Measuring the Connectedness among Chinese Equities, US Equities, Strategic Commodities, and US Economic Policy Uncertainty

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Abstract: After the financial crisis, the volatility of the global stock market, strategic commodity market and the economic uncertainty make it of great importance to study on the volatility spillover between different markets to prevent the global financial market risks. This paper draws on the methods of Diebold, Yilmaz and Antonakakisn to obtain the correlation between the US equities, Chinese equities, Emerging markets equities, strategic commodities (gold and crude oil), and the US economic policy uncertainty [1-6]. This article selects the daily implied volatility data in six markets from March 16, 2011 to June 24, 2021 to calculate the static and dynamic volatility spillover index and compare the rolling window method with time-varying parameter method. The results show that the stock market plays a dominant role in the transmission of volatility, and the spillover index between variables is bidirectional and asymmetric. In the sample period, the system fluctuations originate from other variables, and the stock market has a strong pass-through effect. The total overflow indices obtained by the rolling window method and the time-varying parameter method are similar.

1. Introduction

After the financial crisis, as the representative of emerging markets, China curb a gradual increase impact on the world's financial markets. Politics, war, economic and financial events lead to severe turbulence around the world, such as stock market crash, dramatic fluctuations in strategic commodity market and increasing global economic uncertainty. The interactive effect between different markets is gradually enhanced. China has been the second largest oil consumer since 2003. China's dependence on petroleum products makes it more sensitive to the fluctuations of international oil price. With the development of global economic integration, the financial attribute of oil is gradually enhanced. Besides, gold is also an important strategic reserve asset for a country. In the financial market, gold, as a precious metal, is an alternative investment product for investors and has the function of hedging. In addition, as an important part of the financial market portfolio, strategic commodities represented by oil and gold will affect the investment attitude of investors in the global financial market towards relevant industries, and then affect the stock prices of the industry, which will increase the economic uncertainty. In recent years, especially after the Financial Crisis, the economies of Emerging markets are developing rapidly, and the high growth and high volatility of emerging markets equities have attracted the attention of investors. While emerging markets equities absorb information on the returns and volatility of US equities, oil and gold, the volatility of their equities can also have an impact on financial markets. As a representative of Emerging markets, China has a fast economic development, and is a huge oil consumer and gold producer. Therefore, China plays a vital role in the international crude oil and gold markets. As well as affecting other markets and investors, fluctuations in China's stock market serve as an important basis for economic forecasting and decision-making by policymakers in other countries. Thus, there is a potential interaction between crude oil, gold, economic policy uncertainty, Emerging markets, and the US and China equities. Changes in any one market can have an impact on other markets, and there is volatility spillover effect between markets.

Although there is no definite theoretical analysis among strategic commodity market, economic uncertainty and stock market, relevant studies show that there is a certain correlation among the three market indicators. Pastor et al. pointed out that the investment behavior of macro economy and micro individuals plays an intermediary role in the whole market. In the macro economy, the stock market can usually reflect the state of a country's economic development. The changes and uncertainties of a country's economic policies often have an impact on the stock market, especially the stocks of policy-related industries [7]. Arouri et al. believe that when the stock market experienced large fluctuations, policy makers would make corresponding treatments to relevant events, thus increasing the uncertainty of economic policies [8]. Commodity prices fluctuate due to changes in supply and demand relations and the influence of national policies, and changes in commodity prices will lead to production and investment behaviors of enterprises in the supply chain related to the commodity, and then have an impact on the stock price of enterprises [9]. At the individual investment level, the return and risk of stocks are higher, and investors often add crude oil to their portfolios. Gold is considered to have the role of anti-inflation, preventing unknown risks and adding gold assets with a certain weight in the portfolio is helpful to diversify risks and improve the yield [10-12]. Among emerging markets, China is the second largest economy, and there is a mutual risk spillover effect between the Chinese stock market and the US stock market [13]. Antonakakis et al. studied the relationship between the US stock market, implied volatility and economic policy uncertainty, and the results showed that there was a mutual time-varying correlation between the stock market and economic policy uncertainty [14]. Wang Qizhen et al. study the volatility spillover effect among international oil price, US economic uncertainty and Chinese stock market, and the results show that the international oil price explained most of the volatility [15]. Therefore, the uncertainty of economic policy and the stock and commodity markets have mutual interaction. Sarwar studied the relationship between the US VIX and the stock markets of BRIC countries. The results show that the VIX affect the stock market of China as well as that of the US [16]. Maghyereh et al. found that the implied volatility of crude oil has an impact on the stock markets of both developed and developing countries [17]. Yang and Zhou distinguish the different effects of QE on implied volatility of US Treasuries, developed country stock market indices and commodities [18]. Ji et al. use the DCC-GARCH model to study the dynamic network relationship among the US equities, strategic commodities and BRICS equities, and found that the information transmission network is unstable and time-varying, and the impact of emergencies is different [19].

