. Furthermore, there could be some structural shocks in different domestic and international economic conditions. Due to the oil price control policy and oil price lagging in Chinese crude oil market, both the correlation and hedging effectiveness may decrease. Overall, we think that this newborn crude oil futures market ran well and showed some characteristics of mature futures markets after its launching.

Keywords: Chinese crude oil futures, DCC-GARCH model, Dynamic correlation, Hedging effectiveness

2018 S.-T. Yau High School Science Award

1. Introduction

As an important strategic resource and raw material for energy and chemical industry, crude oil has been playing an important role in economic development and national security, since fluctuations in crude oil prices will lead crude oil producers and consumers into a great deal of uncertainty and have serious impact on not only the national economy but also investors' investment behavior. In addition, as the largest oil importer in the world and one of the seven largest producers, China especially has long-standing and increasing needs of hedging risks of crude oil spot trading. Commodity futures are very important tools to hedge the risk of spot price, but we don't have crude oil futures until March 26, 2018, on which day we launched the crude oil futures in Shanghai International Energy Exchange (INE). This marked the start of a new era in international energy markets. After the launching of Chinese crude oil futures, its daily trading volume has exceeded that of Dubai crude oil futures and become the first one in Asian oil market and the third one in international oil market. On September 7, 2018, Chinese crude oil futures contract SC1809 successfully finished its first delivery, representing the success of passing the test of the market.

As a new comer in international crude oil market, it is very natural to investigate the role and influence of Chinese crude oil futures. In addition, since the main function of futures trading is to hedge the risk of spot trading, we also want to see if Chinese crude oil futures have realized this main function, and what about the hedging effectiveness comparing with other crude oil futures. These questions are what we want to do in this paper.

Since Sdwartz and Szakmary (1994) detected the correlations between crude oil spot and futures markets and found the price discovery function of oil futures, the relationship between oil spot and futures markets have been investigated extensively, such as for WTI (West Texas Intermediate) crude oil market (Bekiros and Diks, 2008; Lee and Zeng, 2011; Silvapulle and Moosa, 2015; Minimol, 2018), and Brent crude oil market (Huang et al, 2009; Chen and Zeng, 2011; Mehrara and Hamldar, 2014). Empirical results in above mentioned papers show that there exists significant correlation between crude oil spot and futures markets, which is hardly accidental since both futures and spot prices reflect the same aggregate value of the underlying asset.

Before the launching of Chinese crude oil futures, most researches on Chinese oil market are about the relationships between Chinese and international crude oil spot prices (e.g. He et al, 2013; Song and Li, 2015; Chan and Woo, 2016), or between Chinese crude oil spot and international crude oil futures (Ge and Wu 2017), or between Chinese heating oil spot and futures markets (e.g. Li and Zhang, 2018). Among them, Ge and Wu (2017) investigated the correlation between WTI crude oil futures and Chinese crude oil spot prices. Their empirical results show that WTI crude oil futures price is an important driving force of the fluctuation of

2018S-T Yau High School Science Award

Chinese crude oil spot price. After the launching of Chinese crude oil futures, Ji and Zhang (2018) presents some stylized facts for this new product using one-minute transaction data in the first two trading months since its inception in March 2018.

The purpose of this paper is to investigate the relationship between this newborn crude oil futures contract and other related products, and its hedging effectiveness against the risk of crude oil spots. We try to provide researchers and market participants some fresh and valuable information to understand Chinese crude oil futures. We first investigate the dynamic correlation between Chinese crude oil futures (SC1809) and its underlying spot (Da Qing) using DCC-GARCH model proposed by Engle (1992) which have been widely used in related literatures. Chang et al (2011) studied the hedging effectiveness of crude oil futures using BEKK-, CCC-, DCC-, and VARMA-GARCH models and found that DCC-GARCH model performed the best while BEKK model was the worst. For comparison, we also calculate the dynamic correlation between Chinese crude oil spot and Chinese energy stock index (300ENI), WTI crude oil futures, Brent crude oil futures, and compare the optimal hedge ratio and hedging effectiveness of Chinese crude oil futures, WTI crude oil futures, Brent crude oil futures and 300ENI against the risk of Chinese crude oil spot.

The rest of the paper is organized as follows: Section 2 and Section 3 introduce the models and data to be used. Section 4 gives the empirical results, and then Section 5 presents the conclusion, policy implication and future improvement of this paper.

2. Methodologies

In this section, we introduce the DCC (Dynamic Conditional Correlation)-GARCH model employed to investigate the dynamic correlation between Chinese crude oil spot and futures prices, and the model to be used to calculate the optimal hedge ratio and hedging effectiveness of Chinese crude oil futures.

