Research on the Time-Varying Impact of Economic Policy Uncertainty on Crude Oil Price Fluctuation

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Abstract: Due to multiple properties, the international crude oil price is influenced by various and complex interrelated factors from different determinants in different periods. However, the previous studies on crude oil price fluctuation with economic policy uncertainty (EPU) haven’t taken a wider range of volatility sources into their analysis frameworks. In this paper, the time-varying parameter factor-augmented vector autoregressive (TVP-FAVAR) model is introduced in order to avoid important information loss, as well as capture the time-varying impact on crude oil price fluctuation by EPU. Furthermore, the differences on crude oil fluctuations from net-oil exporting and net-oil importing country’s EPU are also elaborated. Here are three findings as follows. First, the impacts of global EPU on the crude oil price volatility show time-varying characteristics both in time duration and time-points. Second, the instantaneous impacts of global EPU on the price volatility of crude oil are directly relevant to major events, and the impacts are different in event types as well. Third, the time-varying characteristics depicting the impacts of EPU in countries who are net-oil exporter and net-oil importer on price volatility of crude oil show heterogeneity in fluctuation range, fluctuation intensity, and stage.

Keywords: EPU; oil price volatility; net-oil exporting country; net-oil importing country; TVP-FAVAR

1. Introduction

Economic policy uncertainty (EPU), as a dominant indicator of many events, has a significant external shock on crude oil price fluctuations [1–3]. On the one hand, EPU has an impact on crude oil price volatility through commodity market. When making decisions, different participants in the commodity market will consider the influence of various policy uncertainties on their own cost-effectiveness. Any decision of the participants in the commodity market will cause crude oil price to fluctuate, since crude oil is the most basic commodity and in a very important position in the entire industrial chain. Therefore, EPU affects the fluctuation of crude oil price by impacting the behavior of decision makers in the commodity market [4–11]. On the other hand, EPU affects crude oil price fluctuation via financial market. The crude oil has financial attributes and commodity attributes as well. Faced with EPU, the participants in the commodity market will hedge crude oil to reduce the impact of crude oil on their own production or consumption. In the process of hedging, crude oil prices fluctuate to a certain extent. Besides the hedging of crude oil by commodity market participants, financial market speculators also use different periods or regions’ markets to make cross-market and cross-regional oil speculation. In various oil speculative transactions, EPU is an important factor that affects the speculators’ decision-making. Hence, EPU plays a critical role in predicting the fluctuation of crude oil price.
However, the international crude oil market is quite complex and also determined by other various complicated factors, such as oil supply and demand, financial speculation and geopolitical risk, etc. [12–21]. Thus, the impact of EPU on crude oil price volatility might be time-varying. Our analysis is motived by the striking difference in time period of the correlation between global EPU (GEPU) and oil price. As shown in Figure 1, when there is a sharp increase in the GEPU index (e.g., during the international financial crisis of 2008–2009 and European sovereign debt crisis of 2011–2012), the crude oil price also rises sharply. It implies that in these time periods, GEPU is an important determinant of oil price fluctuation. In contrast, during other periods, the correlation seems less obvious, which means the main driven factors has changed to other variables. What’s more, different volatility sources of oil price are interrelated. For example, the tensions in geopolitical relations between America and the Middle East not only cause changes in international crude oil supply and demand, but also lead to the adjustments of other countries economic policy, and further generate oil price volatility. Therefore, the first objective of this paper is to investigate the time-varying impact of GEPU on the crude oil price volatility empirically, considering the correlations of various complicated factors. The study could not only explain the turmoil in the crude oil market caused by GEPU, but also provide a scientific reference for policy making and investment decision.

![Figure 1. Trend of Brent oil spot price and global economic policy uncertainty (GEPU). Notes: GEPU donates global economic policy uncertainty (EPU) index obtained from http://www.policyuncertainty.com/. Oil price donates Brent oil spot price.](image)

In particular, it is not clear, against the instantaneous shocks of different types of rare events, how crude oil price fluctuation reacts to EPU. Rare events have an instantaneous impact on crude oil price fluctuations, but the degree of action is very large. Meanwhile, because rare events are inherently different in nature and cause, the combination of rate events and EPU result in different EPU impacts on crude oil price fluctuations. In addition, different rare events have different impacts on the commodity market and financial market, which are transmission channels of the impact of EPU on oil price volatility. Thus, the instantaneous impacts of EPU on oil price volatility are different in event types. For example, the global financial crisis affects the EPU’s impact on crude oil price fluctuation through the financial derivative market of commodities. The geopolitical tension causes the change of oil supply and demand relationship and thus causes the EPU’s impact on crude oil price fluctuation. The Sino-US trade friction affects the commodity market and thus acts on the EPU’s impact on crude oil price fluctuation. However, it received little attention. In this paper, the second objective
is to investigate the difference of the time-varying characteristics of the instantaneous impact under different types of major events.

Furthermore, we ask: What is the difference in the time-varying impact of EPU on the crude oil price volatility in net-oil exporting countries and net-oil importing countries? Since different countries have different resource endowments in crude oil, the EPU in different countries causes different influences on crude oil markets. For net-oil exporting countries, they often adjust their economic policies according to the supply and demand of the crude oil market, the substitutability of crude oil products, the technical level, the cost of their own crude oil production, the degree of fiscal dependence on crude oil export, and the risk preference. For net-oil importing countries, they often adjust their economic policies according to their own economic development level, the industrial structure and the pricing ability of the demand side in crude oil markets, the risk preference, etc. Accordingly, the impact of EPU on crude oil price fluctuation in different countries shows heterogeneity. However, we are not clear about it. Therefore, the third objective of this paper is to compare the response of crude oil price volatility to the shocks of EPU in net-oil exporting country and net-oil exporting country.

The main contributions of this paper are as follows. First, the external multi-factor shocks are incorporated into the analysis framework to study the time-varying characteristics of GEPU’s impact on crude oil price fluctuations. The existing research on the dynamic effect of EPU on crude oil price fluctuation is not much. Additionally, the literature on dynamic studies ignored the impact of other key complicated volatility sources of oil price on the relationship between EPU and oil price volatility. Typically, Bekiros et al. [4] compared the application effect on crude oil prices prediction of EPU between time-varying parameter vector autoregressive (TVP-VAR) model and other constant coefficient models. However, they focused on the application comparison of methods. In terms of variable selection, they only consider two variables of EPU and crude oil price, but ignore other key volatility sources. The loss of other key volatility sources makes a difference to the impact of EPU on oil price fluctuation. As we found in the empirical process, based on the basic TVP-VAR framework made up of GEPU and crude oil price fluctuation, when we add a new key volatility source into the framework in turn, the results of GEPU’s impact on crude oil price fluctuation change significantly. Consequently, other key volatility sources are not negligible. Therefore, in this paper, the introduction of the time-varying parameter factor-augmented vector autoregressive (TVP-FAVAR) model included many volatility sources, and not only effectively avoids important information loss, but can also capture the time-varying characteristics of GEPU’s influence on crude oil price fluctuation.

Second, based on the time-varying characteristics, combined with the event analysis, the instantaneous impact of GEPU on crude oil price volatility is analyzed. The oil price volatility reacts differently to GEPU’s shock, when some different rare events occur. However, it received little attention. In this paper, according to the multiple attributes of crude oil, including commodity attribute, financial attribute, and political attribute, rare events are divided into three categories: Commodity market event, financial market event, and political event, from which representative events are selected to analyze and compare the heterogeneity of time-varying characteristics of instantaneous shocks. Our results show that the instantaneous impacts of GEPU on the price volatility of crude oil are different in event types, and the differences are embodied by the length, range, and velocity of shocks.

