

The Spillover Effects of WTI Crude Oil and The Stock Markets of China and The United States

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Abstract. Fluctuations in crude oil prices can affect China's national economy through the transmission of market information. Based on this background, this paper selects the relevant index data of WTI crude oil and the stock markets of China and the United States from January 5, 1993 to April 30, 2024 as the research objects, and constructs the VAR-BEKK-GARCH model, the DY spillover index, and the VAR for Var model to study the volatility spillover and extreme risk spillover between crude oil and the stock markets. The results show that the volatility spillover between WTI crude oil and the stock markets of China and the United States indicates that there is no volatility spillover effect between WTI and the Chinese stock market; when the Chinese stock market rises or falls sharply, it has tail risk spillover effects on the crude oil market, and the risk spillover effect between the crude oil market and the US stock market is asymmetric, with risk spillover typically occurring in the upper quantile rather than the lower quantile. Then, the full sample is divided into two sub-samples based on the 2008 financial crisis as the boundary for research. It is found that the risk spillover effect between WTI crude oil and the stock markets of China and the United States after the crisis is stronger than that before the crisis, which is helpful for investors and relevant practitioners to understand the relationship between the two markets, avoid risks, and promote the healthy and stable development of China's financial market.

Keywords: WTI crude oil; Volatility spillover effect; Tail risk spillover effect.

1. Introduction

Crude oil, as a scarce and non-renewable resource, plays the role of a basic production factor and an important chemical raw material in various industrial systems of countries, and it has an increasingly significant impact on the economic, political and social development of nations. Affected by global economic and international geopolitical factors, international crude oil prices have fluctuated violently and frequently over the past decade. China became the world's largest crude oil importer in 2017, with an external dependence rate exceeding 67%. This has led to significant impacts on crude oil-related products and their downstream industries, as well as the entire national economy when international crude oil prices fluctuate.

With the launch of crude oil futures and related derivatives, the financial characteristics of crude oil have become increasingly prominent, increasing the impact of crude oil price fluctuations on the macroeconomy. The stock market is an economic barometer, and changes in stock prices reflect the direction of economic predictions made by market participants. Oil price fluctuations cause changes in the costs of enterprises relying on crude oil resources, thereby affecting the performance of these enterprises and leading to changes in stock prices that affect the stock market. Especially in March 2018, the listing of Shanghai crude oil futures made efforts to enhance China's pricing power in the international crude oil market, and also made the information transmission between the international crude oil market and China's stock market more complex. Under this background, this paper studies the spillover effect of crude oil price fluctuations on the stock markets of China and the United States based on the transmission theory mechanism between the international crude oil market and the stock market.

2. Literature References

Nowadays, crude oil has become the largest and most traded commodity globally, and its price fluctuations can have a spillover effect on the stock market through information transmission between markets. Since 2008, under the influence of the global financial crisis and the Sino-US trade war, the interconnection between the crude oil market and the stock markets of China and the United States has been increasing. In early 2020, with the outbreak of the COVID-19 pandemic, the four times of stock market crashes in the US and the negative settlement price of crude oil futures have made the spillover of price fluctuations from crude oil to the stock market and the risk spillover more complex. Therefore, it is of practical significance to explore the spillover effect between the crude oil market and the stock market.

For the stock market and the international crude oil market, the information transmission between different markets can be better reflected from the perspective of spillover effects. In previous studies, scholars mainly empirically explored the spillover effects between the crude oil market and the stock market from the angles of mean spillover, volatility spillover, and extreme risk spillover. Mollick and Sakaki (2019)^[1] conducted an empirical study based on the shock transmission and mean-variance model on the impact of 14 major currencies/dollar-related data from 1999 to 2017 on national oil and world asset returns. Jiang and Ye (2022)^[2] studied the relationship between the crude oil market and the stock markets of BRICS countries based on the asymmetric generalized autoregressive fractional time-varying mixed model. Wen (2020)^[3] analyzed the data of crude oil prices and exchange rates of 7 major oil-exporting and oil-importing countries from 2000 to 2018 using the VAR for VaR method, and empirically concluded that there were upward and downward risk spillover effects. The impact of exchange rates on the risk spillover effect of crude oil is greater than that of crude oil on the exchange rate market.