2.1 DCC-GARCH model

The DCC-GARCH model proposed by Engle (2002) is shown as follows:

Let $y_t = (y_{1,t}, y_{2,t})$ denote random variables with mean 0 and satisfy:

$$y_t = \phi_0 + \sum_{i=1}^{k} \phi_i y_{t-i} + u_t = \mu_t + u_t \quad (1)$$

$$\mu_t = E[y_t \mid \Omega_{t-1}] \quad (2)$$

2018S.-T. Yau High School Science Award

$$u_t = H_t^{1/2}\varepsilon_t \sim N(0, H_t) \quad (3)$$

where Ω_t denotes the information set at time t and H_t denotes the conditional covariance matrix given as follows:

$$H_t = D_t R_t D_t \quad (4)$$

where $D_t = diag\{\sqrt{h_{ii,t}}\}$, and $h_{ii,t}$ denotes the conditional variance characterized by a univariate GARCH model given as follows:

$$h_{ii,t} = \omega_i + \sum_{p=1}^{P_i} \alpha_{ip}\varepsilon_{i,t-p}^2 + \sum_{q=1}^{Q_i} \beta_{iq} h_{ii,t-q}\,, \quad (5)$$

and $R_t = (\rho_{ij})_t, i, j = 1,2$ denotes the time-varying matrix of conditional correlation coefficient with dynamic constraint

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1} \quad (6)$$

$$Q_t = (1-\lambda_1-\lambda_2)\overline{Q} + \lambda_1(\varepsilon_{1,t-1}\varepsilon'_{2,t-1}) + \lambda_2 Q_{t-1} \quad (7)$$

where $Q_t = \begin{pmatrix} q_{11,t} & q_{12,t} \\ q_{21,t} & q_{22,t} \end{pmatrix}, Q_t^* = \begin{pmatrix} \sqrt{q_{11,t}} & 0 \\ 0 & \sqrt{q_{22,t}} \end{pmatrix}$, and $\overline{Q}$ denotes the unconditional covariance matrix of standardized residuals. Obviously, the Q matrix being positive definite or positive semidefinite is a sufficient condition for R_t to be positive definite.

2.2 Optimal hedge ratio and hedging effectiveness

In this paper, we mainly consider to use Chinese crude oil futures to hedge the risk of Chinese crude oil spot. We consider a portfolio with two assets including Chinese crude oil spot and futures, and the return of this hedged portfolio can be given by

$$r_{p,t} = r_{S,t} - h_t^* \cdot r_{F,t} \quad (8)$$

where $r_{S,t}$ and $r_{F,t}$ are returns of Chinese crude oil spot and futures at day t, respectively, and h_t^* is the optimal hedge ratio (OHR) at day t. As shown in Johnson (1960) and Baillie and Myers (1991), the dynamic optimal hedge ratio (OHR) is given by

$$h_t^* = \frac{Cov_{SF,t}}{Var_{F,t}} \quad (9)$$

where $Cov_{SF,t}$ and $Var_{F,t}$ are respectively the conditional covariance between returns of crude oil spot and futures, and conditional variance of crude oil futures implied by DCC-GARCH model.

2018S.-T. Yau High School Science Award

The OHR implies that for the propose of minimizing the portfolio risk, a long position in crude oil spot should be hedged by a short position of h_t^* crude oil futures.

Referring to Wang and Liu (2016), the hedging effectiveness of crude oil futures against the risk of spot is measured by the percentage reduction in variance as follows

$$HE_t = \frac{Var_{S,t} - Var_{P,t}}{Var_{S,t}} \tag{10}$$

where $Var_{S,t}$ is the variance of crude oil spot (total risk), and $Var_{P,t}$ represents the hedged risk. So HE measures the hedged risk, meaning that the higher of HE, the better of hedging effectiveness.

