International Journal of English Literature and Social Sciences
Vol-6, Issue-3; May-Jun, 2021

Journal Home Page Available: https://ijels.com/
Journal DOI: 10.22161/ijels

Peer-Reviewed Journal

Economic Policy Uncertainty and International Oil Price Volatility—Based on Continuous Wavelet Transformation and Volatility Spillover Effect Analysis

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Received: 02 Apr 2021; Received in revised form: 01 May 2021; Accepted: 11 May 2021; Available online: 07 Jun 2021

Abstract— *Based on continuous wavelet transform and volatility spillover index of VAR system, this paper quantifies the relationship between economic policy uncertainty and oil price. The result of continuous wavelet transform shows the international oil price is notably related to economic policy uncertainty of world's major economies in 4-month time scope or longer. Besides, the economic policy uncertainty has dynamic net volatility spillover effect to oil price which shows a upward trend. In the background of intensified global economic friction, the research of economic policy uncertainty and oil price relationship is of great realistic significance to ensure China's energy security.*

Keywords— ***Economic policy uncertainty;Oil price;Wavelet analysis;Spillover volatility effect.***

I. INTRODUCTION

Oil is known as the "blood" of industrial economy, and the fluctuation of oil price has significant impact on the national economy. China's economy has achieved rapid development after the reform and opening up, and the demand for crude oil has also increased rapidly. However, China's oil resources are relatively scarce, so it is increasingly dependent on oil imports to meet the needs of economic development. At present, China has surpassed the United States to become the world's largest importer of crude oil, with oil import dependence ratio exceeding 70%.

Crude oil, as a bulk commodity traded worldwide, is affected by geopolitics, economic policies and other factors, and its price fluctuates greatly, which is highly correlated with China's import cost and energy security. Especially after the global financial crisis, global trade protectionism is on the rise, relations between world powers have become more complex, and economic policies of countries around the world have become more uncertain. For example, the "Brexit" and the "trade war between China and the US" in recent years have intensified the uncertainty of economic policies, during which it's clear to see that the international oil price has also fluctuated sharply. And because of the financialization trend of the international crude oil market (Tang and Xiong, 2012; Singleton, 2013), international crude oil price will quickly absorb the market information change, which further increases the volatility of international oil prices. Economic policy uncertainty increases even sharply with the outbreak of COVID-19,when governments around the world positively react to the pandemic shock.At the same time, the fluctuation of the international oil price has reached a historic level, and even the short-term negative price of crude oil appears.In this case, it is of great practical significance to study the impact of economic policy uncertainty on oil price to ensure China's crude oil supply and energy security.

Many scholars have studied the relationship between uncertainty and macroeconomics. On the one hand, uncertainty affects investment through the "real option" mechanism. Bernanke (1983), Brennan and Schwartz (1985), Ramey and Shapiro (2001), and Bloom (2009) indicate that due to the fixed costs of firm investment, when uncertainty in the economy increases, the firm's future returns will also become more uncertain. As a result, companies are delaying their investment plans and waiting for economic uncertainty to decline before making investments. In addition, uncertainty will also affect employment and economic growth. Ramey and Ramey (1995) prove that high economic growth uncertainty can have a negative impact on economic development. Machine learning skills further contribute to quantification of uncertain. In recent years, with the development of textual data analysis techniques, some scholars begin to use textual data extracted from newspapers or corporate annual reports to measure the extent of economic policy uncertainty and the relationship between economic policy uncertainty and macroeconomies. For example, Baker, Bloom et al. (2016) construct the economic policy uncertainty index (EPU) with the method of machine learning, and conclude that when the uncertainty of economic policy rises, the investment of enterprises declines. Caldara and Iacoviello et al. (2020) create the trade policy uncertainty index (TPU) with the data of corporate annual reports, and based on this, construct the general equilibrium model of trade policy uncertainty, drawing the conclusion that the trade policy uncertainty has an inverse relationship with the investment of American enterprises. Subsequently, many papers research based on these indexes. Tan and Zhang (2017) study the impact of economic policy uncertainty on the investment of Chinese enterprises based on the economic policy uncertainty index, concluding that for Chinese enterprises, economic policy uncertainty mainly affect the investment of enterprises through the real optionchannel. Zhao and Ye (2020) analyze relationship between economic policy uncertainty and enterprise financing constraints, suggesting that when economic policy uncertainty rises, enterprises will tend to actively avoid taxes, which will have a adverse effect on economic development.

As one of the most important production inputs for national economic development, petroleum is closely related to macroeconomics. Hamilton (1983) state that oil price shock might lead to economic recession in the United States. Kilian (2009), Kilian and Murphy (2012, 2014) point out that there is an inverse causal relationship between oil price and macro economy, and use the structural vector autoregressive model to show that the global business cycle is the main factor leading to the change of oil price. Aasteveit et al. (2015) analyze the impact of GDP of developed and developing economies on oil prices, and conclude that the economic development of developing countries has a greater impact on oil prices since new millennium. Zhou (2019) use the event based sign restricted vector autoregressive model to reanalyze oil price, and the conclusion is consistent with that of Kilian (2009).That is, oil price fluctuations are mainly caused by global macroeconomic fluctuations.

In the context of intensified world economic frictions and increasingly complex relations between major powers, many scholars have begun to study the relationship between economic policy uncertainty and oil prices. Kang and Ratti et al. (2013) adopt the US economic policy uncertainty index created by Baker et al. (2016) and construct a structural vector autoregressive model containing economic policy uncertainty variables, with the conclusion that positive oil preventive demand shock increases the US economic policy uncertainty, while favorable global economic fluctuations can reduce economic policy uncertainty in the United States. Bekiros et al. (2015) construct a time-varying vector autoregression model and conclude that when taking the nonlinear relationship between economic policy uncertainty and oil price into consideration, the effect of economic policy uncertainty on oil price is quite significant. Aloui et al. (2016) use Copula-GARCH model to analyze the relationship of policy and market uncertainty withoil price.

Their results show that oil price is affected by these two uncertainties only in a specific period, while oil price affect policy and market uncertainty in the whole sample period. Kang et al. (2017a) use the Economic Policy Uncertainty Index (EPU) to analyze the impact of economic policy uncertainty on oil and gas industry and conclude that when economic policy uncertainty rises, oil and gas companies' earnings will decline. In addition, Kang et al. (2017b) show that domestic oil production supply shocks in US and foreign oil supply shocks have different effects on economic policy uncertainty. Through discrete wavelet transform in multiple time scale analysis, Yang (2019) studies the spillover effect of G7 countries' economic policy uncertainty on crude oil price.He shows that economic policy uncertainty have the transmitting effect to oil prices, which is more dramatic in the long run.The impact of US economic policy uncertainty is outstanding: in the long run the fluctuation of economic policy uncertainty in the United States not only significantly affects the fluctuation of oil price, but also has a clear effect on the fluctuation of economic policy uncertainty in other countries.