Whether there are spillover effects between the international crude oil market and the stock market varies depending on the research markets and research methods. Le and Luong (2022)^[4] based on the TVP-VAR model empirically studied the data of the United States and Vietnam from 2010 to 2020 and concluded that the investor sentiment in Vietnam was the main transmitter of the shock, while oil prices and the stock market were the recipients. Chen et al. (2022)^[5] concluded that during the bear market, the uncertainty fluctuations of the crude oil market increased, and there was a significant risk spillover effect on the uncertainty fluctuations of the Chinese stock market. Xiao and Wang (2020)^[6] empirically concluded that there is a nonlinear two-way causal relationship between the stock market and the international crude oil market. Yang et al. (2017)^[7] observed that there is a negative correlation between crude oil price returns and the exchange rate of oil-importing countries, while the relationship with oil-importing countries is uncertain. Pershin(2016)^[8] used the VAR model for daily data of nominal interest rates, crude oil prices, and short-term interbank interest rates from 2003 to 2014, and concluded that the exchange rate behaviors of the three selected countries were different under the oil price shock.

Du and He (2015)^[9] studied the extreme risk spillover effect between the crude oil market and the stock market, indicating that there is a significant extreme risk spillover effect between the two markets. Before the financial crisis, the stock market had a positive risk spillover effect on the crude oil market, while the crude oil market had a negative risk spillover effect on the stock market. After the financial crisis, the two-way positive risk spillover effect significantly increased. Liu (2020)^[10] used the implied volatility index published by the Chicago Board Options Exchange to study the dynamic correlation and risk transmission between the oil market and the US stock market. The results showed that during the global financial crisis, the correlation between the oil market and the stock market significantly increased, and there was a significant two-way implied volatility spillover effect between the oil market and the stock market. Zhu (2021)^[11] concluded that during the COVID-19 period, the risk spillover effect of the crude oil market was stronger than in normal times, and the US and Chinese stock markets had significant risk spillover effects on the crude oil market.

Many researchers have obtained more specific research results by subdividing the risk spillover effects of the extreme risks on the stock market and the crude oil market. Tian et al. (2022) ^[12] conducted a study on the upward and downward risk spillover effects of the crude oil market on the stock market. Through their comparison, they found that the upward and downward risk spillover effects for the United States and Mexico were the smallest, and the downward risk spillover effect was greater than the upward risk spillover effect. Wen (2019) ^[13] analyzed the data from 2000 to 2018 and concluded that there is asymmetric risk spillover in the upward risk situation, but it is not significant in the downward risk situation. Shahzad et al. (2018) ^[14] found that the oil market has asymmetric upward and downward risk spillover effects on the Islamic stock market. Zhang and Ma (2019) ^[15] studied the data between WTI and the stock markets of the United States, the United Kingdom, Japan, and the global market. They concluded that the one-way downward risk spillover effect between WTI and the four stock markets only exists during major events, and it shows a jumping change, but the two-way downward risk spillover effect between the two markets is significant throughout the sample period, that is, the risk spillover effect is significant.

By summarizing and analyzing the existing literature, the following conclusions can be drawn regarding the information transmission effect between the international crude oil market and the stock market:

First, in terms of the methods for studying the information transmission effect between the two markets, many scholars use VAR models and GARCH-type models to study the spillover effects between the crude oil market and the stock market.

Second, in the research on the spillover effect between the international crude oil market and the stock market, most existing literature mainly studies the mean and volatility spillover effects or risk spillover effects between the two markets, while fewer literatures comprehensively study the volatility spillover and risk spillover effects.