Third, the paper studies the difference of the impact of EPU in countries who are net-oil exporting and net-oil importing on crude oil price fluctuation. Different countries have different resource endowments in crude oil, thus leading to the different influence on crude oil markets, and further result in the heterogeneity of the impact of EPU on crude oil price fluctuation. However, it has not been paid special attention to in the existing literature. As a consequence, we select several main net-oil exporters and net-oil importers as samples, and compare the heterogeneity from different perspectives. Through the empirical research, this paper finds that the time-varying impact of EPU on the fluctuation of crude oil price not only has spatial differences in the fluctuation range and fluctuation intensity, but also has stage differences in the action degree, change speed, and change direction, especially after the global financial crisis.
The rest of this paper is arranged as follows: Section 2 presents a brief literature review. Section 3 constructs the TVP-FAVAR model and describes the data. Section 4 gives the main results. Section 5 makes further discussions. Section 6 draws the conclusion of this paper.

2. Literature Review

Our study is related to much existing research. In this section, we revisit the literature on the subject. First, many studies examined the impact of EPU on crude oil price fluctuations by different proxy variables and different static methods. Key previous studies and brief descriptions are presented in Table 1. In general, in terms of proxy variables, some literatures used several related alternative indicators like global industrial production volatility. But since Baker et al. [22] created the EPU index, many empirical studies have emphasized the importance of the EPU index in explaining and predicting the volatility of crude oil price. In terms of approaches, four kinds of methods have been used in the literature: (1) Vector autoregressive (VAR) model and its variants. Typically, Van Robays [23] investigated the impact of macroeconomic uncertainty on crude oil price fluctuations employing a threshold VAR model. He concluded that the greater the macroeconomic uncertainty is, the greater the oil price volatility is. (2) Non-parametric quantile causal test. Balcilar et al. [24] used this method to analyze the predictive ability of EPU in oil price fluctuations. Their empirical results indicate that EPU drives oil price fluctuations. (3) Structural equation model. Wang and Sun [25] studied the impact of EPU and other determinants (demand, supply, and economic activity) on oil price by a structural equation model, and found that economic activity is the most significant factor in explaining the volatility of oil price. (4) Generalized autoregressive conditional heteroskedasticity with mixed data sampling (GARCH-MIDAS) model. For instance, making use of this approach, Wei et al. [2] combined the GEPU index and several national EPU indexes with traditional determinants (such as global oil supply, oil demand, and speculation) to explain the crude oil price fluctuations. Overall, these literatures provide enough evidence that EPU is an important driven factor for crude oil price volatility. However, they didn’t pay much attention on the time-varying characteristics.

Table 1. The static impact of EPU on oil price volatility in previous studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Proxy Variables of EPU</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakas and Triantafyllou [26]</td>
<td>several alternative measures of EPU</td>
<td>vector autoregressive (VAR) model</td>
</tr>
<tr>
<td>Van Robays [23]</td>
<td>global industrial production volatility</td>
<td>threshold VAR model</td>
</tr>
<tr>
<td>Balcilar et al. [24]</td>
<td>GEPU index</td>
<td>non-parametric quantile causal test</td>
</tr>
<tr>
<td>Wang and Sun [25]</td>
<td>Some national EPU indexes</td>
<td>structural equation model</td>
</tr>
<tr>
<td>Wei et al. [2]</td>
<td>GEPU index and several national EPU indexes</td>
<td>generalized autoregressive conditional heteroskedasticity with mixed data sampling (GARCH-MIDAS) model</td>
</tr>
<tr>
<td>Mei et al. [27]</td>
<td>EPU index</td>
<td>GARCH-MIDAS model</td>
</tr>
</tbody>
</table>

Second, a few literatures studied the dynamic relationship between EPU and crude oil price, but the time-varying impact of EPU on oil price fluctuation doesn’t consider other interrelated factors. For example, Yang [3] analyzed the relationship between EPU and crude oil price by introducing the wavelet analysis method into the structural vector autoregressive (SVAR) framework proposed by Diebold and Yilmaz [28,29]. The analysis results of dynamic net spillover indicated that crude oil prices behave like the recipients of EPU information. However, the causal relationship between EPU and oil price increases over time. Bekiros et al. [4] employed the classical vector autoregressive (VAR) model, Bayesian VAR model, and TVP-VAR model respectively to examine the prediction effect of EPU on crude oil price. He found that EPU plays an important role in predicting oil price out-of-sample, especially when accounting for their adaptive nonlinear relationship via a time-varying coefficient approach. In addition, a few literatures studied the dynamic relationship between EPU and crude oil price from the perspective of dynamic correlation coefficient [30,31]. However, in the analytical framework of the aforementioned literatures, main influencing factors are not included completely. For instance, Yang [3] just put the EPUs of G7 countries and oil price in their model.
Bekiros et al. [4] only selected two variables of oil price and EPU index, and ignored other key volatility sources. In fact, just as Wei et al. [2] claimed, oil price has various uncertain determinants, and different determinants are related. Thus, there might exist a bias in their conclusions because of the loss of important information. In addition, the objective of Bekiros et al. [4] is the application comparison of methods. In such conditions, it is necessary to study the time-varying impact of EPU on crude oil price fluctuation from a broad multi-factor perspective.

In particular, there is a study involved in the national difference of the impact of EPU across net-oil exporting countries and net-oil importing countries. In the study of Antonakakis et al. [1], taking the net net-oil exporting countries and net net-oil importing countries as samples, they used a dynamic spillover index to capture the dynamic relationship between oil price changes and EPU. The empirical result shows that EPU is the main transmitter of the shock on oil price volatility between 1997 and 2009. Specially, they found the impact of EPU on crude oil price fluctuations has country-wide differences. Nevertheless, the research has some shortages. On the one hand, the research has not yet further investigated the specific difference of the time-varying impact of EPU on crude oil price volatility from the perspective of the two groups of net-oil exporting country and importing country. On the other hand, it didn’t take the time variation and other volatility sources into account. We think there are both spatial and time heterogeneity of the time-varying impact of different countries’ EPU on crude oil price volatility. Therefore, in view of data availability, this paper fills these gaps by selecting two groups of main net-oil exporting countries and importing countries and using the TVP-FAVAR model.

3. Method

3.1. Model Specification

In this paper, we attempt to construct a TVP-FAVAR model to study the time-varying impact of EPU on oil price volatility. The reasons are as follows. First, crude oil price volatility is subject to multiple external shocks. The relationship between multiple influencing factors is very complex and interrelated. For example, geopolitical risk (GPR) and EPU are correlated, especially around 9/11 and the Iraq war. The interactive relationship between EPU and other volatility sources makes a difference to the impact of EPU on crude oil price volatility. Thus, when studying the impact of EPU on crude oil price volatility, we cannot ignore other key volatility sources of crude oil price. Second, the time-varying characteristics of the impact of EPU on crude oil price fluctuations is necessary to take into account. Third, since the TVP-VAR model has the limitations of model recognition, it fails to incorporate broader volatility sources into the analysis framework. Therefore, this paper uses the researches of Korobilis [32], and Koop and Korobilis [33] for reference, constructs the factor augmented vector autoregression model based on the classical VAR model [34], then conducts time-varying processing on the coefficient matrix of the model [35], and constructs the TVP-FAVAR model. Based on the classic VAR model, this model introduces the idea of dynamic factor expansion and extracts the commodity attribute and financial attribute variables that affect the crude oil price as two common factors, which not only effectively avoid the problem of missing information related to the influencing factors of crude oil price, but also consider the complex relationship between these influencing factors by extracting common factors. In addition, it overcomes the limitations of TVP-VAR model recognition. This paper used the time-varying characteristics of parameter matrix and covariance matrix to capture the dynamic impact of EPU on crude oil price volatility. The p-order TVP-FAVAR model is as follows:

$$x_t = \lambda_y^y y_t + \lambda_f^f f_t + \mu_t
$$

$$\begin{bmatrix} y_t \\ f_t \end{bmatrix} = \epsilon_t + B_{t,1} \begin{bmatrix} y_{t-1} \\ f_{t-1} \end{bmatrix} + \ldots + B_{t,p} \begin{bmatrix} y_{t-p} \\ f_{t-p} \end{bmatrix} + \epsilon_t$$

(1)

