Research on the Relationship between Crude Oil Futures Price and Spot Price

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Abstract: As one of the most prominent energy resources in the world, the futures market of crude oil is playing an important role in the stability of the macro-economy. This paper aims at figuring out the relationships between the crude oil futures price and spot price. The spot and futures prices of WTI crude oil are collected from Jan 2010 to April 2020 on a daily basis, which are used to conduct time series analysis including ADF unit root test, VAR model, Johansen cointegration test, Granger causality test as well as impulse responses analysis. Consequently, both the cointegration equation which represents long-term equilibrium and the error correction model can be derived. Lastly, several suggestions on risk management of crude oil futures market are proposed.

1. Introduction

As an important strategic resource and widely traded commodity, crude oil has long been a political chip which is closely watched by competing countries. Its price fluctuations can be transmitted to other financial markets through various channels on a global scale, which may further affect the stable operation of the macro-economy (Coronado et al., 2016). As a result, a variety of derivatives of crude oil, such as West Texas Intermediate (WTI) and Brent crude oil futures, have emerged over the past decades, aiming to mitigate the price risks of this commodity. Theoretically, crude oil may exhibit periods of relative quiet and also heightened volatility. Due to the detrimental effects that the crude oil futures price volatility may bring about, this paper aims at figuring out the dynamic impacts of crude oil spot prices on its futures prices so as to propose effective suggestions on the risk management of this futures market.

The rest of this paper will be arranged as follows: section 2 is the description of data collection and processing. Next, the theoretical models of time series analysis will be introduced in section 3, then comes to the empirical results. The last part will be some practical advices for risk management of international futures market of crude oil.

2. Data Processing

This paper collected the daily prices for Cushing, OK WTI crude oil and WTI futures from January 2010 to April 30th, 2020, yielding 3767 observations for each time series variable. The spot price series of WTI crude oil is obtained from the official website of the United States Energy Information Administration (EIA) and the futures price is from the website of CME Group. The spot price and futures price are respectively denoted as sp and fp in this paper. Since the American futures market is closed at weekends and legal festivals, this paper makes a smoothing interpolation as follows according to the prices of the two days before and after the blank:

$$n_j = \frac{1}{2}(n_{j-1} + n_{j+1}) \tag{1}$$

In this equation, n_j is the missing price due to special dates. This can be achieved through the interpolation function of EViews. Next, we take the natural logarithm for these two variables, yielding $\ln sp$ and $\ln fp$ series. The descriptive statistics of them are shown in Table 1.

Table 1. Descriptive statistics of $\ln sp$ and $\ln fp$

	$\ln sp$	$\ln fp$
Observations	3767	3767
Mean	4.213882	4.212249
Median	4.233527	4.240175
Maximum	4.735584	4.733827
Minimum	2.303585	2.052841
Std. Dev.	0.345393	0.353238
Skewness	-0.657977	-0.943978
Kurtosis	3.503099	5.595352
Jarque-Bera	311.5381	1616.707

It is obvious that both variables are left-skewed and leptokurtic distributed, the null hypothesis of series normality is also rejected by the J-B statistics. However, the variation extents of these two series are very close to each other, and Figure 1. can prove the substantial co-movement relationship.