3. Data

3.1. Sample selection

This paper studies the spillover effect between the international crude oil market and the stock market. The spot price of WTI crude oil is selected as the indicator to measure the crude oil market. WTI crude oil is the largest scale of crude oil spot trading product and holds a significant position in the trading market. The data is sourced from the website of the U.S. Energy Information Administration. This paper selects the Shanghai Composite Index as the proxy for the Chinese stock market, and selects the highly accurate and continuous SP500 Index as the proxy variable for the U.S. stock market. The stock market index data are all sourced from <https://cn.investing.com/>.

The sample period selected in this paper is from January 5, 1993 to April 30, 2024, and the daily data of the sample is matched by date. Eventually, 7,350 sets of sample values are obtained. To maintain data consistency, this paper converts the Shanghai Composite Index data into U.S. dollar terms using the benchmark exchange rate of RMB to USD (derived from the daily data on Prof. Werner Antweiler's personal website) to eliminate the influence of exchange rates. Additionally, considering the comparability of the sample data, this paper conducts logarithmic difference on the spot price of WTI crude oil, the Shanghai Composite Index, and the SP 500 Index to obtain the logarithmic return series of the above data. The formula for the logarithmic return is as follows

$$R_t = \ln(P_t/P_{t-1}) \quad (1)$$

Among them, R_t represents the return rate of the relevant indicators of the international crude oil market or stock market on the t -th day, while P_t and P_{t-1} respectively represent the prices of the relevant indicators of the international crude oil market or stock market at the t -th and $(t-1)$ -th

moments. In the following text, WTI, SZSS and SP500 are used to represent the logarithmic return rate of WTI crude oil spot, the logarithmic return rate of Shanghai Composite Index and the logarithmic return rate of Standard & Poor's 500 Index respectively.

3.2. Descriptive test

A descriptive statistical analysis was conducted on the sequence data that had undergone logarithmic difference transformation, as shown in the following table:

Table 1. Descriptive Statistical Analysis

	Mean	Max	Min	Standard Deviation	Skewness	Kurtosis
WTI	0.00020	0.4258	-0.7203	0.0287	-1.8031	76.5663
SZZS	0.00015	0.2948	-0.3952	0.0203	-0.1389	42.2869
SP500	0.00033	0.1096	-0.1378	0.0120	-0.5041	15.2215

Note: WTI, SZSS and SP500 represent the logarithmic return rate of WTI, the logarithmic return rate of Shanghai Composite Index, and the logarithmic return rate of S&P 500 Index respectively. ***, ** and * represent significance at 1%, 5% and 10% levels respectively. The following tables all follow this setting and will not be elaborated further.

According to Table 1, the means of WTI, SZSS and SP500 are all positive and close to 0, being 0.00020, 0.00015 and 0.00033 respectively; from the standard deviation perspective, the one with the smallest standard deviation is SP500. Considering the two descriptive statistical values of skewness and kurtosis, the skewness of all sequences is negative, indicating a left-skewed distribution; the kurtosis values of the four sequences are all greater than 3, suggesting that the related sequences of the international crude oil market and the stock market have a sharp peak characteristic, presenting a distinct "sharp peak, thick tail" image feature.

The regression analysis of time series is conducted under the assumption that it is in a stationary state. This assumption provides us with an important theoretical basis. The results of the stationarity tests for each time series are shown in the following table:

Table 2. Stationarity Tests

	WTI	SZZS	SP500
ADF	-21.216***	-58.757***	-92.136***
PP	-91.504***	-86.861***	-92.617***
KPSS	0.0366	0.0483	0.0945

From the Table 2, it can be seen that the ADF and PP stationarity tests on the three-time series (WTI, SZSS, and SP500) have shown that at the 1% significance level, the hypothesis that all sequences have a unit root has been rejected, because their critical values at the 1% significance level are all greater than their t-values. In the KPSS stationarity test, these four-time series cannot reject the initial assumption that they are stable under any circumstances.

By comprehensively analyzing the results of the three stationarity tests, it can be concluded that the three-time series (WTI, SZSS, and SP500) all exhibit a stable trend, so these data can be used to construct relevant models for regression analysis.