Baker et al. (2016) construct the economic policy uncertainty index by dictionary-based machine learning methodology. Through endeavors of scholars across the world, now this index expands to 26 countries. Using updated economic policy uncertainty index, our paper studies the relationship between economic policy uncertainty and international oil price, which mainly has the following contributions compared to aforementioned researches. First, the economic policy uncertainty of important developing countries is included in the research scope. Previous researches (Yang, 2019) mainly study the impact of developed economies' economic policy uncertainty on oil prices. However, as stated by Aasteveit et al. (2015), since the beginning of 21st century, the effect of economic development in developing countries on oil prices is twice of developed countries'. In recent years, as we can see,the economic development of developing countries has been confronted with great external shocks and their economic policy uncertainties have increased significantly. Therefore, it is very necessary to include economic policy uncertainties in developing countries in the research. In order to control the endogenous variable number in the vector autoregression model, this paper incorporates top 5 GDP countries and top 5 oil import countries intoresearch (based on 2018 data, known as the world's major economies), consisting of United States, China, Japan, Germany, India and the United Kingdom. These countries approximately account for half of world' GDP. The second contribution is to use continuous wavelet analysis and rolling window regression to study the dynamic relationship between economic policy uncertainty and oil prices. Continuous wavelet analysis can be applied to non-stationary data, and the relationship between economic policy uncertainty and oil price can be analyzed in both time and frequency domains. Diebold and Yilmaz (2009, 2012, 2014) construct the volatility spillover index based on variance decomposition of vector autoregressions model, by which we measure the connectedness between economic policy uncertainty and oil price. Third, our sample ranges from January 1997 to April 2020,including the COVID-19 period, which provides new empirical evidence for the study of economic policy uncertainty and oil price in the case of major public emergencies.

The rest of the paper is structured as follows. Section 2 describes the data used in this paper. Section 3outlines the research methodology of the article.Section 4 analyzes the empirical analysis results of economic policy uncertainty and oil price. Section 5presents conclusions and suggestions.

II. DATA

The measure of economic policy uncertainty of various countries in this paper comes from the Economic Policy Uncertainty Index (EPU) established by Baker et al.(2016), including economic policy uncertainty indexes of the United States, China, Japan, Germany, India and the United Kingdom from January 1997 to April 2020. At present, European Brent price has become the main reference price of international crude oil, so this paper selects monthly Brent spot price to measure oil price, sourcing from the U.S. Energy Administration (EIA).

As can be seen from Figure 1, during the financial crisis from 2000 to 2008, the world economic environment was relatively harmonious, and the economic policy uncertainty of major economies in the world was at a low level. Under such circumstances, the international oil price also rose all the way, rising from about $30 / BBL in 2000 to $140 / BBL in early 2008.However, after the financial crisis in 2008, the economic policy uncertainty of the world's major economies increased significantly, and oil prices also fluctuated sharply. International oil prices fell from $140 / BBL in 2008 to around $40 / BBL in early 2009, then rose to $120 / BBL in the first half of 2011, and subsequently fell to $30 / BBL in early 2016. In particular, since 2016, with the events such as "Brexit" and "Sino-US trade war", the fluctuation of economic policy uncertainty in the world's major economies shows notable increase. In 2013, the UK voted to leave the EU, which continued to increase its economic policy uncertainty and reached a historic high level around 2017. In terms of China, the uncertainty of economic policy increased significantly since the "trade war between China and the US" in 2017, which is in contrast to the stable situation before. In general, since the 21st century, the economic policy uncertainty of the world's major economies has been negatively correlated with international oil prices, and this correlation seems to be more pronounced after 2016.

III. METHODOLOGY

Wavelet analysis is first applied to signal processing in the industrial field. However, due to its characteristic of analyzing signals in time scale and frequency scale, more and more scholars apply wavelet analysis to the research of economic problems, especially financial time series. Boubaker and Raza (2017) use discrete wavelet transform to analyze the relationship between oil price and stock price. Su et al. (2019) use continuous wavelet transform to analyze the impact of different types of oil price shocks on the uncertainty index based on text measurement (NVIX index). Xu Zhaoyi et al. (2019) propose continuous cross wavelet transform and coherent transform to examine the relationship between Shanghai Composite Index, oil price and gold.

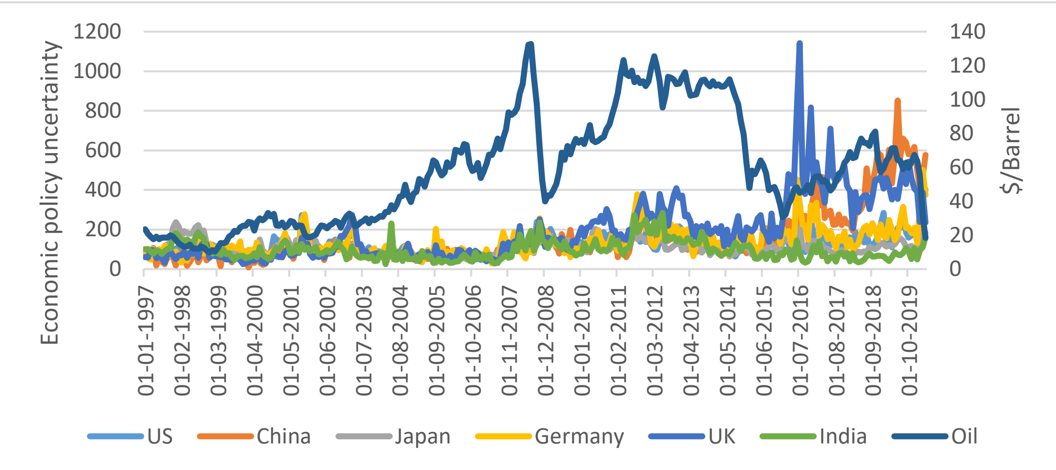

Fig.1 Economic policy uncertainty and oil prices monthly dynamics

Because wavelet analysis can not only process non-stationary data but survey in both time and frequency dimension, we use continuous wavelet analysis to examine the effect of economic policy uncertainty on international oil price. This paper also extends spillover effect index (Diebold and Yilmaz 2009, 2012, 2014) to connectedness between various economic policy uncertainty in different countries and oil price, through variance decomposition in vector autoregression. Further, rolling window method is applied to quantify the dynamic spillover effect in economic policy uncertainty and oil price system.