3. Data Description

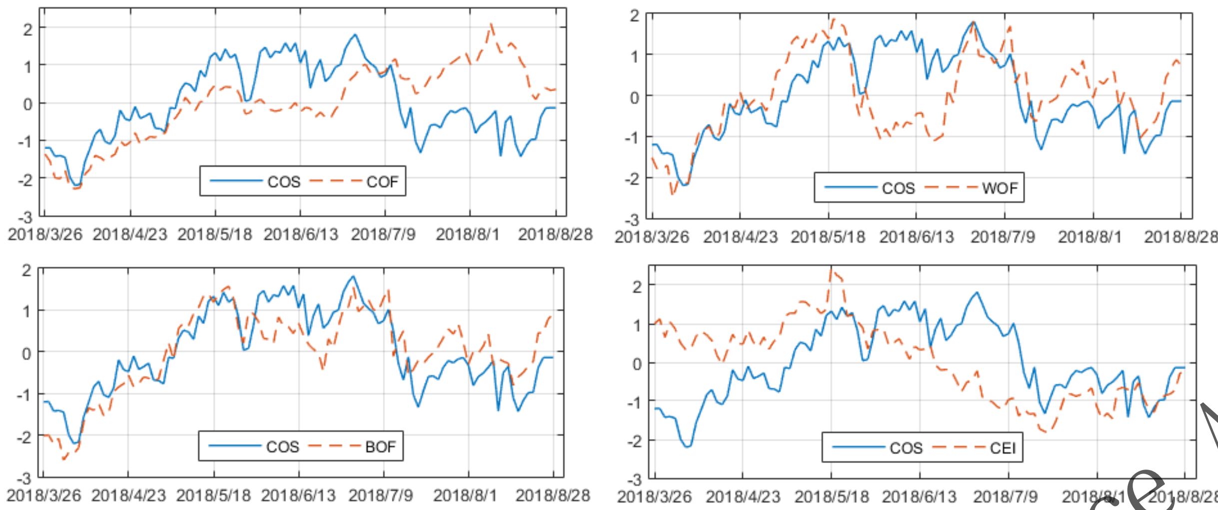
The daily data of Chinese crude oil spot price (COS), Chinese crude oil futures price (COF), WTI crude oil futures (WOF), Brent crude oil futures (BOF), and Chinese energy stock index (CEI), from March 26, 2018 to July 28, 2018, are analyzed in this paer. As a proxy for Chinese crude oil spot price, we use Chinese DaQing crude oil which is the benchmark of Chinese crude oil market. As for Chinese crude oil futures price, we choose the SC1809 futures contract which is the most active futures in Chinese crude oil futures market. Moreover, Chinese energy stock market is represented by China 300 Energy Index (300ENI), and WTI and Brent crude oil futures are represented by WTI 1001 futures and Brent 1001 futures. All the data is collected from the Wind database. The following Table 1 gives the symbols of the variables to be used in this paper.

Table 1. Explanation of variables

Variables	Symbols	Variables	Symbols
Chinese crude oil spot	COS	Brent crude oil futures	BOF
Chinese crude oil futures	COF	Chinese energy stock market index	CEI
WTI crude oil futures	WOF		

The trajectories of the daily series of the five variables over the whole period are shown in Figure 1, where the vertical axes are the standardized data because of their different units, that is, minus the mean and then divided by the standard deviation. We find that the overall changing trend of Chinese crude oil spot price is more consistent with Chinese crude oil futures price than with WTI and Brent crude oil futures. And Chinese crude oil spot prices change seems to be lagged relative to the international crude oil futures price.

2018S · T · Yau High School Science Award



Note: The vertical axes are the standardized data.

Figure 1. Time-variations of the five variables

These data are transformed to first-order difference of logarithm to avoid the need to consider these series as near unit root processes. The summary statistics of the five log-difference series are presented in Table 2, from which we find that the mean return of Chinese crude oil futures is larger than that of WTI crude oil futures while small than Brent crude oil futures. The standardized deviation of Chinese crude oil futures is almost equal to WTI crude oil futures and a little smaller than Brent crude oil futures. These statistics show that Chinese crude oil futures are more close to WTI crude oil futures than Brent crude oil futures. In addition, Chinese crude oil spot price (COS) is the most volatile among these five variables.

Table 2. Summary statistics for log-differences of five variables

	COS	COF	WOF	BOF	CEI
Mean	0.0005	0.0011	0.0008	0.0013	-0.0006
Std. Dev	0.0185	0.0146	0.0147	0.0156	0.0143
5%	-0.0368	-0.0281	-0.0285	-0.0242	-0.024
25%	-0.0107	-0.008	-0.0068	-0.0053	-0.008
Median	0.002	0.0022	0.0027	0.0039	-0.0004
75%	0.0116	0.0098	0.0101	0.0091	0.006
95%	0.0299	0.0251	0.0249	0.0274	0.0215
Skewness	-0.5293	-0.4878	-0.5949	-1.0401	0.2008
Kurtosis	3.739	3.3184	4.258	6.2044	4.2487

Notes: 5%, 25%, Median, 75%, 95% denote the quantiles of log-differences of five variables.