Correlation tests were conducted on the WTI, SZSS and SP500 data, and the results are as follows:

Table 3. Correlation Test

	WTI	SZZS	SP500
WTI	1.0000		
SP500	0.0440	1.0000	
SZZS	0.1729	0.0511	1.0000

From the Table 3, it can be seen that there is a moderate positive correlation between WTI crude oil and the Shanghai Composite Index and the S&P 500 Index. There is no multicollinearity, and a relevant model can be constructed for further analysis.

4. Empirical analysis

4.1. VAR-BEKK-GARCH model

The above statistical tests laid the foundation for constructing the GARCH model. Next, a VAR-BEKK-GARCH model was used for the analysis, and the results are as follows:

Table 4. Results of VAR-BEKK-GARCH among markets

	WTI-SZZS	WTI-SP500
A(1,1)	0.2750***	0.2758***
	(28.4841)	(27.157)
A(1,2)	-0.0013	-0.0086*
	(-0.2916)	(-1.9290)
A(2,1)	0.0034	-0.0771***
	(0.4984)	(-2.9883)
A(2,2)	0.2890***	0.2983***
	(26.2311)	(28.2942)
B(1,1)	0.9519***	0.9554***
	(273.6026)	(270.2633)
B(1,2)	-0.0002	0.0037***
	(-0.1567)	(2.604)
B(2,1)	0.0012	0.0211**
	(0.6105)	(2.4015)
B(2,2)	0.9595***	0.9492***
	(334.61)	(284.5934)
Wald	1.0034	4.5866***
Wald12	0.3423	3.4533**
Wald21	1.7689	4.6708***

In the Table 4, the data in the brackets are t-statistics. The test hypothesis of the Wald statistic is $A(1,2) = A(2,1) = B(1,2) = B(2,1) = 0$, which means there is no volatility spillover effect between the two markets under study. The test hypothesis of the Wald12 statistic is $A(1,2) = B(1,2) = 0$, indicating that there is no volatility spillover effect from market 1 to market 2. The test hypothesis of the Wald21 statistic is $A(2,1) = B(2,1) = 0$, meaning there is no volatility spillover effect from market 2 to market 1.

In terms of volatility spillover, as can be seen from Table 4, all the A(1,1), A(2,2), B(1,1), and B(2,2) in the models are significantly positive, reflecting the long memory and clustering of volatility. For WTI-SZZS, it can be seen that A(1,2), A(2,1), B(1,2), and B(2,1) are not significant, indicating that there is no volatility spillover effect between WTI crude oil and the Chinese stock market. Combining the Wald test results, it can also be concluded that there is no volatility spillover effect between the

two markets. For WTI-SP500, it can be seen that B(1,2) and A(2,1) are significant at the 1% significance level, while A(1,2) and B(2,1) are significant at the 10% significance level. A(2,1), B(2,1), and Wald21 are significant, meaning that the US stock market has a volatility spillover effect on the WTI crude oil market; A(1,2), B(1,2), and Wald12 are also significant, indicating that the WTI crude oil market also has a volatility spillover effect on the US stock market.

In conclusion, there is no volatility spillover effect between WTI and the Chinese stock market; while there is a two-way volatility spillover effect between WTI crude oil and the US stock market.

4.2. Robustness test - DY spillover test

Next, the DY overflow index is used to conduct a robustness test for the spillover of WTI and the stock markets of China and the United States.

In the Table 5, FROM represents the inflow index, which indicates the level of spillover of crude oil or the stock market to other variables; TO represents the outflow index, which indicates the level of spillover of crude oil or the stock market to other variables.