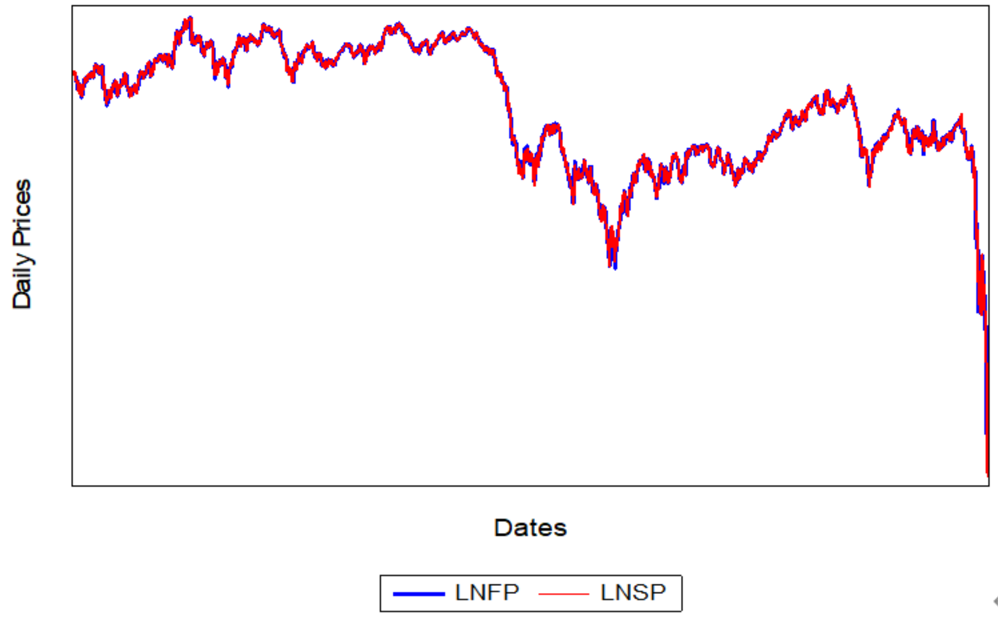

Figure 1. The spot price and futures price of WTI crude oil, Jan 2010-April, 2020

3. Methodology

The main purpose of this chapter is to research the impacts of WTI crude oil price to the WTI futures price through the time series analysis. The basic process is as **Figure 2**.

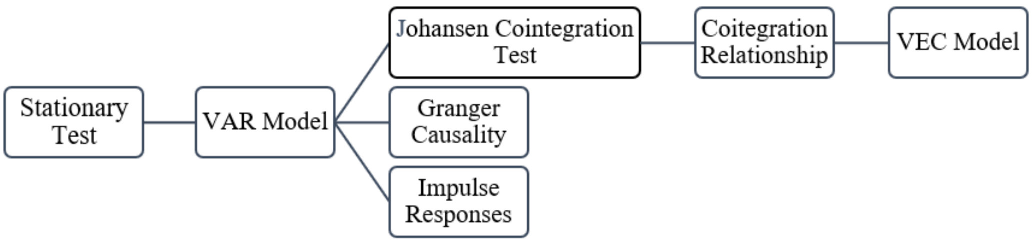

Figure 2. The framework map of the empirical research

3.1 Augmented Dicky-Fuller Unit Root Test

The sample mean, variance and covariance of a stationary time series should be time-invariant so that there are no unit roots for them. This is the prerequisite for the subsequent analysis. According to figure 1, the expression form of ADF test in this study should contain both the intercept term and trend as equation (1):

$$\Delta y_t = \beta y_{t-1} + \mu_t \sum_{i=1}^{p-1} \alpha_i \Delta y_{t-i} + \varepsilon_t + \delta,\ t = 1,2,\ldots,T \quad (2)$$

In the equation above, ε_t represents the intercept and δ is the trend term. The hypothesis of ADF test should be:

$$\begin{cases} H_0: \beta = 0 \\ H_1: \beta < 0 \end{cases} \quad (3)$$

3.2 VAR Model

The VAR model is generally applied in correlated time series and is constructed to analyze the dynamic influences of the random disturbance of WTI crude oil series to the whole variable system in this paper. Furthermore, it is the necessary step prior to the Johansen cointegration test and the Granger causality test. According to Johansen (1988) and Juselius (1990), the general expression of VAR(p) model is:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + BX_t + \varepsilon_t \quad (4)$$

y_t in this equation represents the endogenous vector variable of length m, X_t is the exogenous vector variable of length d, p is the lagged rank, the metric A_1 to A_p of (k × k) and the matrix B of (k × d) are the coefficient matrix to be estimated, ε_t is the random error term. Applying this general expression to our bivariate VAR (2) model, the specific equation should be:

$$\begin{pmatrix} \ln sp_t \\ \ln fp_t \end{pmatrix} = A_1 \begin{pmatrix} \ln sp_{t-1} \\ \ln fp_{t-1} \end{pmatrix} + \cdots + A_p \begin{pmatrix} \ln sp_{t-p} \\ \ln fp_{t-p} \end{pmatrix} + \varepsilon_t \quad (5)$$

3.3 Cointegration Test and Granger Causality Test

Johansen cointegration test aims at examining whether several time series variables with the same difference levels can construct a stationary linear combination in the long run. It can effectively avoid false regression. While the existence of the cointegrating relationships between variables can indicate the long-term equilibrium, Granger causality test is used to determine the endogenous and exogenous variables so that the order in which variables interact with each other is clear.