The TVP-FAVAR is made of factor model and VAR equations. Where $x_t$ (for $t = 1, 2, \ldots, T$) is a $13 \times 1$ vector. These 13 variables are factor variables with commodity and financial attributes affecting crude oil price volatility, including variables affecting oil supply, oil demand, inventory, crude oil
speculation, global liquidity and exchange rate, etc. Due to data availability issues, we only select global GPR as the proxy variable of geopolitical factor. In order to ensure the accuracy of the common factors extracted, we don’t include GPR in \(x_t\). Thus, we set \(y_t = (GPR_t, EPU_t, OPV_t)'\), a 3 \(\times\) 1 vector, where \(GPR_t, EPU_t, OPV_t\) represent GPR, GEPU or country EPU, and crude oil price volatility at time \(t\), respectively. \(f_j\) is 2 \(\times\) 1 common vector extracted from \(x_t\), representing supply and demand factors and financial factors, respectively. \(\lambda^y_t\) is the regression coefficient; \(\alpha^f_t\) is the intercept; \(B_{ij}\) is the VAR coefficient; \(\epsilon_t \sim N(0, \Omega_t)\); \(u_t = r_{1t}u_{t-1} + \cdots + r_{qt}u_{t-q} + v_t\), \(v_t \sim N(0, \exp(h_t))\). This paper adopts the recognition hypothesis commonly found in the factor literature, and assumed that \(E(\epsilon_{it}f_t) = 0\), \(E(\epsilon_{it}\epsilon_{js}) = 0\) for all \(i,j = 1,\ldots,13, i \neq j\) and \(t, s = 1,\ldots,T, t \neq s\).

This model is very flexible, since it allows all parameters to take a different value at each time \(t\). Such an assumption is important, since there is good reason to believe that there is time variation in the loadings and covariances of factor models, which use both financial and macroeconomic data [32,33,36,37]. To estimate the model, we need to define the evolution of the time varying parameters. First, \(\lambda_t = \left(\lambda^y_t, \alpha^f_t\right)'\) and \(\beta_t = \left(\alpha^f_t, \text{vec}(B_{i1})', \ldots, \text{vec}(B_{ip})'\right)'\), subject to a multivariate random walk process, i.e.,

\[
\begin{align*}
\lambda_t &= \lambda_{t-1} + \gamma_t \\
\beta_t &= \beta_{t-1} + \eta_t
\end{align*}
\]

where \(\gamma_t \sim N(0, W_t)\) and \(\eta_t \sim N(0, R_t)\). \(W_t\) and \(R_t\) are covariance matrices. All the disturbance terms in the above equations are not correlated with time or with each other.

In addition, the VAR system in (1) is with drifting coefficients and stochastic volatility. Following Primiceri [35], we define the covariance matrix \(\Omega_t\) of the disturbance term \(\epsilon_t\) is a time-varying process,

\[
\Omega_t = A_t^{-1}\Sigma_t'A_t
\]

where \(\sigma_{ij}\) is the diagonal elements of \(\Sigma_t\). Let \(a_1 = a_{21}, a_{31}, a_{32}, \ldots, a_{k+1,1}'\) represent a stacked vector of the lower-triangular elements in \(A_t\). And \(h_t = (h_{11}, h_{21}, \ldots, h_{kt})'\) with \(h_{ij} = \log \sigma_{ij}^2\), for \(h_{ij} = \ln \sigma_{ij}^2 (j = 1, 2, \ldots, k; t = s + 1, \ldots, n)\), thus \(h_{i+1} = h_i + \alpha_i\). Where \(\sigma_{ii} \sim N(0, S_i)\), \(S_i\) is a covariance matrix.

### 3.2. Data Description

The data frequency in this paper is monthly, and the time span is from January 1997 to June 2019 (1997m1–2019m6, “m” represents month). The following reasons are mainly considered: First, most of the published EPU indexes are based on monthly data, and the global monthly EPU index starts from January 1997. Second, the latest updated Kilian index data, which represents global economic activity, only runs until June 2019. At the same time, some missing data are filled by means of cubic spline interpolation.

The variables in this paper are mainly of five aspects, namely, EPU, geopolitical variables, crude oil supply and demand related variables, related financial variables, and international crude oil price. The variables and data sources are shown in Table 2. First, in order to measure the EPU, we draw on the practice of Li and Zhong [38], and Bahmani-Oskooee and Saha [39], and adopt the EPU index compiled by Baker et al. [22]. We not only select the GEPU index, but also the EPU indexes of 3 major net-oil exporting countries (Russia, Canada, and Brazil) and 3 major net-oil importing countries (China, the United States, and Japan). Second, geopolitical factor can lead to differences in crude oil exporting countries’ expectations of future oil supply and demand, and influence current oil inventory decisions and prices [13,17,19,40–42]. Hence, we refer to Caldara and Iacovielloz [43], Liu et al. [17], Miao et al. [44], and use the global GPR to measure geopolitical factor.
Table 2. Variables and data sources.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Proxy Variables</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil price</td>
<td>Brent crude oil spot price</td>
<td>Energy Information Administration (EIA)</td>
</tr>
<tr>
<td>EPU</td>
<td>Global EPU index, Russia, Canada, Brazil, China, U.S., Japan EPU index</td>
<td><a href="http://www.policyuncertainty.com/">http://www.policyuncertainty.com/</a></td>
</tr>
<tr>
<td>geopolitics</td>
<td>Geopolitical risk index</td>
<td><a href="https://www2.bc.edu/matteo-iacoviello/gpr.htm">https://www2.bc.edu/matteo-iacoviello/gpr.htm</a></td>
</tr>
<tr>
<td>Crude oil speculation</td>
<td>Organization for Economic Co-operation and Development (OECD) crude stocks/EIA U.S. crude stocks</td>
<td>Economy Prediction System China Data (EPS), EIA</td>
</tr>
<tr>
<td>US dollar exchange rate</td>
<td>US dollar real effective exchange rate index</td>
<td>Bank for International Settlements (BIS)</td>
</tr>
<tr>
<td>Global liquidity</td>
<td>World crude oil production volatility index (VIX)</td>
<td>BIS</td>
</tr>
<tr>
<td></td>
<td>London Interbank Offered Rate (LIBOR)</td>
<td>International Monetary Fund (IMF)</td>
</tr>
<tr>
<td></td>
<td>US short-term interest rate</td>
<td>IMF</td>
</tr>
<tr>
<td></td>
<td>Europe short-term interest rate</td>
<td>IMF</td>
</tr>
<tr>
<td></td>
<td>Japan short-term interest rate</td>
<td>IMF</td>
</tr>
<tr>
<td>Crude oil supply</td>
<td>Organization of Petroleum Exporting Countries (OPEC) crude oil remaining capacity</td>
<td>EIA</td>
</tr>
<tr>
<td>Crude oil demand</td>
<td>Global economic activity index</td>
<td><a href="https://sites.google.com/site/lkilian-2019/home">https://sites.google.com/site/lkilian-2019/home</a></td>
</tr>
<tr>
<td></td>
<td>OECD crude oil demand</td>
<td>EPS</td>
</tr>
<tr>
<td>Crude oil inventory</td>
<td>US crude oil inventory</td>
<td>EIA</td>
</tr>
<tr>
<td></td>
<td>OECD crude oil inventory</td>
<td>EPA</td>
</tr>
</tbody>
</table>

Third, some empirical results propose the viewpoint that market supply and demand decide the price of crude oil [14,15,45]. Thus, in this paper, crude oil supply and demand variables are extracted from the aspects of crude oil supply, crude oil demand, and crude oil inventory. Crude oil supply factors include: (1) Organization of Petroleum Exporting Countries (OPEC) remaining crude oil production capacity. The U.S. Energy Information Administration (EIA) described OPEC countries’ excess crude oil capacity as a useful indicator of the overall supply situation in the market [46]. Overcapacity tends to stabilize global markets and help ease supply disruptions. (2) Global crude oil production. Global crude oil production includes OPEC and non-OPEC production. Crude oil production is often influenced by geopolitical developments and factors such as weather-related events, exploration and production costs, investment, and innovation. In terms of crude oil demand factors, Organization for Economic Co-operation and Development (OECD) crude oil demand is selected according to the availability and representativeness of data. Based on the practice of Wei et al. [2], the global economic activity index composed of dry freight index compiled by Kilian and Park [47] is selected. The real activity index is a business-cycle index designed to capture changes in global industrial commodity use. The crude oil inventory factor mainly includes OECD crude oil inventory and US crude oil inventory recorded by EIA.