2. Methodology

By referring to the methods of Antonakakisn, Diebold and Yilmaz, this paper calculates the static and time-varying total spillover index, directional spillover index and net spillover index among the stock markets, strategic commodities and economic policy uncertainty. This paper analyzes the fluctuation linkage and the dynamic changes of the spillover effect among the markets.

Consider a covariance stationary N-variable VAR(p): $x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_i$, where $\varepsilon_i \sim idd(0, \sum)$. The moving average representation is $x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}$, A_0 is an N*N identity matrix and $A_i = 0$ for $i < 0$. Denoting the KPPS H-step-ahead forecast error variance decompositions by $\theta_{ij}^{g}(H)$, we have:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_i)} \tag{1}$$

In order to use the information available in the variance decomposition matrix in the calculation of the spillover index, we normalize each entry of the variance decomposition matrix by the row sum as:

$$\tilde{\theta}_{ij}^{g}(H)=\frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N}\theta_{ij}^{g}(H)} \tag{2}$$

Note that, by construction, $\sum_{j=1}^{N}\tilde{\theta}_{ij}^{g}(H)=1$, $\sum_{i,j=1}^{N}\tilde{\theta}_{ij}^{g}(H)=N$. After that we can construct a total volatility spillover index:

$$S^{g}(H)=\frac{\sum_{i,j=1,i\neq j}^{N}\tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N}\tilde{\theta}_{ij}^{g}(H)}\bullet 100=\frac{\sum_{i,j=1,i\neq j}^{N}\tilde{\theta}_{ij}^{g}(H)}{N}\bullet 100 \tag{3}$$

We measure directional volatility spillovers received by market i from all other markets j as:

$$S_{i.}^{g}(H)=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N}\tilde{\theta}_{ij}^{g}(H)}\bullet 100=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ij}^{g}(H)}{N}\bullet 100 \tag{4}$$

In similar fashion we measure directional volatility spillovers transmitted by market i to all other markets j as:

$$S_{.i}^{g}(H)=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N}\tilde{\theta}_{ji}^{g}(H)}\bullet 100=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ji}^{g}(H)}{N}\bullet 100 \tag{5}$$

Finally, we obtain the net volatility spillover from market i to all other markets j as:

$$S_{i}^{g}(H)=S_{.i}^{g}(H)-S_{i.}^{g}(H) \tag{6}$$

It is also of great importance to calculate net pairwise volatility spillovers, which we define as:

$$S_{il}^{g}(H)=\left[\frac{\tilde{\theta}_{li}^{g}(H)}{\sum_{i,k=1}^{N}\tilde{\theta}_{ik}^{g}(H)}-\frac{\tilde{\theta}_{il}^{g}(H)}{\sum_{l,k=1}^{N}\tilde{\theta}_{lk}^{g}(H)}\right]\bullet 100=\left(\frac{\tilde{\theta}_{li}^{g}(H)-\tilde{\theta}_{il}^{g}(H)}{N}\right)\bullet 100 \tag{7}$$

In the system of TVP-VAR, every parameter is time-varying. So we define the model of TVP-VAR(p) as: $x_t=\sum_{i=1}^{p}\Phi_{it}x_{t-i}+\varepsilon_t$. Using the similar method, we can obtain H-step-ahead forecast error variance decompositions:

$$\theta_{ijt}^{g}(H)=\frac{\sigma_{iit}^{-1}\sum_{h=0}^{H-1}(e_i^{'}A_{ht}P_te_j)^2}{\sum_{h=0}^{H-1}(e_i^{'}A_{ht}\sum_t A_{ht}^{'}e_j)} \tag{8}$$

Then we can calculate the directional volatility spillovers and net volatility spillover based on the result of $\theta_{ijt}^{g}(H)$.