3.4 Vector Error Correction Model

While the cointegration test can determine the long-run stable relationship between WTI oil price and the WTI futures price, Granger causality test can figure out the order of the interrelation between these two variables, ECM serves as a supplement to the description of the long-term equilibrium relationship and captures the short-term non-equilibrium relationship. By this means, the deviation of variables from their long-term equilibrium relationship in the short-term fluctuations can be measured. The form of ECM is actually a two-step regression:

$$\ln fp_t = \alpha_0 + \alpha_1 \ln sp_t + \mu_t \quad (6)$$

$$\Delta \ln fp_t = \beta_0 + \sum_{i=1}^{p-1} \beta_i \Delta \ln sp_{t-i} + \varphi ecm_{t-1} + \mu_t \quad (7)$$

In the equation above, ecm_{t-1} is the short-term error correction term whose coefficient φ can reflect the speed at which the short-run fluctuation is being adjusted to the equilibrium condition. β_i represents the short-term influence of the short-term changes in the spot prices to the WTI futures price.

4. Empirical Results

Firstly, the stationary test result is shown in Table 2.

Table 2. The results of ADF unit root test

Variable	ADF stat.	P-value	Conclusion
$\ln sp$	-1.407125	0.1487	Non-stationary
$\ln fp$	-0.875770	0.3367	Non-stationary

$\Delta \ln sp$	-52.57531***	0.0001	stationary
$\Delta \ln fp$	-16.35774***	0.0000	stationary

*** represents that the null hypothesis of ADF test can be rejected under the 1% significance level.

Therefore, both $\ln sp$ series and $\ln fp$ series are not stationary and are integrated of order 1, as known as I (1). Based on this result, this paper next examines the existence of the cointegration relationship between these two variables by constructing the VAR model first. The optimal lag order for this model is tested to be 2 in terms of the AIC rule. The VAR (2) model constructed is as follows:

Equation 1:

$$\ln fp = 0.9010\, ln\, fp\,(-1) + 0.1199\, ln\, fp\,(-2) + 0.2145\, ln\, sp\,(-1) - 0.2362\, ln\, sp\,(-2) + 0.0031 \quad (8)$$

(0.02942) (0.03337) (0.03476) (0.03476) (0.00396)
[30.6283] [6.42868] [-6.79619] [-6.79619] [0.79390]
R-squared=0.996851 Adj. R-squared=0.996847 F-statistics=297384.7

Equation 2:

$$\ln sp = -0.0496\, ln\, fp\,(-1) + 0.0761\, ln\, fp\,(-2) + 1.1026\, ln\, sp\,(-1) - 0.1286\, ln\, sp\,(-2) - 0.0029 \quad (9)$$

(0.02942) (0.03337) (0.03476) (0.03476) (0.00396)
[30.6283] [6.42868] [-6.79619] [-6.79619] [0.79390]
R-squared= 0.997526 Adj. R-squared= 0.997523 F-statistics= 378820.3

The first line below the equations are the standard deviations of coefficients, on the other hand, the T-statistics of each coefficient lies in the second line.

In the first equation, it can be concluded that both the futures prices of the last two periods and the spot prices of the last two periods have significant effects on today's futures price. While the future price of last period and the spot prices of the last period have similar influences on the current futures price, yesterday's WTI futures price exerts the greatest impact. On the other hand, the spot price of the previous two period has a significantly negative impact on the current futures price, which means today's futures price of WTI crude oil may decline by 23.62% when the spot price two days ago increased by 1%. Similarly, every lag terms of these variables are significant under 1% significance level. Since this VAR (2) is checked to be stationary since all the AR roots are fall in the unit circle, we can now conduct the Johansen cointegration test. The result is demonstrated in Table 3:

Table 3. Johansen cointegrating test results for $ln\, sp$ and $ln\, fp$

No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.004597	17.60571	15.49471	0.0237
At most 1	7.35E-05	0.276405	3.841466	0.5991

* denotes rejection of the hypothesis at the 0.05 level

According to the results in Table 3, the null hypothesis that there is no cointegration relationships between the spot price and the future price of WTI crude oil is rejected under the significance level of 5%, which means there is one cointegrating equation at least. Therefore, there is a long-term equilibrium equation between the futures and spot prices of WTI crude oil. The positive relationship also consistent with the previous case analysis.