Fourth, the related financial variables are mainly extracted from crude oil speculative attribute, global liquidity and U.S. dollar exchange rate. With the improvement of financialization of crude oil, speculation plays an increasingly important role in crude oil price fluctuation [16,48,49]. Specifically, in the selection of crude oil speculation indicators, we refer to Hamilton [14], Kilian and Murphy [16], and Wei et al. [2], and use the ratio of OECD oil inventories to U.S. oil inventories recorded by the EIA to represent oil speculation. As for global liquidity, first of all, as the pricing currency of oil, the U.S. dollar has a natural relationship with the oil price [20,50]. Second, according to the research of Arora and Tanner [51], Wang and Chueh [52], and Beckmann et al. [12], the interest rate affects the U.S. dollar exchange rate, which in turn affects the crude oil futures price and thus affects the fluctuation of international crude oil price [13]. When the Fed lowers interest rates to boost the economy, market expectations for oil demand will change, leading to crude oil price volatility. Hence, this paper selects the real effective U.S. dollar exchange rate index published by Bank for International Settlements (BIS) as well as four main interest rate indexes, namely, London Interbank Offered Rate (LIBOR), U.S. short-term interest rate, Japan short-term interest rate, and Europe short-term interest rate. Interest rate
data comes from the International Monetary Fund (IMF). Besides that, stock market is closely linked to oil price [53–55], thus this paper also selects VIX (volatility index), whose data come from BIS.

In addition, at present, more than 65% of the world’s physical crude oil is priced by the Brent system, which is the benchmark of oil price in the market. Therefore, Brent crude oil spot price published by the EIA is used for crude oil price. The descriptive statistics of relevant data are shown in the Table A1 in Appendix A.

However, crude oil price volatility is a core variable in the research process, which cannot be directly derived from the original variable and needs to be extracted by relevant methods. Crude oil price fluctuations have the autoregressive conditional heteroskedasticity (ARCH) effect [56]. The ARCH family model method is one of the most common methods to extract volatility based on historical information. Among them, generalized autoregressive conditional heteroskedasticity (GARCH) model conveniently describes the high-order ARCH process, so it has strong applicability. Therefore, the single variable GARCH model is used to extract crude oil price volatility in this paper. (See Formula B1 in Appendix B). The crude oil price is stable after the first-order logarithmic difference treatment. The autocorrelation and partial autocorrelation test results of the processed crude oil price series (see Figures A1 and A2 in Appendix A) show that the autocorrelation and partial autocorrelation graphs are 2-order and 1-order truncation. According to Akaike Information Criterion (AIC) and Schwarz Criterion (SC) information criterion, GARCH (1,1) is selected in this paper (see Table A2 in Appendix A). Thus, the trend of crude oil price volatility extracted by autoregressive moving average model (ARMA) (1,2)-GARCH (1,1) process is shown in Figure 2. As can be seen from Figure 2, there are differences in the degree of crude oil fluctuation at different time points. First, crude oil price volatility fluctuated most frequently before 2004. Second, there are significant differences in the performance of oil price before, during, and after the global financial crisis. From the entire sample range, oil price volatility during the global financial crisis reached its peak. In periods of 2004–2007 before the global financial crisis and 2010–2014 after the crisis, the fluctuation range of crude oil price is small, which is consistent with the research conclusions of Salisu and Fasanya [57]. In addition, since 2015, crude oil price volatility has experienced another sharp rise to an obvious peak and then a rapid decline. After a period of stability, significant fluctuations appear in 2019. This indicates that in the face of major political or financial turmoil, a period of low volatility in crude oil price may be followed by a period of high volatility [58].

![Figure 2. Crude oil price volatility trend.](image-url)
Moreover, when establishing the model set in this paper, relevant data need to be preprocessed and tested. According to the general data preprocessing method, all variables are processed by first-order logarithmic difference or first-order horizontal difference. Among them, crude oil speculation, global economic activity index, and all interest rate variables are treated with first-order horizontal difference, while the rest of the variables are treated with first-order logarithmic difference. Lastly, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test results show that all the variables are stable after treatment. The unit root test results are available upon request from the authors.

4. Results

4.1. Overall Time-Varying Characteristics of the GEPU’s Impact on Crude Oil Price Fluctuation

Based on the model specification in Section 3.1, the EPU in the TVP-FAVAR model is replaced by GEPU. Then, the model parameters were estimated by referring to the Gibbs sampling technique of Kim and Nelson [59], Gerlach et al. [60], and the two-step estimation method of Stock and Watson [61]. The first step is to extract the common factor by the standard principal component method. The second step is to treat the common factor as the unobservable parameter and estimate it and other parameters in the model with the Bayesian method. The prior information used for parameter estimation in this paper is following Korobilis [32]. Combined with AIC and SC criteria, the VAR model with a lag of 2 stages is constructed.

Then, the impulse response is calculated as follows. First, in order to calculate the impulse response, we transform the VAR system in the TVP-FAVAR model to its vector moving average (VMA) representation:

\[ y_t = \sum_{j=0}^{\infty} A_{jt} \epsilon_{t-j} \]  \hspace{1cm} (4)

where \( A_{jt} \) is a \( N \times N \) recursively matrices. Next, based on the VMA, the impulse response functions (IRF) of variable \( j \) to variable \( i \) at time \( t \) with H-step-ahead forecast can be calculated:

\[ IRF_{i,j,t}^g(H) = S_t^{-1/2} A_{pd} \sum_t \epsilon_{ij,t} \]  \hspace{1cm} (5)

where \( IRF_{i,j,t}^g(H) \) is the generalized IRF. \( S_t \) is a time-varying variance-covariance matrix of error disturbance vector \( \epsilon_t \). \( \Sigma_t \) represents the covariance matrix for the error \( \epsilon_{ij,t} \). Obviously, the IRF is three-dimensional.

To investigate the overall dynamic characteristics of GEPU’s impact on crude oil price fluctuations from time dimension and response dimension (Time dimension refers to the occurrence time of EPU impact, while response dimension refers to the duration of impact on crude oil price fluctuations.), we draw a three-dimensional impulse response diagram, as shown in Figure 3. Where the X-axis represents the duration of response of crude oil price fluctuations to shocks, the Y-axis represents the time of GEPU shocks, and the Z-axis represents the response degree of crude oil price fluctuations to shocks.
The impact degree shows an overall upward trend of fluctuation. From the direction of short-term impact, most of the time-points, the GEPU has a positive effect on crude oil price fluctuation. However, with the passage of time, the GEPU has a longer lasting effect on crude oil price volatility.

Second, the impact of GEPU on crude oil price volatility has time-varying characteristics in time dimension. The time-varying characteristics of the impact of GEPU on crude oil price fluctuation at different time points are more obvious in the short term, and these obvious time-varying characteristics are mainly manifested in two aspects. On the one hand, the degree and direction of short-term effect change in time dimension. From the perspective of the impact degree, during the sample period from 1997m2 to 2019m6, the impact degree shows an overall upward trend of fluctuation. From the direction of short-term impact, most of the time-points, the GEPU has a positive impact on the crude oil price volatility, that is, the greater the GEPU value is, the greater the impact on the crude oil price volatility is.

At the same time, the GEPU also presents a period of negative impact on the crude oil price volatility, and the negative impact generally occurs between 2005 and 2007. On the other hand, the periodic peak points of the short-term shock curve of GEPU on crude oil price fluctuations mainly appear at a certain point during some major events, but the peaks vary in size. For example, the peak in 1998 corresponds to the Asian financial crisis in 1998; the peak in 2000 corresponds to the bursting of the Internet bubble; the peak in 2003 corresponds to the Iraq war in 2003. Peaks in 2008, 2015, and 2018 correspond to the global financial crisis in 2008, a slump in global commodities in 2015, and the trade war between China and the United States, respectively.