3.1 Coherent wavelet transform analysis

Traditional time-frequency analysis methods such as Fourier transform requires time series to be stationary, but the wavelet transform analysis method emerging in recent years can deal with non-stationary signals, so wavelet analysis is better than traditional time-frequency time series processing methods. By decomposing the price signal into several wavelets of different frequencies and projecting the time series into a two-dimensional time-frequency space, the wavelet transform method can analyze the interdependence between variables at the scale of time and frequency.Wavelet analysis decomposes time series data into localized frequency and provides information about each frequency component. By extracting the information, wavelet analysis provides a means to understand time series from the multi-scale perspectives of both time and frequency.

Fourier analysis decomposes the signal into a series of sinusoidal or cosine wave combinations and transforms them in the whole time domain, which is not good for the processing of jump signals and non-stationary signals. In comparison, the parent wavelets used by wavelet analysis generate and decay in a limited time, including Haar wavelet, Coiflets wavelet, Morlet wavelet, etc., which effectively overcome the shortcomings of Fourier transform. Among them, Morlet's specification (Goupillaud et al., 1984) is a prevailing wavelet specification that can show the joint behavior of time series data in terms of both time and frequency (Yang et al., 2017). Therefore,in this framework, the wavelet is defined as (Grinsted et al., 2004):

$$\psi_0(\eta) = \pi^{-\frac{1}{4}} e^{i w_0 \eta} e^{-\frac{\eta^2}{2}} \quad (1)$$

Where w_0 and η are parameter of frequency and time respectively. And η is the product of s multiplies t, where s is the time scale and t is time. The Morlet wavelet with w_0=6 is usually a good choice to extract time series information because it can best handle the tradeoff between time and frequency (Grinsted et al., 2004; Vacha and Barunik,2012).In essence, continuous wavelet transform take wavelet as band pass filter, with time series continuous wavelet $W_n^X(s)$expressed as follows:

$$W_n^X(s) = \sqrt{\frac{\delta t}{s} \sum_{n'=1}^{N} x_{n'}}\, \psi_0 \left[(n' - n)\frac{\delta t}{s}\right] \quad (2)$$

Where $\delta_t$is the uniform time step and n=1, …, N. Wavelet power can interpret the degree of the local variance of x_n scale by scale. Following the contribution of Grinsted et al. (2004), we have the null hypothesis that $x_n$stem from an AR(1) stationary process, so that we can get the statistical significance of the wavelet power.

Based on these equations and conditions, WTC analysis considers W^{XY} , with W^{XY} is defined as $W^X W^{Y*}$,where * means the complex conjugation. $|W^{XY}|$ is the cross wavelet power and reveals areas with high common power. WTC is a way to measure the comovement of two time series in different time scales and frequencies. The WTC of two time series is as follows (Grinsted et al., 2004):

$$R_n^2(s) = \frac{|S(s^{-1}W_n^{XY}(s))|^2}{S(s^{-1}|W_n^X(s)^2|)S(s^{-1}|W_n^Y(s)^2|)} \quad (3)$$

where S is a smoothing operator and 0 ≤R_n^2≤ 1.

3.2 volatility spillover effect

Diebold and Yilmaz (2009) use variance decomposition of vector autoregressive model to measure the volatility spillover effect of variables in the vector autoregressive system, so as to measure the mutual influence among financial assets. To circumvent he limitation of variables ordering in vector autoregression system, Diebold and Yilmaz (2009) adopt the generalized VAR framework of Koop, Peresan and Potter (1996) and Peresan and Shin (1998) to produce variance decompositions that are invariant to the ordering. As a result, connectedness in the system is calculated, including total spillovers, directional spillovers ,net spillovers and net pairwise spillovers.

First, consider an N-variable VAR(p) model, as expressed by (4):

$$x_t = \sum_{l=1}^{p} \Phi_l \, x_{t-l} + \varepsilon_t \quad (4)$$

Where $x_t$is the N x 1 vector of the observed variables at time t, and Φ is the N x N coeficient matrix. The error vector $\varepsilon_t$is independent and identically distributed.

In this model, provided the stability of the system, the VAR process can also be transform into the vector moving average form, as represented below:

$$x_t = \sum_{l=0}^{\infty} \psi_l \, \varepsilon_{t-l} \quad (5)$$

Where ψ_l is the (N X N) matrix of infinite lag polynomials that can be calculated from $\psi_l = \sum_{j=1}^{p} \Phi_j \, \psi_{l-j}$. As the orders of the variables in the VAR system may influence the impulse response or variance decomposition results, to eliminate variable ordering effect, generalized VAR framework introduced by Koop、Pesaran and Potter（1996）and Pesaranand Shin（1998）(hereafter KPPS) is used. Denoting the KPPS H-step-ahead forecast error variance decompositions by θ_{jk}^{H}, for H = 1,2,…, we have

$$\theta_{jk}^{H} = \frac{\sigma_{kk}^{-1}\sum_{h=0}^{H-1}(e'_j\psi_h\Sigma_\varepsilon e_k)^2}{\sum_{h=0}^{H-1}(e'_j\psi_h\Sigma_\varepsilon\psi_h' e_k)} \quad (6)$$

Where Σ is the variance matrix for the error vector ε, σ_{kk} is the standard deviation of the error term for the kth equation, and e_k is the selection vector with one as kth element and zeros otherwise. However, the sum of the elements in each row of the variance decomposition table is not equal to one: $\sum_{k=1}^{N}\theta_{jk}^{H} \neq 1$. 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 in the row as :

$$\tilde{\theta}_{jk}^{H} = \frac{\theta_{jk}^{H}}{\sum_{k=1}^{N}\theta_{jk}^{H}} \quad (7)$$

In this way now we have $\sum_{k=1}^{N}\tilde{\theta}_{jk}^{H} = 1$ and $\sum_{j,k=1}^{N}\tilde{\theta}_{jk}^{H} = \mathrm{N}$.

3.2.1 Total spillovers

The total spillover index measures the contribution of spillovers of volatility shocks across asset classes in the system to the total forecast error variance. By forcast error from KPPS VAR decomposition, we can calculate total spillover index as below:

$$S^{H} = 100\, x\, \frac{1}{\mathrm{N}}\sum_{\substack{\mathrm{j,k}=1\\ j\neq k}}^{N}\tilde{\theta}_{jk}^{H} \quad (8)$$

3.2.2 Directional spillovers

Not only can we calculate the total spillover effect in the system, but it’s possible to examine the direction of volatility spillovers across variables by KPPS variance decomposition. As the generalized impulse reponses and variance decompositions are independent to variables ordering, through normalization of the generalized variance decomposition matrix we measure the directional volatility spillovers received by variable j from all other variables as :

$$\mathrm{s}_{N,j\leftarrow\bullet}^{H} = 100x\frac{1}{\mathrm{N}}\sum_{\substack{\mathrm{j,k}=1\\ j\neq k}}^{N}\tilde{\theta}_{jk}^{H} \quad (9)$$

Similarly, the directional volatility spillovers transmitted by variable j to all other variables is expressed as below:

$$\mathrm{s}_{N,j\rightarrow\bullet}^{H} = 100x\frac{1}{\mathrm{N}}\sum_{\substack{\mathrm{j,k}=1\\ j\neq k}}^{N}\tilde{\theta}_{jk}^{H} \quad (10)$$

3.3.3 Net spillovers

By directional spillovers, we can measure net volatility spillover from variable j to all other variables :

$$\mathrm{s}_{j}^{H} = \mathrm{s}_{N,j\leftarrow\bullet}^{H} - \mathrm{s}_{N,j\rightarrow\bullet}^{H} \quad (11)$$

The net volatility spillover index is simply the difference between the gross volatility shocks transmitted to and those received from ll other markets.