2018S.-T. Yau High School Science Award

4. Empirical analysis

In this section, we employ DCC-GARCH model introduced in Section 2.1 to analyze the dynamic correlations between Chinese crude oil spot and futures. For comparison, we also calculate the dynamic correlations between Chinese crude oil spot and Chinese energy stock index, WTI crude oil futures, and Brent crude oil futures. In addition, we apply the hedging model described in Section 2.2 to investigate the hedging effectiveness of Chinese crude oil futures against the risk of Chinese crude oil spot and see which of the four products is the best hedging instrument: WTI crude oil futures, Brent crude oil futures, and Chinese energy stock index.

4.1 Dynamic correlation analysis

Firstly, we apply the AR(1)-DCC-GARCH(1,1) model to four pairs of variables, that is COS-COF, COS-WOF, COS-BOF, and COS-CEI. The estimation of DCC-GARCH models are shown in Table 3.

Table 3. Estimation results of DCC-GARCH models

		COS	COF	WOF	BOF	CEI
GARCH	$\phi_0(10^{-4})$	5.511	2.080	8.040	15.0000	-6.258
	ϕ_1	-0.0732	0.1097	-0.0369	-0.1640	-0.0405
	$\omega(10^{-4})$	1.8788	0.1390	0.0249	0.0000	0.1228
	α	0.0863	0.0005	0.0000	0.0000	0.0000
	β	0.3562	0.9305	0.9893	1.0000	0.9400
DCC			COS-COF	COS-CEI	COS-WOF	COS-BOF
	λ_1		0.1842	0.1199	0.1044	0.0854
	λ_2		0.1769	0.7569	0.0695	0.1120

From Table 3 we can obtain the dynamic correlation coefficients between four pairs at each time point as shown in Figure 2.

2018S.-T Yau High School Science Award

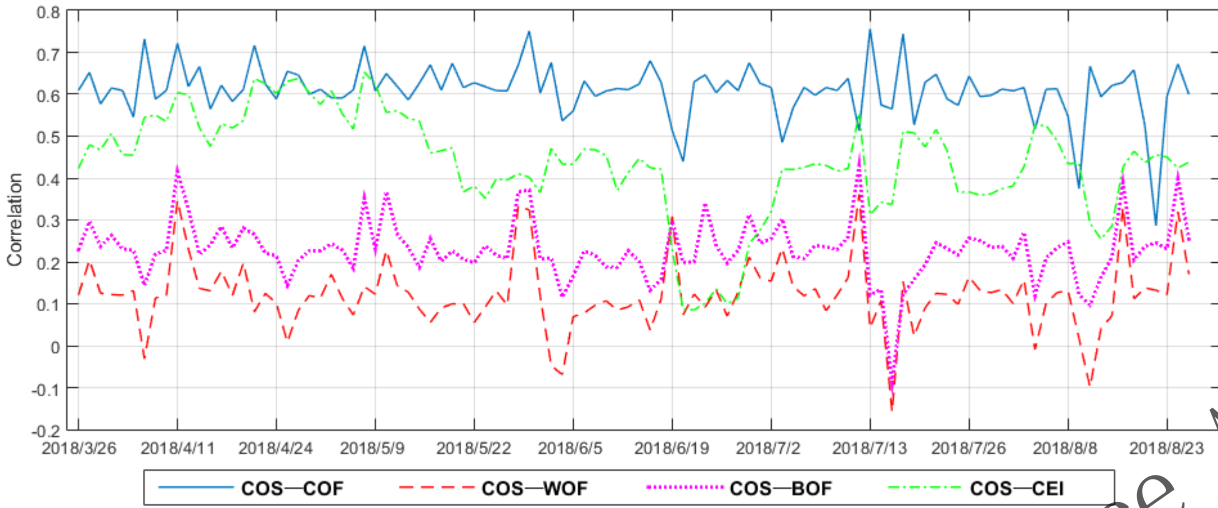


Figure 2. Dynamic correlations between four pairs of variables

From Figure 2 we can find that correlations between Chinese crude oil spot and domestic and international crude oil futures show significant positive correlations in most periods. And the correlations between COS (Chinese crude oil spot) and COF (Chinese crude oil futures) are stronger than COS-WOF (WTI oil futures) and COS-BOF (Brent oil futures) in the whole period, and even the correlation between COS (Chinese crude oil spot) and CEI (Chinese energy stock index) is stronger than COS-WOF and COS-BOF in most periods. These results are different from existed related literatures stating that Chinese crude oil market depends more on international crude oil market than Chinese energy stock market (Li and Zhang, 2018). This phenomenon may show that Chinese crude oil market or energy stock market displays domestic characteristics. In addition, the stronger correlation between COS-BOF than COS-WOF shows that Chinese crude oil spot market is more relevant to European crude oil market than American one.