However, the concrete direction of the causality is still not revealed, say, which variable causes influences on the other firstly. Since both $\ln sp$ series and $\ln fp$ series are not stationary and are integrated of order 1, their Granger causality should be tested at the first order difference form.

Table 4. The result of Granger causality test

Null Hypothesis:	Lag length	F-Statistic	Prob.	Result
$\Delta \ln sp$ does not Granger Cause $\Delta \ln fp$	1	42.0651	1.E-10	Reject
$\Delta \ln fp$ does not Granger Cause $\Delta \ln sp$	1	4.15462	0.0416	Reject
$\Delta \ln sp$ does not Granger Cause $\Delta \ln fp$	2	66.2784	5.E-29	Reject
$\Delta \ln fp$ does not Granger Cause $\Delta \ln sp$	2	5.5964	0.0037	Reject

According to the result in Table 4, the spot price and futures price of WTI crude oil are Inter-Granger causality at the significance level of 5% when including 1 lag and at the significance level of 1% when including 2 lags.

Up to now, we are able to build a VECM to describe the short-term fluctuation relationship between the spot and futures price of WTI crude oil since they are cointegrated. Firstly, the long-run equilibrium cointegration equation is obtained through OLS regression of $\ln fp$ on $\ln sp$, the result is shown as Table 5:

Table 5. The result of cointegration regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$\ln sp$	0.974052	0.001392	699.7020	0.0000
α_0	0.110931	0.005884	18.85165	0.0000
R-squared	0.992368	Mean dependent var		4.213882
Adjusted R-squared	0.992366	S.D. dependent var		0.345393
F-statistic	489582.9	Durbin-Watson stat		0.134747
Prob(F-statistic)	0.000000			

Therefore, the cointegration equation of the spot price and futures price would be:

$$\ln fp = 0.1109 + 0.9741 \ln sp$$

According to the F-statistics and t-statistics, this cointegration equation is robust and the coefficient is highly significant. Next, by conducting the Wald test on the coefficient of $\ln sp$, the null hypothesis being $H_0: \alpha_1 = 1$, the p-value is 0.672 > 0.05. Therefore, logarithm price difference between WTI crude oil spot and futures is estimated to be 0.1109 on average in the long run. In addition, the price ratio of the spot and futures fp/sp =1.1173. It can be concluded that, the development trend between the price of WTI crude oil and WTI futures is almost completely synchronous.

Next step is to extract the residual series of equation (6) as the correction term of short-term fluctuations, and add it into the dynamic regression equation (8). The VECM result is as:

Equation 3:

$$\Delta\ln fp_t = -0.0003 - 0.3069\,\Delta\ln fp_{t-1} - 0.0275\,\Delta\ln fp_{t-2} + 0.4096\,\Delta\ln sp_{t-1} + 0.0801\,\Delta\ln sp_{t-2} - 0.0024 ecm_{t-1} \quad (10)$$

Equation 4:

$$\Delta\ln fp_t = -0.0004 - 0.1061\,\Delta\ln fp_{t-1} + 0.0162\,\Delta\ln fp_{t-2} + 0.4096\,\Delta\ln sp_{t-1} + 0.1546\,\Delta\ln sp_{t-1} + 0.0237\,\Delta\ln sp_{t-2}\, 0.0199 ecm_{t-1} \quad (11)$$

According to equation 3, the coefficient of ecm_{t-1} is negative, which means the current futures price would be adjusted to be higher if the futures price in the last period is lower than the equilibrium price ($ecm_{t-1} < 0$). Similarly, when the futures price of the last period is higher than the equilibrium price ($ecm_{t-1} > 0$), the current futures price should be corrected to be lower. In addition, although both futures price and spot price can affect the current WTI price, the influence of the spot price seems to be stronger and more significant.

Lastly, to visualize the magnitude of the inter-influence, this paper applies the impulse response analysis. The result is shown as Figure 3**.** While the vertical axis stands for the impulse extent, the horizontal axis stands for the lag periods from 1 to 10. The solid lines in the figure are the function value of impulse responses, and the dotted lines are the confidence interval band of function value plus minus twice the standard deviation.