3. Empirical analysis

3.1 Data and sample analysis

Daily implied volatility data for Chinese equities, US equities, emerging markets equities, crude oil, gold and index of US economic policy uncertainty from March 16, 2011 to June 24, 2021 are used in this paper. The US economic policy uncertainty index based on newspaper reference by Baker, and the data is from policy uncertainty website (www.policyuncertainty.com). Similar to the US VIX, the

implied volatility indices for Chinese equities, emerging markets equities, oil and gold are derived from the prices of put and call options and represent forward-looking indicators of realized volatility in asset markets over the next 30 days. All of the implied volatility indices takes the first difference of the natural logarithm. The main statistical features of the six volatility indices are presented in Table.1. The skewness of the six variables are all greater than 0, and the kurtosis are all greater than 3. It can be seen that the six variables show non-normal characteristics. The values of JB test also indicate that the six variables do not meet the characteristics of normal distribution. The results of ADF test reject the hypothesis that each variable contains unit root, and each sequence is stationary.

3.2 Static volatility spillovers

In this paper, AIC criterion is used to determine the order of VAR, and the order of VAR is 8 order lagging. Table.2 uses VAR model to estimate the static volatility spillover index proposed by Diebold and Yilmaz. The 6×6 table formed by the 6 variables in the table reflects the size of the spillover effect among each other. Its ij^{th} entry is the estimated contribution to the forecast error variance of market i coming from innovations to market j. The diagonal elements refer to the proportion of contribution that the prediction variance of the variable comes from itself. Hence the off-diagonal column sums (labeled to others) or row sums (labeled contributions from others), are the "to" and "from" directional spillovers, and the "from minus to" differences are the net volatility spillovers. Besides, the total volatility spillover index is in the lower right corner of the spillover table.

Table.1. Summary statistics for volatility indices

	VIX	EM	CHN	OVX	GVZ	EPU
Mean	-0.00024	-0.00024	-0.00020	-0.00011	-6.84E-05	-6.53E-05
Median	-0.00629	-0.00593	-0.00430	-0.00383	-0.00433	-0.00842
Max.	0.768245	0.976168	0.790511	0.857700	0.480734	3.215618
Min.	-0.31414	-1.01357	-0.69191	-0.62225	-0.30692	-3.14833
Std.Dev.	0.079779	0.073543	0.062613	0.059031	0.055177	0.495343
Skewness	1.202397	0.231820	0.826662	1.726403	0.841393	0.097178
Kurtosis	9.791388	38.30953	28.81293	33.72096	8.673453	5.562474
Jarque-Bera	5593***	134362***	72089***	102977***	3773***	712***
ADF	-55.48***	-59.54***	-25.56***	-52.60***	-33.43***	-28.66***

Notes: Std.Dev denotes standard deviations. Jarque-Bera stands for Jarque-Bera test of normality. ***indicates statistical significance at 1% level.