Interestingly, we also find that at six time points the correlations between COS and WOF are negative, that is April 9 (-0.03), June 4 (-0.048), June 5 (-0.069), July 18 (-0.158), August 6 (-0.01), and August 14 (-0.1). Especially on July 18, the correlation between COS and BOF quickly declined to -0.09. From the trajectory of Chinese crude oil spot prices, we find that the spot price in China dropped to the lowest level after a period of rising, which was due to that U.S president Trump asked OPEC (Organization of Petroleum Exporting Countries) to increase oil production. Furthermore, we find that returns of Chinese crude oil spot at these six time points (3.16% on April 9, 3.25% on June 4, -4.47% on July 18, -2.46% on August 6, and 4.65% on

2018S.-T. Yau High School Science Award

August 14) are larger than 95% quantile or smaller than 5% quantile which are extreme cases, showing that the negative correlations between COS and WOF or BOF often occur in periods of extraordinary volatile time points in Chinese crude oil market. Other reasons include the oil price control policy, the lagged change of oil prices, and the lower degree of marketization of Chinese oil market.

The empirical results of Li and Zhang (2018) show that the correlations among Chinese fuel oil spot, fuel oil futures and energy stock index are lower than those among American corresponding markets, which indicates that, to some extent Chinese oil market is incomplete and Chinese oil price is more determined by international oil market rather than Chinese economy. Fortunately, this new emerging crude oil futures market seems to improve this phenomenon: the correlation between Chinese crude oil futures and spot is strong enough (the average level is 0.61).

2018S.-T. Yau High School Science Award

4.2 Hedging analysis for Chinese crude oil spot market

Since one of the main functions of commodity futures is to hedge the risk of spot market, we investigate the optimal hedge ratio and hedging effectiveness of Chinese crude oil futures against the risk of its spot price, and compare the results with those of WTI crude oil futures, Brent crude oil futures, and Chinese energy stock index, as shown in Figure 3 and Figure 4.