3.3.4 Net pairwise spillovers

The net pairwise volatility spillover between asset j and k is the difference between the gross volatility shocks transmitted from market j to market k and those transmitted from k to j.

$$\mathrm{s}_{jk}^{H} = 100x\frac{1}{\mathrm{N}}(\tilde{\theta}_{kj}^{H} - \tilde{\theta}_{jk}^{H}) \quad (12)$$

IV. EMPIRICAL RESULTS

Figure 2 shows the power spectrum of the correlation between economic policy uncertainty and oil price of major economies in the world, from January 1997 to April 2020. The vertical axis measures the frequency scale, while the horizontal axis represents the time scale of policy uncertainty and oil price coherence. Colors indicate the energy of the correlation between economic policy uncertainty and oil prices. The darker the color, the stronger the correlation, while the dark red areas inside the black line indicate that the coherence is significant at the 5% level. As can be seen from the figure above, economic policy uncertainty generally has a significant impact on oil prices in cycles of more than 4 months, which is consistent with the analysis of Kilian and Vega (2011), that is, changes in macroeconomic factors will not have an impact on oil prices in the current month.

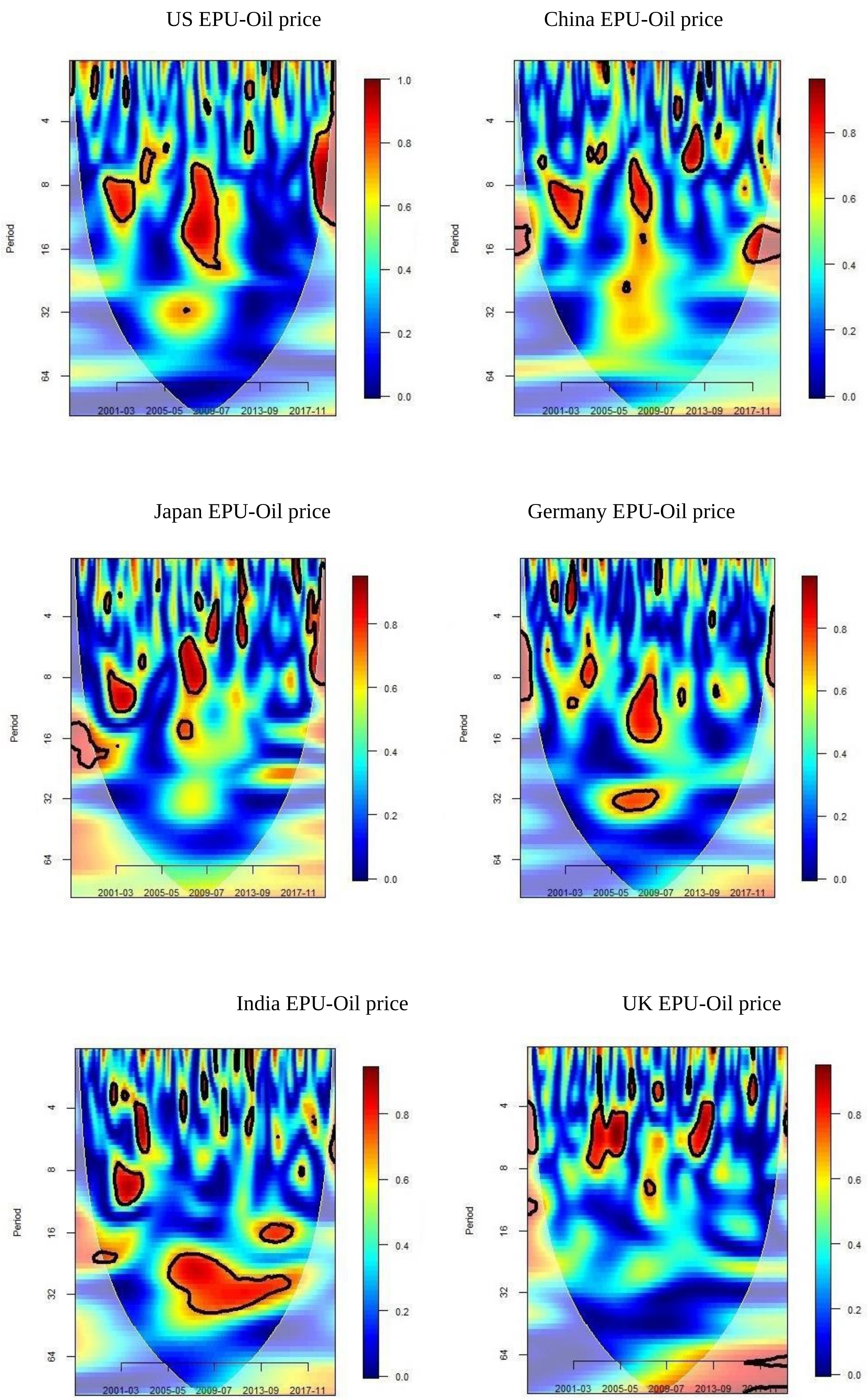

Fig 2: Continuous wavelet coherence of economic policy uncertainty and oil price

4.1 US economic policy uncertainty and oil price

The significant time horizon for coherence between US economic policy uncertainty and oil price exceeding the significant level are mainly in 2001-2002, 2008-2009 and 2017-2020.US suffered from 911 terrorist attack in 2001, leading to increase of economic policy uncertainty then, and it affectedoil price in approximately 6 months. In 2008, the "subprime mortgage crisis" also had a serious impact on the US economy when US economic policy uncertainty again had a significant impact on oil prices, and this time the impact was greater than the 2001-2002 period, reflecting the significant rise of economic policy uncertainty and its clear coherence with crude oil prices in the 6-16 month cycle. The significant mutual effect between economic policy uncertainty and oil price has recurred since 2017,with impact period mainly in 4 to 12 months. On one hand, oil prices reacted to the aggressive protectionist policies of the US that began in 2017; On the other hand, the "COVID-19" in 2020 had an impact on the US economy, bringing about rising uncertainty of economic policy depressing international oil price.