4.2. Time-Varying Characteristics of the Instantaneous Impact of GEPU on Crude Oil Price Fluctuation

It has been observed from the Section 4.1 that GEPU’s impact on crude oil price volatility is not only time-varying in time dimension and duration, but also directly related to rare events. This paper describes the impact of GEPU on crude oil price fluctuation caused by major events as instantaneous impact. In order to further study the characteristics of instantaneous shocks of events, we select typical...
time points of different types of events. According to different crude oil price formation mechanism, the major event types can be roughly divided into three categories. As crude oil is the main variety of commodities, its price formation has the commodity attribute, therefore, the instantaneous impact of GEPU on crude oil price volatility is closely related to major events in the commodity market. The Sino-US trade friction in 2018 is a major event of this type. Crude oil, as a basic raw material, will be related to hedging in the financial market in the supply chain. So crude oil price has the attribute of financial products in the formation. The global financial crisis in 2008 is such a major event. In addition, the geopolitical relations are directly related to the supply and demand of crude oil, so they will also cause the instantaneous impact of GEPU on crude oil price fluctuation. Among the time-varying impact, the Iraq war in 2003 is such a major event. Based on this, this paper analyzes the instantaneous impact effect of three major events: The outbreak of the Sino-US trade war (commodity market event) in 2018m7, the global financial crisis (financial market event) in 2008m9 and the Iraq War (geopolitical event) in 2003m4.

The instantaneous impacts of GEPU on crude oil price fluctuation at the times of three major events are plotted into Figure 4. It can be seen from Figure 4 that when different types of major events occur, the instantaneous impact characteristics of GEPU on crude oil price fluctuations are shown in two aspects:

![Figure 4. Responses of crude oil price volatility to GEPU's shock at special time points. Notes: 2003.4, 2008.9, 2018.7 represent April 2003, September 2008, July 2018, respectively.](image)

On the one hand, when different types of major events occur, the instantaneous impact of GEPU on crude oil price fluctuations shows a consistent trend. From the perspective of instantaneous impact direction, at the time points of different events, GEPU has a positive effect on the fluctuations of crude oil price in each period. In other words, after the occurrence of three major events of different types, the larger the GEPU is, the more violent the fluctuations of crude oil price will be. From the trend of instantaneous impact degree, after the occurrence of any major event of any type, the impact of GEPU on crude oil price fluctuations will first increase and then decrease, and the impact effect will reach the maximum in the next two periods. Moreover, when the major events appear, they are generally overreacted in the current period and the next two periods, and tend to be stable after the second period.

On the other hand, under different events, there are significant differences in the length, range, and speed of the impact of GEPU on crude oil price volatility. First of all, from the perspective of the duration of the impact of GEPU on crude oil price fluctuation, the impulse response duration at the two time points of the 2003m4 Iraq war and the 2008m9 global financial crisis is relatively short,
and the impact effect basically disappears in the next 10 periods or so. However, at the time point of the Sino-US trade friction in 2018m7, the impact lasts longest. Secondly, from the perspective of the fluctuation range of GEPU’s impact on crude oil price fluctuation, the response value at the time point of global financial crisis in 2008m9 is relatively small, while that of trade friction in 2018m7 is relatively large. Thirdly, from the perspective of the transmission speed of GEPU’s influence on crude oil price fluctuation, the GEPU transmits to oil price volatility fastest under the event of recent global financial crisis, reaching the maximum in the next first period. While the impulse response values of 2003m4 and 2018m7 both reach the maximum in the next second period.

4.3. Spatial Heterogeneous Effect of EPU on Oil Price Volatility in Net-Oil Exporter and Net-Oil Importer

4.3.1. A Comparison of the Continuous Response of Oil Price Volatility to Country EPU Shocks

This section aims to investigate the spatial heterogeneity between net-oil exporting countries and net-oil importing countries. In terms of method, we still use the TVP-FAVAR model, which is as follows:

\[
x_t = \lambda^y_t y_t + \lambda^f_t f_t + \mu_t
\]

where \(x_t\) (for \(t = 1, 2, \ldots, T\)) is a \(13 \times 1\) vector including 13 factor variables with commodity and financial attributes affecting crude oil price volatility. \(y_t = (GPR_t, CEPU_t, OPV_t)\), a \(3 \times 1\) vector, where CEPU represents a country EPU. Other assumptions are consistent with the model specification in Section 3.1. In terms of the selection of countries of net-oil exporting and net-oil importing, combined with the availability of EPU index data, the three countries of Russia, Canada, and Brazil that have long been top net-oil exporters, and the three countries of China, U.S., and Japan that have long been top net-oil importers, are selected.

Then, keeping other variables unchanged, we replace the country EPU (CEPU) in the model with EPU of each selected country and estimate the model, respectively. The estimation method is same with Section 4.1. Similarly, combining AIC and SC criteria, the lag order of VAR model selection is 2. In addition, we set \(M = 10,000\) times and discard the first 1000 MCMC algorithm samples. Lastly, we obtain the results by the software of MATLAB 2019 a.

Combined with the result in Section 4.1, EPU’s impact on crude oil price volatility is relatively significant in the short term. So, the selected duration of shock is the next fourth period, when the response of oil price volatility to the shocks of EPU in all selected countries on are relatively large. The responses of crude oil price fluctuations to shock of EPU in each country are shown in Figure 5. To intuitively catch the difference, Figure 5 lists the shocks of EPU on prices of crude oil in Russia, Canada, and Brazil on the left, while it lists the shocks of EPU on prices of crude oil in China, United States, and Japan on the right.
First, it can be seen from Figure 5 that the impact of EPU in different net-oil exporting and net-oil importing countries shows significant difference in time-varying characteristics. Obviously, as main net-oil exporting countries, the shocks of EPU on the oil price volatility show time-varying characteristics with large jump fluctuations in Russia, Canada, and Brazil, while the shocks of EPU show time-varying characteristics with small continuous fluctuations in China, United States, and Japan. In addition, the mean fluctuation range of the response of oil price volatility to shocks of EPU in net-oil exporting countries and net-oil importing countries are 0.00558 and 0.00447. This further shows that the fluctuation range of the impact of EPU in net-oil exporting country is greater than net-oil importing country.

Second, we can see from Figure 5 that the shocks from EPU in three net-oil exporting countries on the pricing volatility of crude oil are varying strongly, while the shocks from EPU in three demand countries are varying relatively weakly. To sufficiently reveal the differences, we further calculate the variation coefficient of response value of crude oil price volatility to EPU in three net-oil exporting

Figure 5. Responses of oil price volatility to EPU across net-oil exporting and net-oil importing country. Notes: Net-oil-exporting countries (Russia, Canada, Brazil), net-oil importing countries (China, U.S., Japan).
and three net-oil importing countries at the next fourth period, which is used to compare the intensity fluctuations of shocks. According to the calculating results, the variation coefficient of the response value of oil price volatility to the shock of Russia EPU, Canada EPU, and Brazil EPU are 4.178, 2.399, and 1.399, respectively. For the country of net-oil exporting, the mean variation coefficient is 2.64. While the variation coefficient of the response value of oil price volatility to the shock of China EPU, US EPU, and Japan EPU are 1.086, 2.101, and 2.355, respectively. For the country of net-oil importing, the mean variation coefficient is 1.84. Obviously, the intensity fluctuations of shocks from EPU in net-oil exporting countries on price of crude oil are stronger than net-oil importing countries.