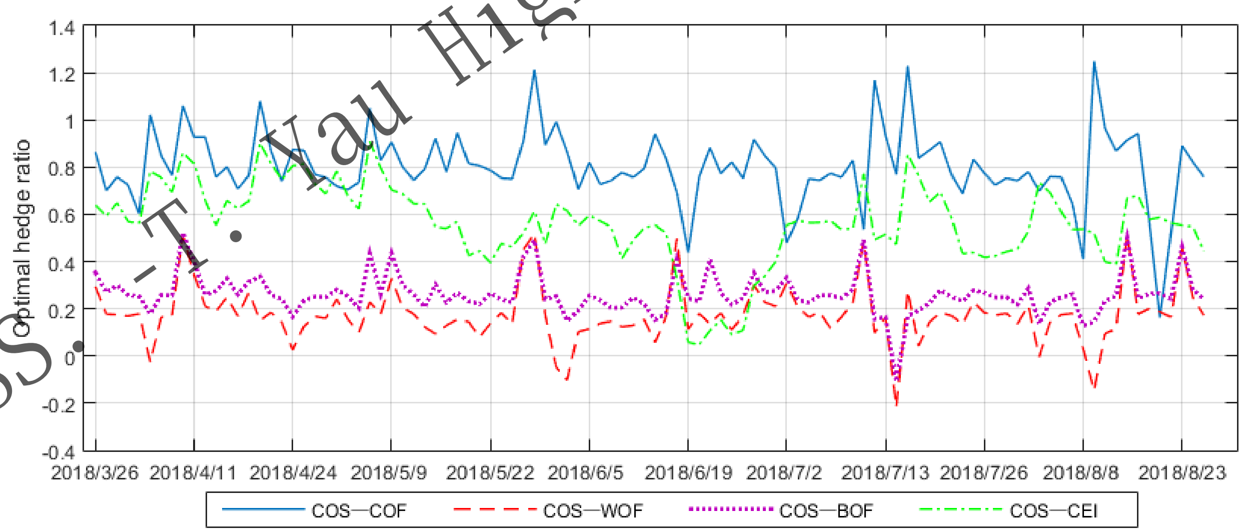


Figure 3. Optimal hedge ratio of COF, WOF, BOF, and CEI against COS

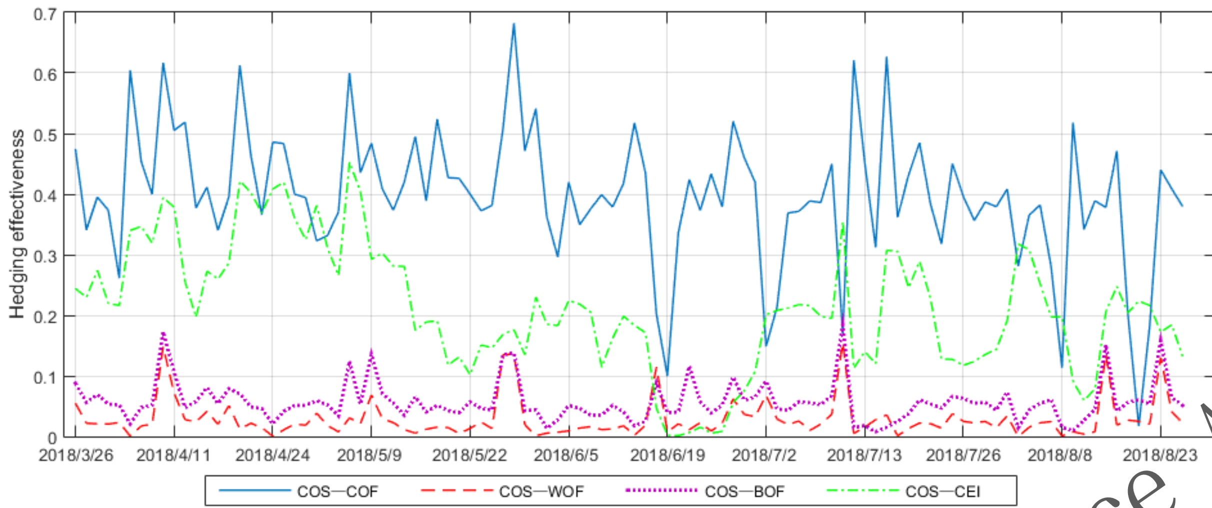


Figure 4. Hedging effectiveness of COF, WOF, BOF, and CEI against COS

From Figure 3 we can see that the optimal hedge ratio using Chinese crude oil futures is the largest in most of the time periods, while that using WTI crude oil futures is the smallest. Similarly, using Chinese crude oil futures can reduce average 40% of the spot price risk and the highest hedging effectiveness can be 68%. The smallest hedging effectiveness is using WTI crude oil futures, which are less than 10% in most periods.

From Figure 2-4 we can conclude that the larger correlation, the larger optimal hedge ratio, and the better hedging effectiveness. All of the dynamic correlation, optimal hedge ratio, and the hedging effectiveness for Chinese energy stock index experienced a marked drop from June 20 to June 28, even less than those using WTI or Brent crude oil futures. This may be due to the Chinese stock market crash starting from the first half year, when the Shanghai Composite Index fell 5% in ten days (from June 15 to 25). Chinese energy stock index also declined influenced by the weak stock market while Chinese crude oil futures is hardly affected and kept buoyant during this period. Similar to the conclusion about dynamic correlation, both the optimal hedge ratio and hedging effectiveness show regional characteristics. Also, Chinese crude oil futures indeed can be used as a new and effective hedging instrument against the risk of Chinese crude oil spot price for investors.

5. Conclusions and suggestions

This paper contributes to the existed few literatures about the new established Chinese crude oil futures market by analyzing the relationships between Chinese crude oil spot and futures markets, and two main international crude oil futures markets (WTI and Brent). Since Chinese

2018S. T. Yau High School Science Award

crude oil futures market just emerged on March 26 of 2018, it should present properties different from other futures markets that have been operating for a long period of time. It would be legit if we take a look into this new market and it is likely for us to draw some useful conclusions for Chinese energy market development and market regulations.

The results we obtain can be concluded as follows. Firstly, the correlations between Chinese crude oil spot and futures markets are higher than those between Chinese crude oil spot and other three related markets: WTI crude oil futures, Brent crude oil futures, and Chinese energy stock market. These results indicate that Chinese crude oil futures market ran well and had the characteristics of mature commodity futures market. Secondly, during the period of strong correlation between Chinese crude oil spot and other four markets we consider, both the optimal hedge ratio and hedging effectiveness are large, while Chinese crude oil futures market possesses the highest level in all three aspects. This phenomenon show that Chinese crude oil market presented regional characteristics in these periods. Thirdly, the dynamic correlation, optimal hedge ratio, and hedging effectiveness show that there are some structural shocks possibly because of the oil price control policy, oil market imperfection, and oil price delay in China.