4.2 China economic policy uncertainty and oil price

The significant time horizons for China economic policy uncertainty and oil price are 2001-2003, 2008-2009, 2012-2013 and 2017-2020. Since China joined the WTO in 2001, its economic environment has been greatly improved and economic policy uncertainty has been clearly reduced. It seemed that the change of China's economic policy uncertainty impacted oil price from 2001 to 2003, with the significant area locating in 6 to 10 months. Similarly, during financial crisis period from 2008 to 2009 economic policy uncertainty in China had a clear coherence relationship with oil price, while the duration and strength then were weaker than that in United States.In addition, the China's economic policy uncertainty showed coherence with oil price since 2017, which could be attributed to "US-China trade war" and "COVID-19" disease, mainly in frequency period of about 16 months.

4.3 Japan economic policy uncertainty and oil price

The notable coherence between Japan economic policy uncertainty and oil price are 2001-2002, 2009-2009 and 2017-2020. In 2001, when the Internet stock bubble burst and Japan's high-tech industry suffered, it could be that the fluctuation of economic policy uncertainty had an impact on the oil price in the 6-12 month cycle. And the 2008 financial crisis also had great impact on the Japanese economy, with rising economic policy uncertainty again taking effect on oil prices in the 5 to 8 month cycle. Besides, in recent years, the coherence between economic policy uncertainty in Japan and oil price is evident. Since 2018, the uncertainty of Japan's economic policy has shown a significant interaction with international oil prices in frequency scope of 4 to 8 months.

4.4 Germany economic policy uncertainty and oil price

In comparison, the uncertainty of German economic policy mainly had a significant impact on oil prices during the "subprime crisis" period, with significant cycle in 8-16 months and around 32 months.

4.5 India economic policy uncertainty and oil price

The economic policy uncertainty in India has significant coherence relationship with oil price during 2001-2002 and 2005-2015. The interaction between India economic policy uncertainty and oil price is distinct in 8 to 12 months from 2001 to 2002, while for the subsequent significant time horizon the notable frequency period is 16 to 32 months. After the new millennium, the rapid development of Indian economy along with loose economic policy environment contributed to rising import of crude oil, which affected oil price.

4.6 UK economic policy uncertainty and oil price

UK economic policy uncertainty has a significant correlation with oil prices from 2002 to 2005 and from 2009 to 2013, with a significant interaction between the two variables largely over 4 to 8 month period. From 2002 to 2005, the UK faced a relatively favorable economic environment with stable domestic economic development and significantly reduced economic policy uncertainty, when UK's economic policy uncertainty also showed a clear coherence with oil price. However, as UK economy suffered from financial crisis and European debt crisis from 2019 to 2013, the economic policy uncertainty and oil price interaction became outstanding again at that time. Besides, according to the wavelet power chart, the "Brexit" event could lead to coherence of UK economic policy uncertainty and oil price, but the impact did not last long.

Through continuous wavelet analysis can we analyze the relationship between economic policy uncertainty and international oil price in time and frequency dimension, whereas we can further examine the volatility spillover effect in the system by DY spillover index(Diebold and Yilmaz 2009,2012,2014).

Table 1: Unit-root test for economic policy uncertainty and oil price variables

Variable	ADF(Constant）	ADF（Trend）	PP（Constant）	PP（Trend）
Oil	-11.196***	-11.285***	-11.196***	-11.269***
China EPU	-4.723***	-4.881***	-39.762***	-41.303***
Germany EPU	-7.906***	-7.942***	-52.505***	-58.956***
India EPU	-11.845***	-11.804***	-37.250***	-37.124***
Japan EPU	-5.593***	-5.629***	-31.234***	-31.871***
UK EPU	-6.122***	-6.150***	-27.367***	-27.393***
US EPU	-8.888***	-8.925***	-28.404***	-28.726***

In order to carry out the following analysis of volatility spillover effect, we express the variables in the form of returns, and carry out unit root test to validate stationary. Through ADF and PP test, all variables in returns form are stationary and significant at the level of 1%.

Table 2 describes the spillover effects of economic policy uncertainty and oil price volatility from February 1997 to April 2020. Its ijth entry is the estimated contribution to the forecast error variance of asset i coming from innovations to asset j. Hence ,the off-diagonal column sums(labeled contributions To others) and row sums(labeled contributions From others) ate the "to" and "from" directional spillovers, and the "from minus to" differences are the net volatility spillovers. In addition, the total volatility spillover index appears in the lower right corner of Table 2.

Consider the spillover results in table 2. The total volatility spillover effect in economic policy uncertainty and oil system is 11.73, indicating the volatility forecast error variance that comes from spillovers is not large. In terms of economic policy uncertainty variable, we find Japan, UK and India's economic policy uncertainty comparatively stable,with little impact received in the system. Nevertheless, the economic policy uncertainty of Germany is greatly affected by the fluctuations of other variables, among which the economic policy uncertainty of China showing the largest impact, which reflects the strong economic interdependence betweenthe two countries. In fact, China has been Germany's largest trading partner since 2017. Since Germany's oil consumption is heavily dependent on imports, the fluctuation of oil prices also has a great impact on the uncertainty of German's economic policy. As for China, the economic policy uncertainty of Germany transmits greatest volatility, while the impact of US economic policy uncertainty is only inferior to that of Germany. As integrating deeply with world development, the economic policy uncertainty of Germany, Japan and China all clearly affect that of United States. Besides, oil price has volatility spillover effect to the economic policy uncertainty of US. According to data in table 2, the spillover effect of US' economic policy uncertainty on oil price fluctuations was the largest, followed by the UK and Germany.