4.3.2. A Comparison of Relative Importance of Country EPU on Oil Price Volatility

Section 4.3.1 has shown that the pricing volatility of crude oil shocked by EPU in net-oil exporting and net-oil importing countries shows differences in different times points. However, we are not clear on the relative importance of EPU on the pricing volatility in net-oil exporting and net-oil importing countries. This paper adopts the methods Antonakakis et al. [62], and Antonakakis et al. [63] to calculate the average dynamic spillover, which improves the ordinary method calculating spillover index proposed by Diebold and Yilmaz [28,29]. The measurement of spillover index based on TVP-VAR model instead of the rolling-window estimation can adjust immediately to events. We put EPUs in the six selected countries and crude oil price volatility into the TVP-VAR framework. Based on the generalized forecast error variance decomposition (GFEVD), the formula of average dynamic spillover index is as follow:

$$\text{average dynamic spillover index} = \frac{\sum_{t=1}^{T} \tilde{\phi}_{CEPU,OPV,t}^{g}(H)}{N \times T}$$

where $\tilde{\phi}_{CEPU,OPV,t}^{g}(H)$ is the H-step-ahead GFEVD in forecasting variable OPV (oil price volatility) that is due to the shocks of variable CEPU (a country EPU). $N$ represents the number of variables in the framework, $T$ represents the sample size. The details of calculating the average dynamic spillover of crude oil price can be referred to Formula B2 in Appendix B. The calculating results are shown in Table 3.

<table>
<thead>
<tr>
<th>Net-Oil Exporter</th>
<th>Russian</th>
<th>Canada</th>
<th>Brazil</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>spillover</td>
<td>1.319%</td>
<td>1.192%</td>
<td>1.089%</td>
<td>1.20%</td>
</tr>
<tr>
<td>net-oil importer</td>
<td>China</td>
<td>Japan</td>
<td>US</td>
<td>mean</td>
</tr>
<tr>
<td>spillover</td>
<td>0.576%</td>
<td>0.894%</td>
<td>1.085%</td>
<td>0.85%</td>
</tr>
</tbody>
</table>

Notes: Variance decompositions are based on 10-step-ahead forecasts, a time-varying parameter vector autoregressive (TVP-VAR) lag length of order 2.

Overall, the importance of EPU in net-oil exporting countries on the pricing volatility of crude oil is higher than that in net-oil importing countries. From Table 3, with regard to individual country, the average dynamic spillover from EPU to pricing volatility of crude oil in every net-oil exporting country is stronger than that in every net-oil importing country. With regard to ensemble, the mean of the average dynamic spillover from EPU to the pricing volatility of net-oil exporting countries (1.20%) is stronger than that net-oil importing countries (0.85%).

4.4. Time Heterogeneous Effect of EPU on Oil Price Volatility in Net-Oil Exporter and Net-Oil Importer

EPUs in net-oil exporters and net-oil importers have time-varying impacts on crude oil price, but this time-varying effect also has difference in stages. That is, taking the event as a stage, the time-varying characteristics in the previous phase of the event are basically the same, and the time-varying characteristics in the phase after the time are basically the same. In this section, we mainly compare the stage differences of the shocks of EPU in net-oil exporting and net-oil importing countries on the crude oil price fluctuation in time.
Based on the estimate results in Section 4.3.1, the impulse response of crude oil price fluctuation to three net-oil exporting country EPUs’ shocks (Russia, Canada, Brazil) and three net-oil importing country EPUs’ shocks (China, United States, Japan) in the next fourth period are averaged, respectively. According to the calculation of impulse response in Section 4.1, the measurements of the average impulse response are as follows:

\[ A_{ex}IRF^g_t = \frac{IRF^g_{REPU, OPV} + IRF^g_{CEPU, OPV} + IRF^g_{BEPU, OPV}}{3} \]  \tag{8}

\[ A_{im}IRF^g_t = \frac{IRF^g_{ChEPU, OPV} + IRF^g_{UEPU, OPV} + IRF^g_{JEPU, OPV}}{3} \]  \tag{9}

where \( A_{ex}IRF^g_t \) and \( A_{im}IRF^g_t \) represent the spatial average generalized impulse response of oil price volatility to shocks of net-oil exporting country EPU and net-oil importing country EPU, respectively. REPU, CEPU, BEPU, ChEPU, UEPU, and JEPU represent EPU in Russia, Canada, Brazil, China, US, and Japan, respectively. \( IRF^g_{REPU, OPV} \) represents the generalized IRF of oil price volatility to shock of Russia EPU.

The spatial average impulse responses of oil price volatility to the shocks of EPU in net-oil exporting countries and in net-oil importing countries are shown in Figure 6. From Figure 6, there are stage differences in the spatial average shocks of net-oil exporting and net-oil importing countries’ EPU on crude oil price fluctuation, especially in the post global financial crisis.

![Figure 6](image_url)

Figure 6. The spatial average response of crude oil price fluctuation to the EPU shocks of net-oil exporter and net-oil importer in the fourth period.

On the one hand, the spatial average impact of EPU in net-oil exporter and net-oil importer on crude oil price fluctuations has a stage difference in the degree. As can be seen from Figure 6, for example, from 2014m6 to 2015m9, the average shock of EPU in net-oil exporting countries on crude oil price is significantly greater than in net-oil importing countries. While, in the period of the Sino-US trade war from 2018m9 to 2019m6, the average shock of net-oil importer EPU on crude oil price fluctuation is greater than that of net-oil exporter EPU.

On the other hand, the average impact of EPU in net-oil exporter and net-oil importer on crude oil price fluctuations has a stage difference in the speed and trend of change. From the speed of change, shortly after the end of the financial crisis (2009m6–2011m6), the shock of net-oil exporter EPU on crude oil price fluctuation declines sharply, while net-oil importer country EPU’s shock on crude oil
price fluctuation falls relatively slowly. From the trend of change, during 2014m6–2015m9, when crude oil prices plummets, the shock of net-oil exporter EPU on crude oil price fluctuations shows an inverse V shape that the shock increases first and then decreases. The shock of net-oil importer EPU on crude oil price fluctuations shows the opposite, with a V-shape that decreases first and then increases.

5. Discussion

5.1. Understanding of the Time-Varying Impact of GEPU on Oil Price Fluctuation

First, why is the direction of short-term impact of GEPU on oil price fluctuation negative in the period of 2005–2007? In order to explain it, we could analyze from the feature of GEPU trend. The GEPU is relatively low during this period of 2005–2007 (see Figure 1), which indicates that the adjustment range of economic policies is not large. Combined with the global economic development in this period, the global economy, especially the emerging markets, is relatively prosperous. When the economy is in a stable period, the government generally does not make frequent adjustments to economic policies, and the formation of crude oil price fluctuations is more influenced by demand and other factors [14]. In other words, the adjustment of GEPU has a positive feedback mechanism, that is, it is positively promoting economic growth and stability, while the fluctuation of crude oil price is, on the contrary, decreasing.

Second, what does it mean that the periodic peak points of the short-term shock mainly appear at a certain point during some major events and the peaks vary in size? Obviously, the characteristics of periodic peak points indicates that the impact degree of GEPU on crude oil price volatility is strongly related to with major events. What’s more, there is a strong correlation between the mechanism of the impact of GEPU on crude oil price fluctuations and major events and the nature of the events themselves. For example, political events and economic events have different influences on crude oil price fluctuations. Geopolitics and other major events have a direct impact on oil supply and demand. While financial crisis, trade friction, and other major economic events often occur because governments frequently intervene in the economy to deal with economic events and significantly improve the GEPU. Thus, this causes the crude oil price volatility to show a strong positive reaction to the impact of GEPU [1].

In addition, why the instantaneous impact of GEPU are different in event types? Looking into the reason of it, different major events lead to jump shocks, which generated from commodity market, financial markets, and geopolitics, corresponding to commodity attribute, financial attribute, and political relations among the net-oil exporters and net-oil importers. Specifically, on the one hand, the absorption process of different major events has some different situations, such as slow response and overreaction. In other words, the length of smooth trailing in the later period of the instantaneous impact is directly related to the duration of major events. For example, the China-US trade friction in 2018 lasts for a long time, thus the subsequent GEPU has a longer impact on the crude oil price volatility at the time point of the full outbreak of the event. On the other hand, the larger degree of the impact of GEPU under the China-US trade friction is mainly attributed to the increasing degree of economic globalization and international cooperation.