Finally, we'd like to give some suggestions for policy makers and market participants. Firstly, the newborn Chinese crude oil futures market has a close relationship with Chinese crude oil spot market. The oil price control policy will lower the correlation between them two and has a negative effect on the hedging effectiveness, which is unfavorable for crude oil spot traders. Thence, Chinese government should improve the risk control and management of the crude oil market and the degree of marketization. Secondly, since the hedging effectiveness using Chinese crude oil futures is significantly higher than using the two international benchmarks, Chinese crude oil futures can be a better hedging instrument than the two international crude oil futures for investors hedging the risk of Chinese crude oil spot price .

2018S.-T. Yau High School Science Award

References

[1] Baillie, R.T. and Myers, R. (2010). Bivariate GARCH estimation of optimal commodity futures hedge. *Journal of Applied Econometrics,* 6 (2), 109-124.

[2] Bekiros, S.D. and Diks, C.G.H. (2008). The relationship between crude oil spot and futures prices: Cointegration, linear and nonlinear causality. *Energy Economics*, 30 (5): 2673-2685.

[3] Chang, C., McAleer, M., and Tansuchat, R. (2011). Crude oil hedging strategies using dynamic multivariate GARCH. *Energy Economics*, 33 (5), 912-923.

[4] Chan, H.L. and Woo, K.Y. (2016). An investigation into the dynamic relationship between international and China's crude oil prices. *Applied Economics*, 48 (24): 2215-2224.

[5] Chen, L. and Zeng, Y. (2011). The properties and cointegration of oil spot and futures prices during financial crisis. *Energy Procedia*, 5: 353-359.

[6] Engle, R. (2002). Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. *Journal of Business and Economic Statistics*, 20 (3), 339-350.

[7] Ge, Y. and Wu, H. (2017). Can international crude oil futures stabilize the crude oil spot price fluctuations in China? *International Conference on Economics*.

[8] He, Y., Wang, B., Wang, J., Xiong, W. and Xia, T. (2013). Correlation between Chinese and international energy prices based on a HP filter and time difference analysis. *Energy Policy*, 62 (9): 898-909.

[9] Huang, B.N., Yang, C.W. and Hwang, M.J. (2009). The dynamics of a nonlinear relationship between crude oil spot and futures prices: A multivariate threshold regression approach. *Energy Economics*, 31 (1): 91-98.

[10] Ji, Q. and Zhang, D. (2018). China's crude oil futures: introduction and some stylized facts. Forthcoming in *Finance Research Letters*.

[11] Johnson, L.L. (1960). The theory of hedging and speculation in commodity futures. *Review of Economic Studies*, 27 (3), 139-151.

[12] Lee, C.C. and Zeng, J.H. (2011). Revisiting the relationship between spot and futures oil prices: Evidence from quantile cointegration regression. *Energy Economics*, 33 (5): 924-935.

[13] Li, P. and Zhang, Z. (2018). The relationship among China's fuel oil spot, futures and stock markets. *Finance Research Letters*, 24, 151-162.

2018S.-T. Yau High School Science Award

[14] Mehrara, M. and Hamldar, M. (2014). The relationship between spot and futures prices in Brent oil crude market. *International Journal of Learning*, 39 (1): 15-19.

[15] Minimol, M.C. (2018). Relationship between spot and future prices of crude oil: A cointegration analysis. *Theoretical Economics Letter*, 8 (3): 330-339.

[16] Sdwartz, T.V. and Szakmary, A.C. (1994). Price discovery in petroleum markets: arbitrage, cointegration, and the time interval of analysis. *Journal of Futures Markets*, 14 (2): 147-167.

[17] Silvapulle, P. and Moosa, I.A. (2015). The relationship between spot and futures prices: Evidence from the crude oil market, *Journal of Futures Markets*, 19 (2): 175-193.

[18] Song, C. and Li, C. (2015). Relationship between Chinese and International Crude oil prices: A VEC-TARCH approach. Mathematical Problems in Engineering, 155 (1): A2968.

[19] Wang, Y. and Liu, L. (2016). Crude oil and world stock markets: volatility spillovers, dynamic correlations, and hedging. *Empirical Economics*, 50 (4), 1481-1509.