Therefore, both the spot prices and futures prices of WTI crude oil have impacts on the current futures price while that of the futures prices are stronger. This is consistent with the conclusion of VECM and the influence tends to increase over time. On the contrary, neither previous spot prices or the previous futures prices have significant impacts on the current WTI spot price. The response of the spot price is the most sensitive when the lag period is 2, after which it is less and less possibly affected by the WTI prices.

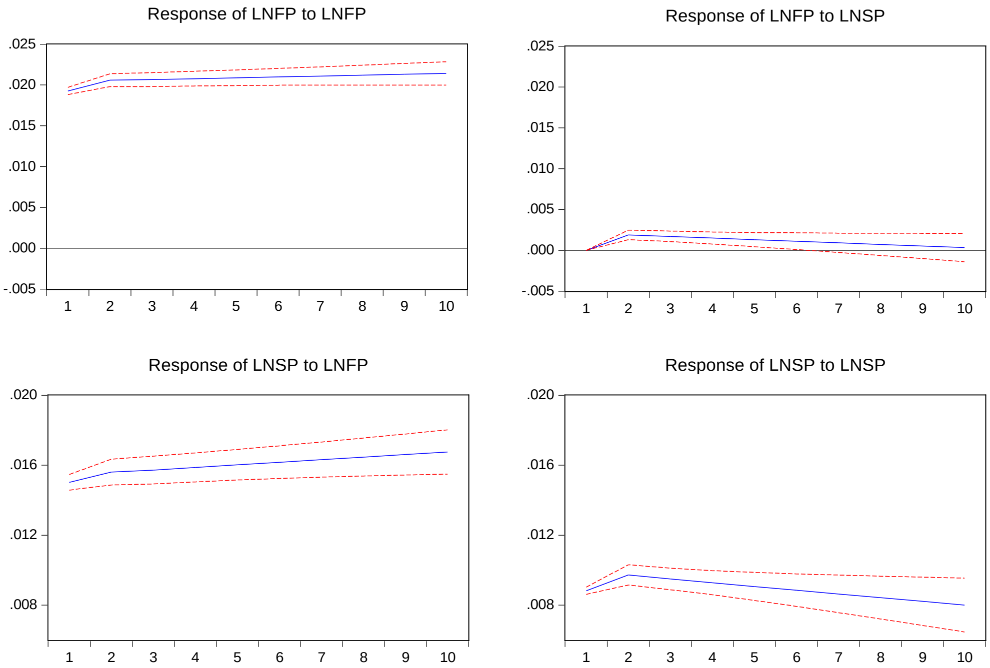

Figure 3. Impulse responses result

5. Suggestions on Better Risk Management

(1) For futures exchange

Firstly, the exchange should set more reasonable limits of price fluctuation according to the characteristics of crude oil price fluctuation. Too high limits will lead to excessive speculation, which will make the futures price soar in a trading day; on the contrary, too low limits will inhibit the price fluctuation, which will lead to the market operation is not smooth. Secondly, it can set up more scientific trading margin ratio, such as floating margin system so it can directly compensate for the market price risk.

(2) For futures companies

First of all, futures companies can update their risk identification system and pay more attention to the potential risks of customers. With the development of electronics and technology, increasing risk identification models can be widely used in risk judgment. Secondly, futures companies can set up special risk control departments to strengthen the risk management of business headquarters and branches, which will further guarantee the security of their futures products.

(3) For investors

As one of the participants in the futures market, investors should first fully understand the characteristics and connections of domestic and foreign oil futures markets. Secondly, selecting reliable futures companies and managers will greatly reduce the risk of loss. Based on this condition, they should then comprehensively apply the methods of fundamental analysis and technical analysis to judge the changing trend of futures market more accurately.

6. Conclusion

In conclusion, this paper conducts an empirical analysis of the interrelationship between WTI spot price and the futures price. According to the results of the VAR model, Johansen test, Granger causality test, VEC model and the impulse responses, it can be concluded that the spot price and futures price of WTI crude oil are inter-Granger causality and are cointegrated in the long run. The long-term equilibrium relationship and short-term shocks can be reflected in VAR and VECM respectively. Lastly, this paper comes up with some suggestions on the better risk management of the futures market from three perspectives, which are for exchanges, futures companies and investors.

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