In Table 2, static directional spillovers are all greater than 0, indicating that there are correlations and fluctuation transmission among the six variables. The total spillovers index of 38.7 shows that in the system composed of the six variables, 38.7% of the variance of prediction error comes from the contributions of other variables besides the six variables, indicating that there is a large interaction between the six variables. The forecast variance of EPU is 98.3% from itself, while there is a large volatility spillover effect among US VIX, China VIX and Emerging markets VIX, and the volatility spillover index is 15% to 25%. It can be seen that with the development of world multi-polarization and the increasing attention of foreign investors on Emerging markets equities, especially Chinese equities, the correlation between the US market and the Chinese market is enhanced, and the volatility in either market will have spillover effect on the other. The volatility spillover index of Chinese market to Emerging markets is 19.3%, and the volatility spillover index of Chinese market from Emerging markets is 21.1%. It can be seen that among emerging markets equities, the volatility spillover effect of Chinese equities to other markets is large. The spillover indices of OVX and GVZ to other markets (mainly the stock market) are 25.2% and 26.2% respectively, while the spillover indices from other markets (mainly the stock market) are 34.3% and 35.2% respectively. It can be seen that the financial attribute of crude oil and gold are enhanced, and they are closely related to the stock market. However, the stock market, as a major component of the investment portfolio, still has a greater impact on strategic commodities than the impact of commodities on the stock market. The difference between

the volatility spillover of strategic commodities (gold and crude oil) to other variables and the volatility spillover subject to other variables indicate that the directional spillover index is bidirectional and asymmetric.

Table.2. Static volatility spillover table

	VIX	EM	CHN	OVX	GVZ	EPU	From others
VIX	44.6	23.3	16.7	7.2	7.8	0.4	55.4
EM	22.4	44.7	19.3	6.7	6.6	0.2	55.3
CHN	17.5	21.1	49.4	5.6	6.0	0.3	50.6
OVX	10.6	10.1	7.8	65.8	5.3	0.4	34.2
GVZ	11.1	10.1	8.3	5.2	64.8	0.3	35.2
EPU	0.2	0.3	0.2	0.4	0.5	98.3	1.7
To others	61.9	65.0	52.4	25.2	26.2	1.6	232.3
Net	6.5	9.8	1.9	-9.1	-9.0	-0.1	38.7

3.3 Dynamic total volatility spillovers

There are some limitations in using rolling window to measure the volatility spillover index among variables. So this paper compare rolling window with time-varying parameter.

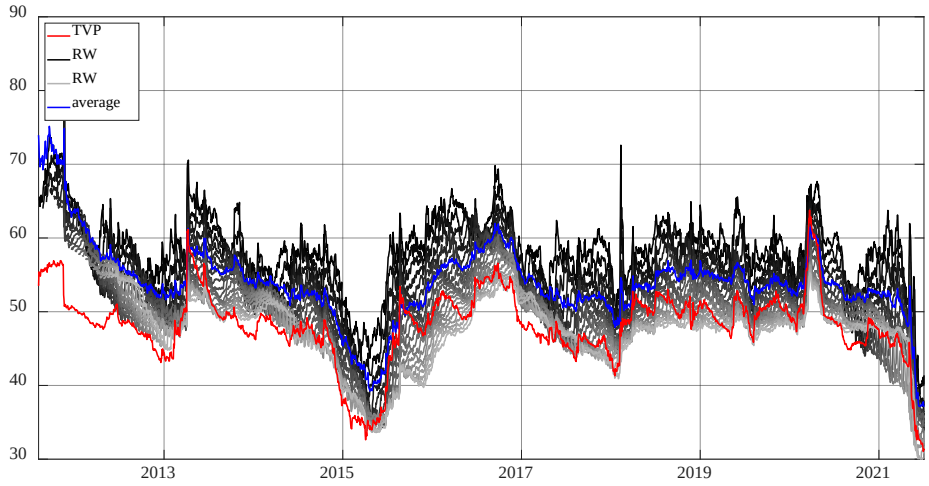

Figure 1. Dynamic total connectedness, rw=100,110, …,300. The darker the series, the smaller the window size.

Firstly, the rolling sample needs to determine the rolling window, and the choice of the rolling window is subjectivity, which affects the result of the spillover index. Secondly, rolling samples will lead to the loss of data, and there are problems in the analysis of data with a small number of samples. Figure 1 shows the spillover indices under the rolling sample and the time-varying parameter vector autoregression model, in which a total of 21 different rolling Windows (100,110..., 300) and their average spillover index. Firstly, the mean value of the spillover indices obtained by the rolling window is similar to the spillover indices based on time-varying parameters. Secondly, the size of the window has a great influence on the spillover index. With the decrease of the size of the rolling window, the result fluctuates greatly, and the overall spillover indices are higher than those based on time-varying parameters. With the increase of the rolling window, the dynamic fluctuation range of the spillover indices decreases.