Table 2: Volatility spillover table of economic policy uncertainty and oil price

	US EPU	China EPU	Japan EPU	Germany EPU	UK EPU	India EPU	Oil	From
US EPU	87.12	2.55	3.22	4.03	0.1	0.65	2.3	1.84
China EPU	1.52	88.22	1.11	7.27	1.44	0.41	0.36	1.73
Japan EPU	4.71	0.85	92.74	4.11	3.59	6.16	0.22	2.81
Germany EPU	2.5	4.95	0.87	80.06	1.6	2.02	3.51	2.21
UK EPU	0.98	2.01	0.81	1.12	90.31	0.46	1.75	1.02
India EPU	0.4	1.08	0.31	1.73	1.04	89.95	2.39	0.99
Oil	2.77	0.35	0.93	1.68	1.92	0.34	89.47	1.14
To	1.84	1.68	1.04	2.85	1.38	1.44	1.5	11.73

We have useful results on the total spillover effects from our full sample. However, these results are not helpful in analyzing how connectedness changes over time. If we only focus on the static results, the VAR estimate over the whole sample may smooth out the results when there is time variation in the relationship between the variables. In order to better understand the dynamics of spillover effects, we employ a moving-window to examine the spillover results in the system. The estimation window is fixed at 100 months and 10 one-step-ahead spillover measurements are produced. Figure 3 shows the dynamics of total volatility spillover, in which the gross volatility spillover of the system can be divided into several stages. Before 2008, the total spillover effect in the system showed a downward trend, dropping from 40% to about 30%. Then it sharply rose to 40% with the onset of financial crisis, but dropped gradually to 30% in 2010 as economy began to recover. It is worth noting that the total volatility spillover effect in the system continued to rise after 2010 and reached a high level of 50% in 2017, reflecting the increasing volatility spillover effect of economic policy uncertainty and oil price system. Finally, the total volatility spillover effect of the system fell in 2018, but rose again after the COVID-19 began in 2020. In general, the interaction between economic policy uncertainty and the oil price showed a clear upward trend after the 2008-2009 financial crisis.

Fig 3. Total volatility spillovers

Figure 4 shows the dynamic directional volatility effect from each of the variable to others in the VAR system. The spillover effect of US economic policy uncertainty on the fluctuations of other variables in the system is between 6% and 9%. A notable fluctuation can be detected is from 2017 to 2019, when president trump took office and implemented aggressive trade protection policies at first, then the spillover effect of the uncertainty of US economic policy on other variables in the system dropped to about 7% followed by trade and peace talks. The impact of China's trade policy uncertainty on the system fluctuations is around 4% to 6%, while the spillover of China's policy uncertainty on oil price fluctuations has risen rapidly from 4% to more than 6% after 2017, reflecting the increasing uncertainty of China's economic policy in the face of an more complex external environment. In 2011, the spillover effect of Japan's economic policy uncertainty on the system sharply increased from 4% to 8%, and then maintained to the level of over 8%, reflecting expanding impact of Japan economic policy uncertainty to world economy. The impact of German policy uncertainty on other variables in the system is relatively stable, ranging from 6% to 8%, and this volatility spillover effect has declined in recent years. Since 2012, with the economic development and the strengthening of international ties, the volatility spillover effect of the economic policy uncertainty in India on the system has increased from 4% all the way to nearly 10%, and this effect has subsequently decreased to about 5% in 2020. Before 2017, the impact of economic policy uncertainty on system fluctuations in the UK showed a downward trend. However, since 2017, the "Brexit" event has increased the uncertainty of the UK's economic policy, and the spillover effect of the uncertainty of the UK's economic policy on the system has been enhanced. As can be seen from Figure 3, the aggregate impact of oil prices on the fluctuations of economic policy uncertainty in the world's major economies is between 2% and 6%. In particular, two oil crashes are worthy of attention. One is from 2014 to 2016, the directional spillover effect of oil price fluctuations on other variables increased from 2% to about 5%. The other is in "COVID-19" period, when the directional volatility spillover effect of oil sharply increased from 3% to more 6%.

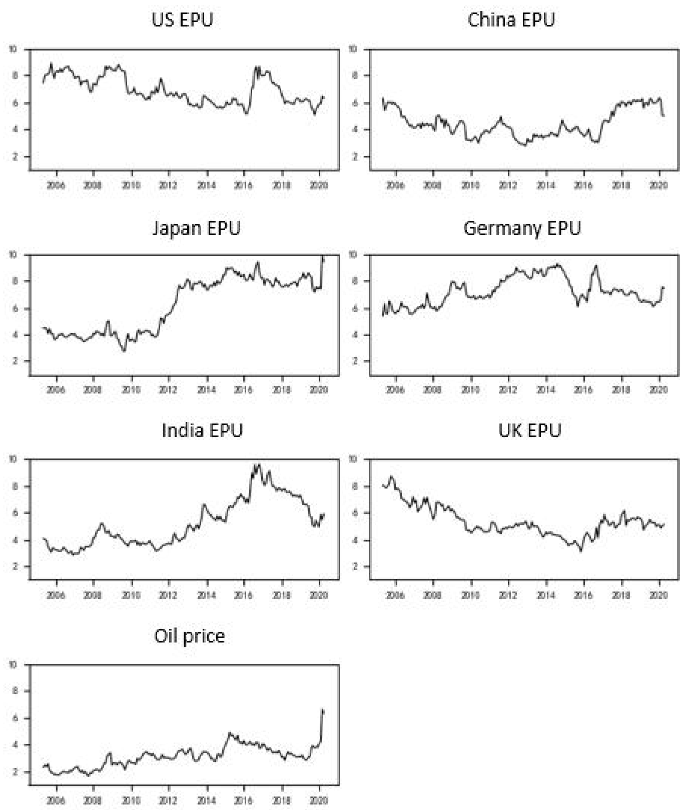

Fig 4: Directional volatility spillovers, FROM

In Figure 5, we present the directional volatility spillovers from the others to each of the variable in economic policy uncertainty and oil price system. The volatility received by US economic policy uncertainty from other variables ranges from 6% to 8%. With increasing exposure to external shocks, the volatility spillover effect from other variables to China's economic policy uncertainty rose from 4% to 7% since 2016. Since 2010, the volatility spillover effect of other variables on economic policy uncertainty of Japan and Germany enhanced, but stabilized after 2016. Prior to 2008 financial crisis, the directional volatility from others to India economic policy uncertainty are roughly smooth at 4%, whereas it showed an increasing trend afterwards. The reception of UK economic policy uncertainty from others are largely stable, at about 6%. The spillover effect of economic policy uncertainty in the world's major economies on oil prices is between 4 and 6 percent. Starting in 2020, the COVID-19 increased uncertainty in economic policy, and its impact on oil price fluctuations increased from 4% to 6%.