Table 5. Static Analysis of Spillover in the WTI Crude Oil Market and the Stock Markets of China and the United States

	WTI	SZZS	SP500	From others
WTI	96.86	0.23	2.91	3.14
SZZS	0.28	98.60	1.12	1.40
SP500	2.96	0.35	96.69	3.31
To others	3.24	0.58	4.02	7.84
Including own	100.10	99.19	100.72	TCI
net	0.10	-0.81	0.72	7.85/300.01=2.62%

According to the static analysis of the spillover effect in Table 5. we can see the following: Firstly, from the overall perspective of the crude oil market and the stock market variables, the total spillover index in this static period is 2.62%. The spillover effect of the WTI crude oil market on the crude oil market is 96.86%, indicating that 96.86% of the fluctuations in the crude oil market are caused by the spillover of its own fluctuations. Ignoring the influence of crude oil on itself, the total spillover received by other markets from the crude oil market is 3.24%, while the spillover index of the crude oil market on other markets is 3.14%. That is to say, both the spillover index of the crude oil market on other markets and the spillover index of other markets on the crude oil market are relatively high, which is in line with the characteristic of the strong volatility of the crude oil market itself.

Secondly, when analyzing the spillover index of the WTI crude oil market and the stock markets of China and the United States, by comparing the spillover index between WTI and SZZS, SP500, it can be found that the spillover effect of WTI on the US stock market is greater than that of WTI on the fluctuations of Chinese stocks; the spillover index of WTI affected by the US stock market is also greater than the spillover influence of Chinese stock market on WTI. This is consistent with the conclusion drawn from the VAR-BEKK-GARCH model in the previous text.

4.3. Tail risk Spillover

This paper uses the MVQM-CAViaR(1,1) model to study the risk spillover effect between the international crude oil market and the Chinese and US stock markets. The main research focuses on the VaR at the quantiles of 0.05, 0.1, 0.9, and 0.95. The first two quantile levels (i.e., 0.05 and 0.1) and the latter two (i.e., 0.9 and 0.95) respectively represent the downside risk and the upside risk.

Table 6. Estimation Results of WTI Crude Oil and SZSZ Full Sample MVQM-CAViaR(1,1)

	0.05	0.1	0.9	0.95
c1	-0.0005***	-0.0004***	0.0005***	0.0007***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
a11	0.0430***	0.0382***	-0.0478***	-0.0704***
	(0.0025)	(0.0025)	(0.0013)	(0.0023)
a12	0.0162***	0.0145***	-0.0064***	-0.0146***
	(0.0021)	(0.0027)	(0.0017)	(0.0029)
b11	0.9889***	0.9867***	0.9845***	0.9859***
	(0.0019)	(0.0023)	(0.0020)	(0.0019)
b12	-0.0016	-0.0024	-0.0051***	-0.0045***
	(0.0012)	(0.0017)	(0.0014)	(0.0011)
c2	-0.0003***	-0.0001***	0.0001***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
a21	0.0140***	0.0048***	-0.0063***	-0.0099***
	(0.0011)	(0.0007)	(0.0003)	(0.0005)
a22	-0.0148***	-0.0063***	0.0062***	0.0036***
	(0.0012)	(0.001)	(0.0005)	(0.0008)
b21	-0.0052***	-0.0038***	-0.0020***	-0.0023***
	(0.0011)	(0.0009)	(0.0005)	(0.0005)
b22	0.9978***	0.9976***	0.9974***	0.9973***
	(0.0007)	(0.0006)	(0.0005)	(0.0004)

Table 6 presents the estimated results of MVQM-CAViaR(1,1) for WTI crude oil and the Shanghai Composite Index throughout the entire sample period. From this table, it can be seen that the coefficient a11 is significant in all four quantiles, indicating that the growth of current stock returns in China leads to an increase in risk at the 0.05 and 0.1 quantiles, while the growth of stock returns reduces the risk at the 0.9 and 0.95 quantiles. The coefficient a12 is significant and close to 0 in all four quantiles, suggesting that the lagged WTI crude oil return VaR depends on the Shanghai Composite Index. The coefficients b11 and b22 are significant in all four quantiles at the 1% significance level and are close to 1, indicating a strong persistence in the VaRs of WTI crude oil and Chinese stocks. The coefficients b12 and b21 reflect the risk spillover effect between the markets. The coefficient b12 is significant only at the 0.9 and 0.95 quantiles, indicating an upward risk spillover effect of WTI crude oil market risk on the Chinese stock market risk. The coefficients b21 are significant at the 0.05, 0.1, 0.9, and 0.95 quantiles, indicating that a significant increase or decrease in the stock market has a tail risk spillover effect on the crude oil market.