3.4 Directional volatility spillovers

The directional volatility spillover index is calculated according to models (4)~(6). Figure 2 shows the directional volatility spillovers of stock markets, commodity markets and economic policy uncertainty. There are three different color line in every market, which refer to three kinds of volatility spillovers.

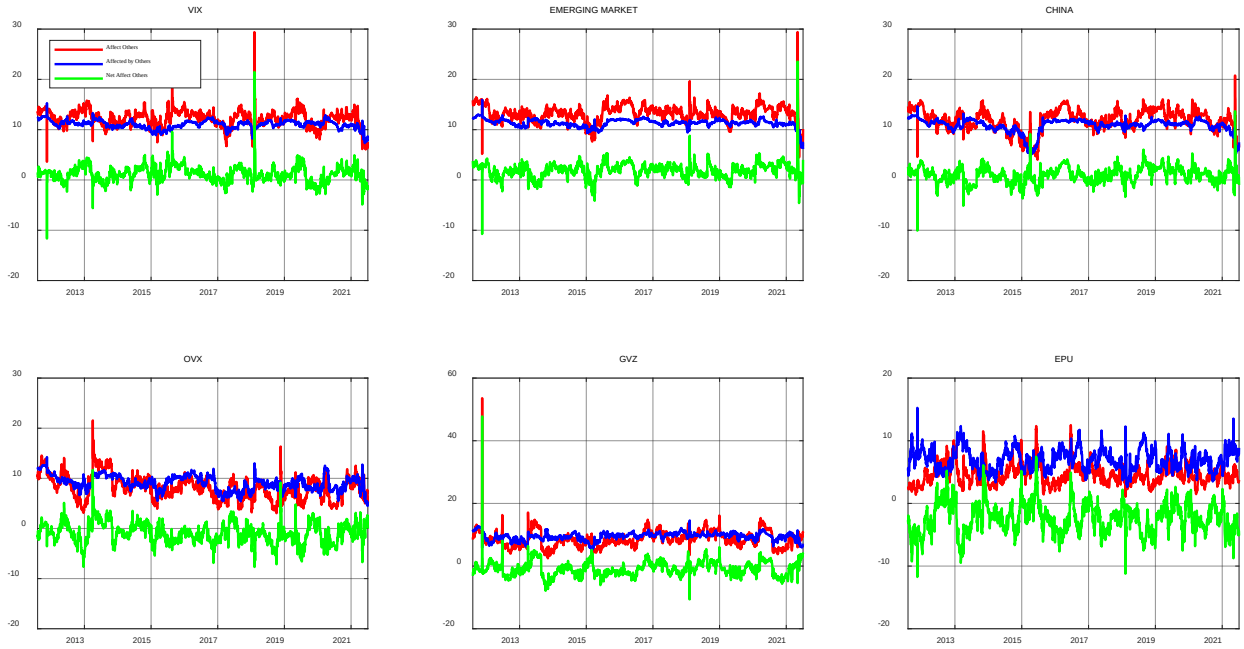

Figure 2. Directional volatility connectedness

As can be seen from Figure 2, the fluctuation ranges of the indices of volatility spillover effect of the US equities, Emerging markets equities, Chinese equities, crude oil, gold and economic policy uncertainty on other variables are 0~30%, 0~30%, 0~30%, 0~60% and 0~20% respectively. The fluctuation range of the spillover effect from other variables for these markets is kept at 0~20%. First of all, in the whole sample range, the red curve of the equities, especially the American equities, is higher than the blue curve in most cases, that is, the American equities dominate in the correlation of various markets. The net spillover index of strategic commodity markets (crude oil and gold) change between positive and negative, while the net spillover index of economic policy uncertainty is negative in most cases. In conclusion, the spillover index of each variable is bidirectional and asymmetric when the dynamic technology is added. The volatility spillover effect of the stock market on strategic commodity market and economic policy uncertainty is larger than the volatility spillover effect of the two maekets on the stock market.