5.2. Explanation of the Spatial Heterogeneous Effect of EPU in Net-Oil Exporter and Net-Oil Importer

According to the feature of fluctuation of impulse response in Section 4.3.1, the price fluctuation of crude oil responses to EPU in net-oil exporting countries is more sensitive than in net-oil importing countries. This may originate from the difference of EPU levels. For example, except for the period during 2000 to 2003 (bursting of internet bubble in America and 911 terrorist incident) and the period during 2008 to 2009 (financial crisis), the overall EPU in Russia (net-oil exporter) is higher than that in United States (net-oil importer) (see Figure A3 in Appendix A), which results in that the shocks from EPU in Russia on the price of crude oil are stronger than that in America.
With regard to the different importance of EPU in net-oil exporting and net-oil importing countries on the pricing volatility of crude oil, we could explain from the actual situation. Due to the continuous increase of production capacity in non-OPEC members like Russia, Canada, and Brazil, who are main net-oil exporting countries, oil export has been one of their main financial sources. They are undermining the pricing power of OPEC on the world crude oil market. Once facing international economic crisis or excess crude oil capacity that further influence their financial situation, economic growth as well as the forex market, these countries will continuously adjust relevant economic policies, like expending production or supporting the production of energy enterprises. Thus, the change of EPU in net-oil exporter lead to strong volatility of international crude oil market. However, as net-oil importing countries like United States, China, and Japan, their real economic activities impact directly on the price of crude oil. In the past twenty years, these countries devoted to developing their economics. Except during the financial crisis, their situations of economic development are stable. Hence, the EPU in net-oil importing countries shows weak effect on the price of crude oil except during the financial crisis. This results in the fact that the average effect of EPU on pricing volatility of crude oil in net-oil importing countries is smaller than that in net-oil exporting countries.

5.3. Understanding of the Stage Difference of the Impact of EPU in Net-Oil Exporter and Importer

In this section, the reasons for some significant stage differences of the impact of EPU in net-oil exporter and net-oil importer on crude oil price fluctuations described in Section 4.4 are discussed. For example, during 2014m6–2015m9, the average shock of net-oil exporting countries EPU on crude oil price is significantly greater than that of net-oil importing countries. It attributes to the real background. Since the second half of 2014, crude oil prices plummeted due to oversupply of global oil, OPEC price wars, and the rise of shale oil in North America. The plunge in oil prices had a huge impact on the economy and oil production of OPEC and non-OPEC net-oil exporting countries. Thus, crude net-oil exporters such as Russia, Canada, and Brazil actively adopted the adjustment of economic policies and their EPU levels increased. Conversely, the plunge in oil prices is generally good for net-oil importing countries, and their EPU levels are relatively low. Therefore, the average shock of net-oil exporting country EPU on crude oil price fluctuations during this period is significantly greater than net-oil importing country EPU. While, in the period of the Sino-US trade war, the result is reversed. Because both China and the United States are major net-oil importing countries. The Sino-U.S. trade war caused a serious impact on China, the export-oriented world’s second largest economy. China’s EPU level increased significantly, which had a major impact on crude oil price fluctuations. While the net-oil exporter is relatively less affected by the Sino-US trade war, so its EPU has relatively less impact on crude oil price fluctuations. In addition, during 2009m6–2011m6, the shock of EPU in net-oil exporter has a faster rate of change than the EPU in net-oil importer. The reason is that the EPU of the net-oil exporter directly affects the crude oil market price by affecting the supply of crude oil, while the EPU of the net-oil importer first affects the actual economic activities [7,9] and then affects the demand for crude oil, which in turn affects the fluctuation of crude oil prices [4,6].

Based on the above discussion, we could conjecture that the stage difference in the shock of EPU in net-oil exporting and net-oil importing countries on crude oil price fluctuation is relevant to the dominant position of supply and demand. When the average impact of EPU in net-oil exporting countries on crude oil price is greater than in net-oil importing countries, the crude oil price at this stage is dominated by supply pricing. Whereas when the average shock of the net-oil exporters EPU on crude oil price fluctuation is significantly smaller than that of the net-oil importer EPU, the crude oil price at this stage is dominated by demand pricing. In addition, the strong correlation between the stage difference in the shock of EPU on oil price volatility and the dominant position of supply and demand also shows that crude oil prices are dominated by commodity attributes as the formation mechanism.
6. Conclusions

In this paper, we study the time-varying effect of EPU on pricing volatility of crude oil by using the TVP-FAVAR model. The conclusion is summarized as follows:

First, the shocks from GEPU on pricing volatility of crude oil show time-varying characteristics in time durations and time-points. For the durations, the shocks from GEPU on pricing volatility of crude oil in short term are more significant than that in medium and long term, but with the passage of time, the GEPU has a longer lasting effect on crude oil price volatility. For the time-points, from the perspective of trend, the short-term shocks from GEPU on pricing volatility of crude oil show upward trend. From the perspective of the direction of short-term impact, the positive impact prevails, but the GEPU presents a period of negative impact on the crude oil price volatility between 2005 and 2007. This is relevant to the trend of GEPU. From the stage peak points, the periodic peak points of the short-term shock curve of GEPU on crude oil price fluctuations mainly appear at a certain point during some major events, but the peaks vary in size.

Second, the instantaneous shocks from GEPU on pricing volatility of crude oil directly relate to major events. In addition, the relevance is different with respect to event type. The differences are embodied by the length, range, and speed of shocks. From the perspective of the length, the time duration of GEPU’s impact on crude oil price fluctuation under the events of Iraq war and global financial crisis are relatively shorter than Sino-US trade friction. This links to the duration of major events. From the perspective of the fluctuation range, the response value at the time point that is during the global financial crisis is relatively small, while during Sino-US trade friction is relatively large. This attributes to the increasing degree of economic globalization and international cooperation. From the perspective of the transmission speed, the GEPU transmits to crude oil price fluctuation fastest under the event of global financial crisis, reaching the maximum in the next first period.

Third, the time-varying characteristics of shocks from EPU in net-oil exporting and net-oil importing countries on the pricing volatility of crude oil show heterogeneity in fluctuation range and fluctuation intensity. On the one hand, from the fluctuation range, the average fluctuation range of the response of oil price volatility to shock of EPU in net-oil exporting countries and net-oil importing countries are 0.00558 and 0.00447. On the other hand, from the fluctuation intensity, the mean variation coefficient of the response value of oil price volatility to the shock of EPU in net-oil exporting countries and net-oil importing countries are 2.64 and 1.84. In addition, from the relative importance, the mean of the average spillover from EPU in net-oil exporting countries to oil price volatility (1.20%) is greater than net-oil importing countries (0.85%).

Fourth, the time-varying characteristics of shocks from EPU in net-oil exporting and net-oil importing countries on the pricing volatility of crude oil show stage differences in degree, changing speed, and changing trend, especially after the recent global financial crisis. From the impact degree, during 2014m6–2015m9, the average shock of EPU in net-oil exporting countries on crude oil price is significantly greater than that in net-oil importing countries. While from 2018m9 to 2019m6, the result is the reversed. From the changing speed, during 2009m6–2011m6, the shock of EPU in net-oil exporter has a faster rate of change than that in net-oil importer. From the changing trend, during 2014m6–2015m9, the shock of crude net-oil exporter EPU on crude oil price fluctuations shows an inverse V shape, while that of net-oil importer EPU shows a V-shape. Overall, the stage difference in the shock of EPU in net-oil exporting countries and net-oil importing countries on crude oil price fluctuation is relevant to the dominant position of supply and demand.

In future research, the transmission mechanism may be examined by lots of theoretical models and large time-varying parameter models. In addition, the comparison of the impact degree of GPR to EPU on oil price fluctuation from the perspective of dynamic may be also considered.

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T.L., D.X., and P.F.; writing—review & editing, Y.F., T.L., D.X., and P.F. All authors have read and agreed to the published version of the manuscript.