Table 7. Estimation Results of WTI Crude Oil and SP500 Full Sample MVQM-CAViaR(1,1)

	0.05	0.1	0.9	0.95
c1	-0.0005*** (0.0001)	-0.0004*** (0.0000)	0.0003*** (0.0001)	0.0005*** (0.0000)
a11	0.0292*** (0.0022)	0.0245*** (0.0017)	-0.0384*** (0.0022)	-0.0568*** (0.0041)
a12	0.0899*** (0.0042)	0.0813*** (0.0028)	-0.0041 (0.0054)	-0.0566*** (0.0059)
b11	0.9839*** (0.0064)	0.9894*** (0.0030)	0.9788*** (0.0036)	0.9801*** (0.0039)
b12	0.0093 (0.0106)	-0.0019 (0.0053)	-0.0258*** (0.0072)	0.0182** (0.0079)
c2	-0.0003*** (0.0001)	-0.0002*** (0.0000)	0.0003*** (0.0001)	0.0004*** (0.0001)
a21	0.0056*** (0.0017)	0.0019** (0.0009)	0.0002 (0.0018)	0.0006 (0.0026)
a22	0.1441*** (0.0077)	0.0818*** (0.0024)	-0.1480*** (0.0053)	-0.1762*** (0.0060)
b21	0.0146** (0.0067)	0.0015 (0.0020)	0.0158*** (0.0033)	0.0139*** (0.0030)
b22	0.9542*** (0.0105)	0.9812*** (0.0033)	0.9474*** (0.0058)	0.9481*** (0.0059)

Table 7 presents the estimated results of MVQM-CAViaR(1,1) for WTI crude oil and the S&P 500 throughout the entire sample period. From the above table, it can be seen that the coefficient a11 is significant in all four quantiles, indicating that the growth of current US stock returns leads to an increase in risk at the 0.05 and 0.1 quantiles, while the growth of stock returns reduces the risk at the 0.9 and 0.95 quantiles. The coefficient a12 is significant and close to 0 (except at the 0.9 quantile), indicating that the lagged WTI crude oil return VaR depends on the S&P 500. The coefficients b11 and b22 are significant at the 1% significance level in all four quantiles and are close to 1, indicating that there is a strong persistence in the VaRs of WTI crude oil and US stocks. The coefficients b12 and b21 reflect the risk spillover effect between the markets, with coefficient b12 being significant at the 1% level at the 0.9 quantile and at the 5% level at the 0.95 quantile, indicating an upward risk spillover effect from the WTI crude oil market risk to the US stock market risk. Coefficient b21 is also significant at the 0.9 and 0.95 quantiles, indicating an upward risk spillover effect from the US stock market risk to the WTI crude oil market risk.

In summary, the risk spillover effect of WTI crude oil on the stock markets of China and the United States is as follows: (1) In China, a significant tail risk spillover effect occurs when the stock market rises or falls, and the risk of the WTI crude oil market has an upward risk spillover effect on the stock market of China. (2) In the United States, the risk spillover effect between the crude oil market and the stock market is asymmetric, with risk spillover typically occurring in the upper quantiles rather than the lower quantiles. (3) There is a strong persistence in the VaRs of WTI crude oil and US stocks.

4.4. Tail risk test of the sub-sample

The entire sample period will be divided into two sub-samples to study the changes in the risk spillover effect. The global financial crisis that broke out in 2008 had a significant impact on the global economy. Based on this, this paper follows Garcia-Appendini and Montoriol-Garriga(2013)^[16] and divides the period based on 2007 as the starting point. The first sub-sample is from January 1993 to June 2007, and the second sub-sample is from July 2007 to April 2024. This section mainly studies

the risk spillover effect between the two markets, so it mainly focuses on the research of the coefficients b_{12} and b_{21} .