3.5 Net pairwise volatility spillovers

Although the spillover effect of a single variable on all other variables can measure the association of a single variable in the whole system, it cannot explain the relationship between specific two variables in detail. Therefore, this paper further studies the spillover effect relationship between one variable and any other variable.

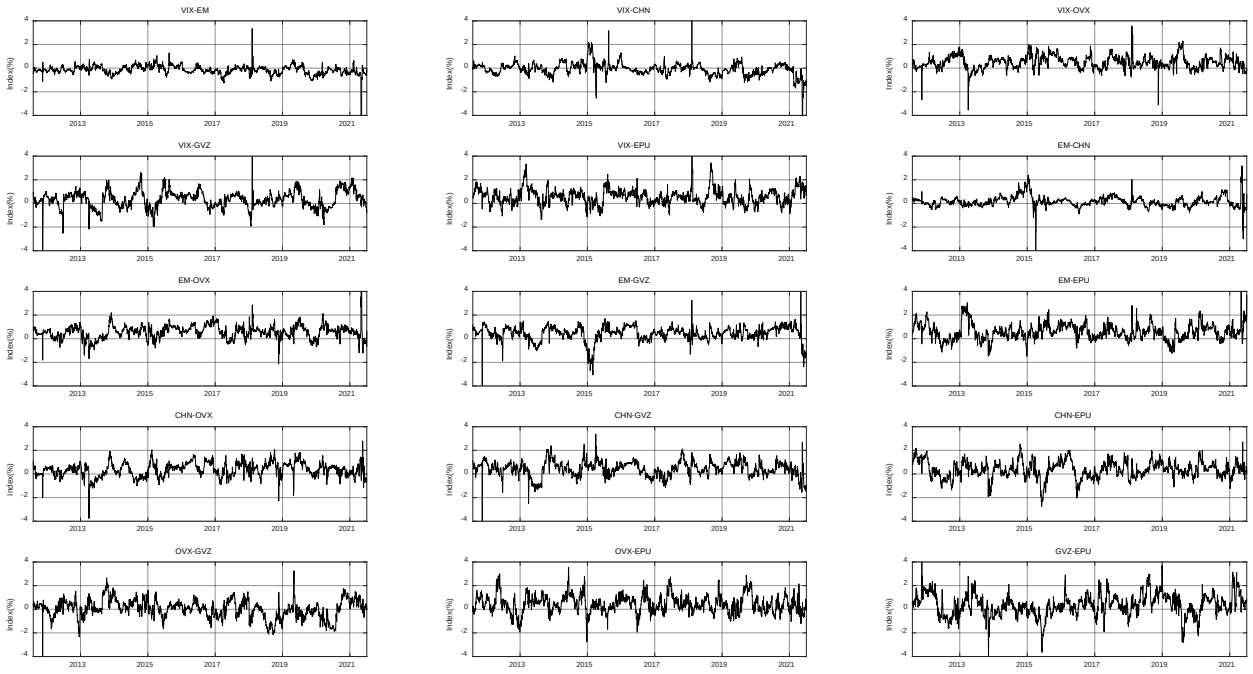

Figure 3. Net pairwise volatility connectedness

Figure 3 shows the directional volatility spillovers of each variable. It can be seen that the net volatility spillovers among US VIX, Emerging markets VIX and China VIX is roughly around 0. It can be seen that the volatility spillover effect of each other is roughly the same. The volatility spillovers from VIX of US, Emerging markets and China to strategic commodities (gold and crude oil) in most cases were greater than 0 indicating that gold and crude oil is the volatility spillover receiver. As part of diversified portfolio, gold and crude oil are influenced by the main financial products in the financial markets – the stock market. The US and Emerging markets' spillover effect on economic policy uncertainty are greater than 0, mainly because a larger proportion of individual investors in US invest in stock market. In order to protect the social public assets, economic policies give priority to maintaining and stabilizing the stock market in the United States. So policy is often affected by the U.S. stock market fluctuations. However, the spillovers of Chinese market to the economic policy uncertainty were mostly negative before 2017. The main reason is that the QE policy of The Federal Reserve after the financial crisis had a great impact on China's stock market until the end of 2014. For instance, the Operation Twist on June 20, 2012 and QE3 monthly purchase of American MBS on September 13, 2012 had a positive volatility spillover effect on Chinese stock market; In 2016, the economy of US gradually recovered and the policy of raising interest rates was put on the agenda. Therefore, the uncertainty of economic policy had a certain impact on The Chinese stock market. Crude oil and gold, as two commodities for stock market investors to diversify their risks, have a large correlation. Therefore, it can be seen that during the sample period, the spillover index between them jumps around 0, that is, they have similar spillover effect with each other. Gold is closely linked to the US dollar. A strong US dollar will lead to a decline in gold price, while a weak US dollar will lead to a rise in gold price. In the phase of US Federal Reserve cutting interest rates three times after the QE, the raising increase rates after the economic recovery in 2017 and the global economic slowdown from July to October 2019, economic policy uncertainty has a significant positive spillover effect on the gold market.

4. Conclusions

Based on the methods of Diebold, Yilmaz and Antonakakisn, the paper calculates the volatility spillover of the basic rolling window and the time-varying parameters respectively on the basis of the calculation of static volatility spillover index. The indices are obtained by the prediction variance

decomposition under the basic framework of vector autoregression (VAR) model to study the interaction between the US VIX, Chinese VIX, Emerging markets VIX, VIX of strategic commodities (crude oil and gold) and uncertainty of economic policy and the characteristics of dynamic changes.