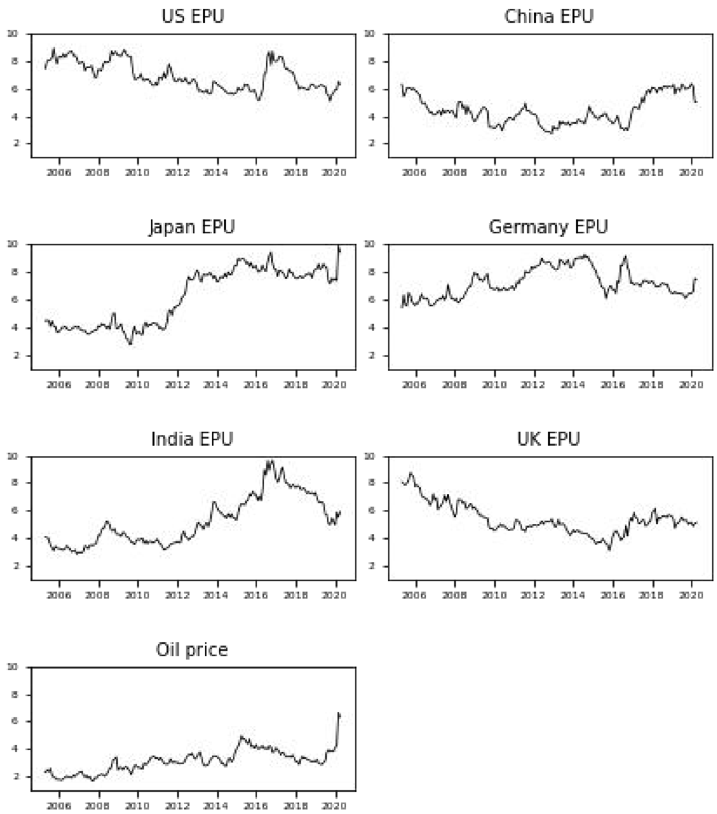

Fig 5: Directional volatility spillovers, TO

As shown in Figure 6, we can calculate the difference between the "Contribution from" column sum and "Contribution to" row to get the net volatility spillover. And we present net pairwise volatility spillover plot as described at the end of section 3, which is in Figure 7.

The net volatility spillover effect of US economic policy uncertainty is basically positive, while its variation can be differentiated into two stages. Before 2016, the net volatility transmission effect of the US economic policy uncertainty showed a downward trend, and it mainly affected the UK economic policy uncertainty and oil price fluctuations (Figure 7). Since 2016, the net effect of US economic policy uncertainty on system fluctuations increased from nearly 0 to about 2%, and then this effect began to fall in 2018. At this stage, US economic policy uncertainty mainly generated net volatility spillover effect on Japan's economic policy uncertainty.

Before 2016, the net volatility spillover of China's economic policy uncertainty is around 0. However, this effect turned to negative value afterwards, as external environment had a larger impact on Chinese economic development, mainly by economic policy uncertainty of Germany and India. Then he net volatility effect rose again in 2018 but finally dropped below 0 since the outbreak of "COVID-19".

The financial crisis acted as the watershed for net fluctuation spillover effect of economic policy uncertainty in Japan.Before the financial crisis, the net volatility spillover effect of economic policy uncertainty in Japan was basically negative, so other variables had a greater impact on the uncertainty of economic policy in Japan at this stage. However, after 2012, the "transmitted" value of Japan's economic policy uncertainty to system fluctuations began to be larger than its "received" value, and this gap has stabilized at about 2% since 2014. The net volatility spillover effect of Japanese economic policy uncertainty was mainly transmitted to Germany and the United Kingdom, reflecting the enhanced impact of Japanese economic policy on the European economy. In addition, Japan's economic policy uncertainty also had a positive volatility spillover effect on oil prices from 2012 to 2016, but this effect began to decline after 2016, as the economic friction between the United States, China and other countries during this period played a larger role on oil price.

The net volatility spillover level of economic policy uncertainty in Germany was relatively stable before 2014. However, since 2014, the influence of economic policy uncertainty in Germany on the other variables has been strengthened, and this influence tends to slow down in recent years.

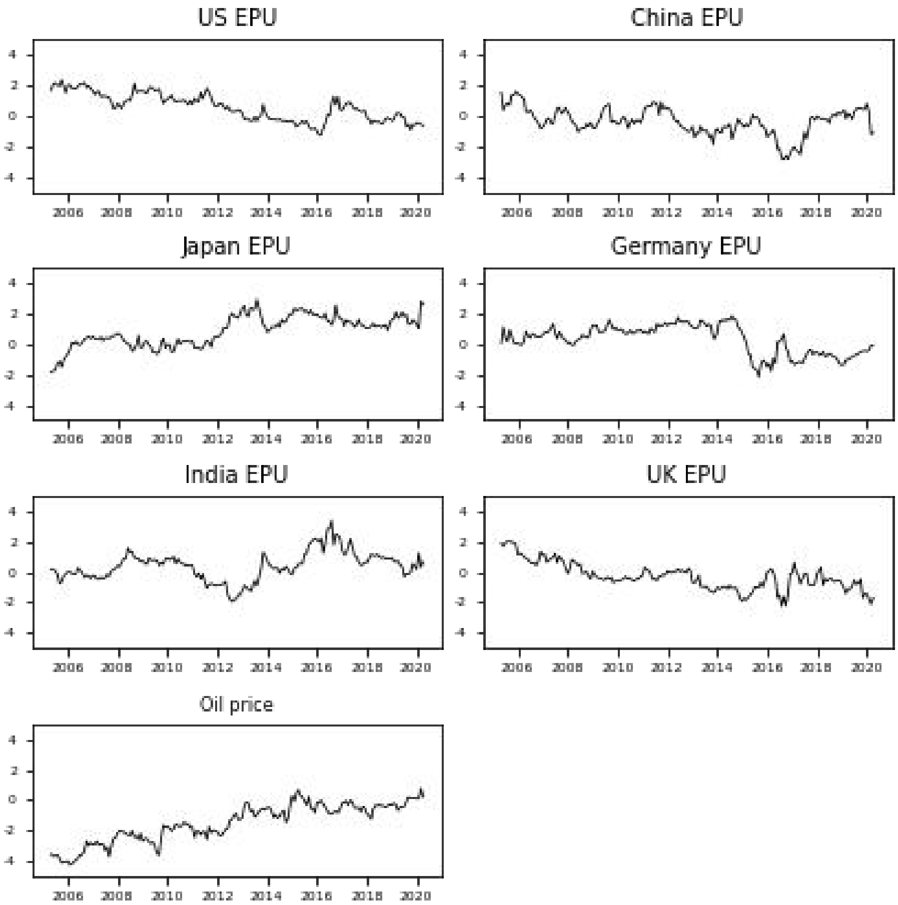

Fig 6: Net volatility spillovers, economic policy uncertainty and oil price

After the 2008 financial crisis, the net impact of India's economic policy uncertainties gradually decreased, when there was increasing external shock to India's economic development. However, when it came to 2012 to

2017, the net fluctuation spillover effect of economic policy uncertainty in India began to rise and reached about 4% in 2017, as India's economic policy were more related to world economy, which notably reflected in China, Germany and Japan's economic policy uncertainty. However, since 2017, the impact of economic policy uncertainties in India on the system has dropped again, reflecting the rising volatility spillover effect of other variables on the India's economic policy uncertainty during this period.