2018S.-T. Yau High School Science Award

Appendix

The Matlab codes used in this paper are as follows:

```
[price,text]=xlsread('data.xls');%loading the data and date
date=char(text(2:end));

zp=zscore(price);%standardize raw sample for comparison

figure(1),subplot(2,2,1),
plot(zp(:,[1,2]));
set(gca,'xtick',1:17:length(date));
set(gca,'xticklabel',date(1:17:length(date),:));
legend({'COS','COF'});
grid on
subplot(2,2,2),
plot(zp(:,[1,3]));
set(gca,'xtick',1:17:length(date));
set(gca,'xticklabel',date(1:17:length(date),:));
legend({'COS','WOF'});
grid on
subplot(2,2,3),
plot(zp(:,[1,4]));
set(gca,'xtick',1:17:length(date));
set(gca,'xticklabel',date(1:17:length(date),:));
legend({'COS','BOF'});
grid on
subplot(2,2,4),
plot(zp(:,[1,5]));
set(gca,'xtick',1:17:length(date));
set(gca,'xticklabel',date(1:17:length(date),:));
legend({'COS','CEI'});
grid on

ret=price2ret(price);% transform the price to first-order difference of logarithm
```

2018S.-T. Yau High School Science Award

```
%summary statistics
mean0=mean(ret);
std0=std(ret);
quan5=quantile(ret,0.05);
quan25=quantile(ret,0.25);
quan50=quantile(ret,0.5);
quan75=quantile(ret,0.75);
quan95=quantile(ret,0.95);
skew0=skewness(ret);
kurt0=kurtosis(ret);

% AR(1) model
mdl1=arima(1,0,0);
resid=zeros(102,5);
est1=estimate(mdl1,ret(:,1),'Display','off');
resid(:,1)= infer(est1,ret(:,1));% obtain the standardized residuals

est2=estimate(mdl1,ret(:,2),'Display','off');
resid(:,2)= infer(est1,ret(:,2));% % obtain the standardized residuals

est3=estimate(mdl1,ret(:,3),'Display','off');
resid(:,3)= infer(est1,ret(:,3));% % obtain the standardized residuals

est4=estimate(mdl1,ret(:,4),'Display','off');
resid(:,4)= infer(est1,ret(:,4));% % obtain the standardized residuals

est5=estimate(mdl1,ret(:,5),'Display','off');
resid(:,5)= infer(est1,ret(:,5));% % obtain the standardized residuals

for i=2:5
   data=resid(:,[1,i]);
   dccP=1;%set the param.#
   dccQ=1;
   archP=1;
   garchQ=1;
   % use DCC-GARCH matlab package from Kevin Sheppard
```

2018S.-T. Yau High School Science Award

```
  [d_parameters,d_loglikelihood,d_Ht,d_Qt,d_stdresid,d_likelihoods,d_stderrors,d_A,d_B,d_jointscores]...
     =dcc_mvgarch(data,dccP,dccQ,archP,garchQ);
   % d_Ht is the conditional covariance matrix, d_paramters is the estimation of the DCC-GARCH model

  %%% compute correlation
  for t=1:102
     Qstar=zeros(2,2);
     Qstar(1,1)=sqrt(d_Qt(1,1,t));
     Qstar(2,2)=sqrt(d_Qt(2,2,t));
     Rt=inv(Qstar)*d_Qt(:,:,t)*inv(Qstar);
     d_corr(t,i-1)=Rt(1,2);
  end

  %%% hedge results
  for t=1:102
     OHR(t,i-1)=d_Ht(1,2,t)/d_Ht(2,2,t); % optimal hedge ratio
     delta=OHR(t,i-1);
     Var_p=d_Ht(1,1,t)+delta^2*d_Ht(2,2,t)-2*delta*d_Ht(1,2,t);
     HE(t,i-1)=(d_Ht(1,1,t)-Var_p)/d_Ht(1,1,t); % hedging effectiveness
  end
end

figure(2),
plot(d_corr);
set(gca,'xtick',1:9:length(date));
set(gca,'xticklabel',date(1:9:length(date),:));
legend({'COS—COF','COS—WOF','COS—BOF','COS—CEI'});
grid on

figure(3),
plot(OHR);
set(gca,'xtick',1:9:length(date));
set(gca,'xticklabel',date(1:9:length(date),:));
legend({'COS—COF','COS—WOF','COS—BOF','COS—CEI'});
grid on
```

2018S.-T. Yau High School Science Award

```
figure(4),
plot(HE);
set(gca,'xtick',1:9:length(date));
set(gca,'xticklabel',date(1:9:length(date),:));
legend({'COS—COF','COS—WOF','COS—BOF','COS—CEI'});
grid on
```

2018S. -T. Yau High School Science Award

Acknowledgement

I deeply appreciate Mr. Jie LI, a student of Beihang University for helping me downloading data and giving me helpful comments and suggestions during the writing of the paper.

2018S. -T. Yau High School Science Award