In the static analysis of each market, the correlation of volatility spillover exists among the six variables, and the directional volatility spillover effect between a single variable and other variables is bidirectional and asymmetric. The stock market plays a leading role in the transmission of volatility, and within the stock market, there is a large correlation between Chinese and American stock markets, while the spillover effect of American stock markets is bigger. In the analysis of dynamic volatility spillovers calculated by rolling window technique and time-varying parameter method, the larger the rolling window is, the smaller the fluctuation of dynamic fluctuation overflow index is, and the results obtained by rolling window are similar to those obtained by time-varying parameter. The directional spillover index of variables has the characteristics of bidirectional and asymmetric, and the stock market still plays a dominant role in the transmission of volatility. In the analysis of the dynamic spillover index of the two variables, the correlation between the three stock markets is similar, and the net spillover effect of the stock market on the strategic commodity market is generally greater than 0, while the Chinese stock equities are greatly affected by the uncertainty of economic policy during a specific event.

Therefore, according to the conclusion obtained in this paper, the stock market, strategic commodity market and economic policy uncertainty are correlated, that is, the six variables are closely related and affect each other. Due to the volatility spillover effect among variables, the volatility of one market will have a certain impact on all other markets, and the volatility of other markets will have a certain inverse volatility transmission on this market, so that the volatility of this market has the characteristics of durability. Therefore, the study of this paper is of great significance to prevent the volatility risk of China's stock market. First of all, with the rapid development of China's economy, the financial market is in urgent need of further improvement. China's stock market is greatly affected by the international financial market, especially the American stock market and the policy uncertainty of the United States. Therefore, China needs to strengthen the supervision of financial institutions, strengthen the stability of financial institutions in domestic financial market, and strengthen and improve the risk disclosure mechanism of financial institutions. Second, the financial system should be analyzed from a comprehensive point of view. There are close linkages among financial markets, and policy makers need to take into account the risk transmission mechanism among various markets and the uncertainty of other countries' policies. Finally, for institutional and individual investors, commodity market and stock market have a close volatility linkage effect, so although gold and crude oil can be used as a part of the diversification of investment, the volatility of stock market will be transmitted to the strategic commodity market (gold and crude oil), thus affecting the returns of investors. So when deciding on a portfolio and assessing risk, you need to take into account the interconnections between your investments.

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