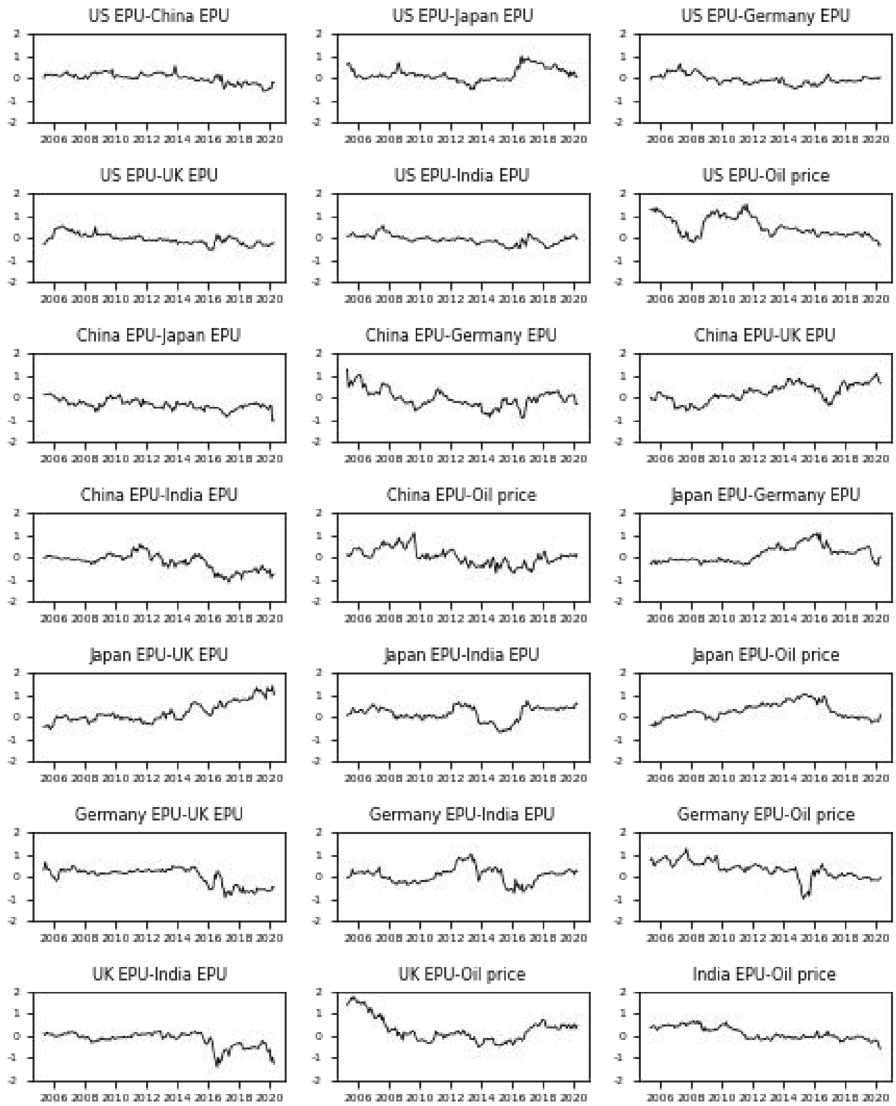

Fig 7: Net pairwise volatility spillovers, economic policy uncertainty and oil price

As can be seen from Figure 6, the net volatility spillover effect of economic policy uncertainty in the UK is generally negative, but around 2017, this effect rapidly rose from negative to positive, and then fell back. This shows that "Brexit" has a temporary effect, which is consistent with the results of continuous wavelet analysis.

As can be seen from Figure 6, volatility spillover effect is generally transmitted from economic policy uncertainty of major economies to oil prices, which is consistent with the conclusions of Herrera et al. (2011), Salisu et al. (2017) and Yang (2019). Besides, this result also supports the conclusion of Kilian (2009), that is, oil price and macroeconomic variables should be mutual causality, and oil price shock cannot be simply regarded as exogenous variable in economic model. From a dynamic point of view, the net impact of economic policy uncertainty on oil price fluctuations before 2016 shows a gradual decline, reflecting the increased impact of other factors (such as the shale revolution) on international oil prices. However, since 2016, the impact of economic policy uncertainty of major economies on oil price fluctuations has been strengthened again. The overall net spillover effect of international oil price has shown two downward trends in 2017 and 2018, reflecting the impact of "Brexit", "Sino-US trade war" and other factors on international oil price during this period.

V. CONCLUDING REMARKS

As international trade protectionism intensifies, economic frictions increase and economic policy becomes more uncertain around the world, oil price shows strong volatility. With the increasing dependence of crude oil import in China, it is of great practical significance to study the relationship between economic policy uncertainty and oil price for ensuring crude oil supply in China.The continuous wavelet analysis shows that the economic policy uncertainty of the major economies in the world has a significant correlation with the international oil price in the cycle of 4 months or more, and the impact is mainly concentrated in the period of the Internet bubble crash in 2001-2002, the financial crisis in 2008-2009, and the period of "Sino-US trade war" and "COVID-19" after 2017. In addition, we use the volatility spillover index (Diebold and Yilmaz 2009, 2012, 2014) to further measure the volatility spillover effect in the economic policy uncertainty and oil price system, and the result is as follows. First, there's notable increase of total volatility spillover between economic policy uncertainty and oil price after the 2008 financial crisis. Second, the world's major economies economic policy uncertainty has positive net volatility spillover effect on oil price. This effect showed a downward trend before 2016, while it enhanced again during "Brexit" period in 2016 and "US-China trade war" period since 2017. Last, both the level and volatility of world's major economies increased clearly since 2016, and the net volatility spillover to oil price in large part came from economic policy uncertainty of China and UK.

Having examined relationship between economic policy uncertainty and oil price, our research has policy implications as described below. First, it's preferable to hedge in advance, in order to lower the risk of future price fluctuations. Since there is a significant correlation between economic policy uncertainty and the international oil price in the cycle of 4 months or more, we suggest to hedge in the long period. Second, we should improve oil storage infrastructure and increase the oil storage capacity. In fact, the construction of energy storage facilities in China lags far behind the developed countries in the world. But when we have integrated storage facility, we can be more flexible even if the price fluctuates to a larger extent. Third, it's necessary to promote energy technology advancement and effectively reduce the external dependence in oil. As a good example, the US has achieved energy independence by shale revolution. However, China also has ample shale resource in Sichuan, Chongqing.etc, we have great potential for future supply. General Secretary Xi put forward the major energy strategic thought of "four revolutions and one cooperation", to promote the revolution of energy technology and industrial upgrading. Accordingly, we should increase investment in scientific research, promote technological innovation in energy exploration and development, and enhance the independence of China's energy supply.

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