Table 8. Estimation Results of Subsample MVQM-CAViaR(1,1)

	WTI			
	0.05	0.1	0.9	0.95
Subsample 1				
A)SZZS				
b12	-0.0095 (0.0456)	-0.0113 (0.0199)	-0.0078*** (0.0028)	-0.0071** (0.0029)
b21	0.0020 (0.0360)	0.0032 (0.0094)	0.0017 (0.0023)	-0.0008 (0.0027)
B)SP500				
b12	0.0422 (0.0587)	0.0320*** (0.0117)	0.0368*** (0.0091)	-0.0019 (0.0023)
b21	0.0002 (0.0037)	0.0201*** (0.0057)	0.0166*** (0.0037)	0.0130*** (0.0022)
Subsample 2				
A)SZZS				
b12	0.0127 (1.0517)	0.0165*** (0.0036)	0.0259*** (0.0029)	0.0073 (0.0161)
b21	0.3715** (0.1810)	-0.0059*** (0.0009)	-0.0039*** (0.0005)	0.0128*** (0.0045)
B)SP500				
b12	-0.0021 (0.0074)	-0.0058 (0.0039)	0.0118* (0.0062)	0.0332*** (0.0104)
b21	-0.0072*** (0.0021)	-0.0044*** (0.0013)	0.0177*** (0.0038)	0.0247*** (0.0060)

During the first sub-cycle process, the results estimated from the observation samples show that for the Shanghai Composite Index, only b_{12} was significantly negatively influential at the 0.9 and 0.95 quantiles; while during the second sub-cycle process, the significance of the b_{12} and b_{21} coefficients significantly increased at all four quantiles. Regarding the b_{12} coefficient of the S&P 500, it can be known that after the financial crisis, in cycle 2, the upward risk spillover risk was stronger at 0.9 and 0.95 than in the first sub-cycle. At the quantiles of 0.05 and 0.1, it was not significant, thus the spillover effect showed an asymmetric characteristic.

In summary, after the 2008 financial crisis, the risk spillover effect between WTI crude oil and the stock markets of China and the United States was stronger than that before the crisis, and the b_{21} coefficient in all four quantiles was significantly positive after the crisis, indicating that whether it is the Shanghai Composite Index of China or the S&P 500 Index of the United States, a significant increase or decrease will have a tail spillover effect on WTI crude oil.

5. Summary

(1) In terms of volatility spillover, by using the VAR-BEKK-GARCH model to study the volatility spillover between WTI crude oil and the stock markets of China and the United States, it was concluded that there is no volatility spillover effect between WTI and the Chinese stock market; while there is a two-way volatility spillover effect between WTI crude oil and the US stock market. Then, using the DY spillover index to further study the volatility spillover among various markets, comparing the spillover index between WTI and the stock markets of China and the United States, it

can be found that the spillover effect of WTI on the US stock market is greater than that on Chinese stocks; the spillover index of WTI affected by the US stock market is also greater than the spillover effect of the Chinese stock market on WTI. In conclusion, the volatility spillover of WTI and the US stock market is stronger than that of the Chinese stock market.

(2) This paper uses the MVMQ-CAViaR(1,1) model to study the risk spillover effect between the international crude oil market and the stock market. It indicates that in China, a significant tail risk spillover effect exists when the stock market rises or falls, and the risk of WTI crude oil market has an upward risk spillover effect on the Chinese stock market. In the United States, the risk spillover effect between the crude oil market and the stock market is asymmetric, and the risk spillover usually occurs in the upper quantile rather than the lower quantile. Then, the full sample is divided into two sub-samples based on the 2008 financial crisis as the boundary for research. It is found that after the 2008 financial crisis, the risk spillover effect between WTI crude oil and the stock markets of China and the United States is stronger than that before the crisis, and the significant rises and falls of the Shanghai Composite Index and the S&P 500 Index after the crisis will have tail spillover effects on WTI.

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