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### Appendix A

**Table A1.** Descriptive statistics of variables.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Median</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Std. Dev</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD crude oil demand</td>
<td>47,735.65</td>
<td>47,484.06</td>
<td>52,580.14</td>
<td>44,183.20</td>
<td>1719.99</td>
<td>0.413</td>
<td>2.651</td>
</tr>
<tr>
<td>Global economic activity index</td>
<td>4.999</td>
<td>−11.359</td>
<td>189.22</td>
<td>−161.643</td>
<td>69,812</td>
<td>0.650</td>
<td>2.874</td>
</tr>
<tr>
<td>World crude oil production</td>
<td>73,848.74</td>
<td>73,900.31</td>
<td>84,645.72</td>
<td>64,307.90</td>
<td>5219.372</td>
<td>0.073</td>
<td>2.031</td>
</tr>
<tr>
<td>OPEC crude oil remaining capacity</td>
<td>2.644</td>
<td>2.180</td>
<td>7.160</td>
<td>0.670</td>
<td>1.424</td>
<td>0.881</td>
<td>3.120</td>
</tr>
<tr>
<td>US crude oil inventory</td>
<td>995,480.9</td>
<td>1,008,253.0</td>
<td>1,227,678.0</td>
<td>895,337.0</td>
<td>104,992.0</td>
<td>0.048</td>
<td>2.084</td>
</tr>
<tr>
<td>OECD crude oil inventory</td>
<td>4172.41</td>
<td>4177.71</td>
<td>4713.24</td>
<td>3735.10</td>
<td>226.99</td>
<td>0.355</td>
<td>2.582</td>
</tr>
<tr>
<td>VIX</td>
<td>2.0262</td>
<td>18.630</td>
<td>59.890</td>
<td>9.510</td>
<td>7.858</td>
<td>1.589</td>
<td>6.923</td>
</tr>
<tr>
<td>Libor</td>
<td>2.928</td>
<td>3.580</td>
<td>7.550</td>
<td>0.210</td>
<td>2.456</td>
<td>0.187</td>
<td>1.430</td>
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<tr>
<td>US short-term interest rate</td>
<td>2.234</td>
<td>1.430</td>
<td>6.540</td>
<td>0.070</td>
<td>2.160</td>
<td>0.580</td>
<td>1.767</td>
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<tr>
<td>Japan short term interest rate</td>
<td>0.113</td>
<td>0.069</td>
<td>0.521</td>
<td>−0.071</td>
<td>0.172</td>
<td>1.352</td>
<td>3.546</td>
</tr>
<tr>
<td>Europe short term interest rate</td>
<td>1.787</td>
<td>2.040</td>
<td>5.060</td>
<td>−0.370</td>
<td>1.731</td>
<td>0.162</td>
<td>1.514</td>
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<tr>
<td>US dollar exchange rate index</td>
<td>110,186</td>
<td>111,300</td>
<td>129,030</td>
<td>93,060</td>
<td>9.202</td>
<td>−0.023</td>
<td>2.112</td>
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<tr>
<td>Crude oil speculation</td>
<td>4.223</td>
<td>4.137</td>
<td>4.765</td>
<td>3.773</td>
<td>0.248</td>
<td>0.538</td>
<td>2.044</td>
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<tr>
<td>Geopolitical risk index</td>
<td>95.45</td>
<td>74.57</td>
<td>545.09</td>
<td>25.52</td>
<td>67,991</td>
<td>2.921</td>
<td>15.982</td>
</tr>
<tr>
<td>Crude oil price</td>
<td>56.328</td>
<td>55.240</td>
<td>132.720</td>
<td>9.820</td>
<td>32.668</td>
<td>0.419</td>
<td>2.053</td>
</tr>
<tr>
<td>Global EPU</td>
<td>115.304</td>
<td>103.178</td>
<td>342.146</td>
<td>53.020</td>
<td>49.583</td>
<td>1.363</td>
<td>5.151</td>
</tr>
<tr>
<td>Russia EPU</td>
<td>123.066</td>
<td>103.851</td>
<td>400.017</td>
<td>12.399</td>
<td>80.089</td>
<td>1.072</td>
<td>3.686</td>
</tr>
<tr>
<td>Canada EPU</td>
<td>146.031</td>
<td>125.343</td>
<td>449.624</td>
<td>30.097</td>
<td>88.713</td>
<td>1.015</td>
<td>3.526</td>
</tr>
<tr>
<td>Brazil EPU</td>
<td>141.950</td>
<td>123.320</td>
<td>676.955</td>
<td>22.296</td>
<td>90.368</td>
<td>2.128</td>
<td>9.643</td>
</tr>
<tr>
<td>Japan EPU</td>
<td>109.354</td>
<td>104.122</td>
<td>239.028</td>
<td>48.886</td>
<td>36.304</td>
<td>1.182</td>
<td>4.591</td>
</tr>
<tr>
<td>China EPU</td>
<td>165.736</td>
<td>110.673</td>
<td>959.852</td>
<td>9.067</td>
<td>157.397</td>
<td>2.399</td>
<td>9.517</td>
</tr>
<tr>
<td>U.S. EPU</td>
<td>119.329</td>
<td>109.028</td>
<td>284.136</td>
<td>44.783</td>
<td>46.361</td>
<td>1.045</td>
<td>4.010</td>
</tr>
</tbody>
</table>

**Table A2.** Comparison between AIC and SC of alternative models.

<table>
<thead>
<tr>
<th>Model Form</th>
<th>GARCH (1,1)</th>
<th>GARCH (2,1)</th>
<th>GARCH (1,2)</th>
<th>GARCH (2,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC</td>
<td>−3.688916</td>
<td>−3.670475</td>
<td>−3.688831</td>
<td>−3.679751</td>
</tr>
<tr>
<td>SC</td>
<td>−3.585374</td>
<td>−3.563569</td>
<td>−3.582025</td>
<td>−3.559482</td>
</tr>
</tbody>
</table>

**Figure A1.** Autocorrelation function of stable Brent oil price.
Appendix B

Appendix B.1. The Extraction of Oil Price Volatility

The basic form of generalized conditional heteroscedasticity model GARCH (p, q) is as follows:

\[ r_t = c_1 + \sum_{i=0}^{R} \phi_i r_{t-i} + \sum_{j=0}^{M} \phi_j \varepsilon_{t-j} + \varepsilon_t \]  
\[ \varepsilon_t = \sqrt{h_t} \mu_t \]  
\[ h_t = \alpha_0 + \beta_1 h_{t-1} + \cdots + \beta_p h_{t-p} + \alpha_1 \varepsilon_{t-1}^2 + \cdots + \alpha_q \varepsilon_{t-q}^2 \]

Equation (A1) is the mean value equation, assuming \( r_t \) is crude oil price and obeys ARMA (M, N) process \( \varepsilon_t \) is the random disturbance term in Equation (A1). Equation (A2) is the distribution assumption, and Equation (A3) is called the conditional variance equation, where \( h_t \) is the conditional...
standard deviation, that is, the conditional volatility; \( \mu_t \) is an identically distributed independent random variable; \( h_t \) and \( u_t \) are independent from each other, and \( \mu_t \) is a standard normal distribution.

**Appendix B.2. The Average Dynamic Spillover Index**

Consider the time-varying parameter regression model specified by:

\[
y_t = X_t \beta_t + A_t^{-1} \Sigma_t \xi_t, \quad t = s + 1, \ldots, n, \quad \xi_t \sim N(0, I_K)
\]

where \( y_t \) and \( \xi_t \) are \( N \times 1 \) vectors, the coefficients \( \beta_t \), and the parameters \( A_t \) and \( \Sigma_t \) are \( N \times N \) matrices. It is assumed that the parameters in the TVP-VAR model obey random-walk processes.

In order to compute the generalized impulse response functions (GIRF) and the generalized forecast error variance decomposition (GFEVD), we transform the TVP-VAR model to its vector moving average (VMA) representation:

\[
y_t = \sum_{j=0}^{\infty} A_{jt} \xi_{t-j}
\]

where \( A_{jt} \) is a \( N \times N \) recursively matrices. \( A_{jt} = \beta_{1,t} A_{j-1,t} + \ldots + \beta_{p,t} A_{j-p,t} \). Where \( A_{0,t} = I \).

The spillover index of Diebold and Yilmaz [29] is estimated based on the generalized forecast error variance decomposition (GFEVD) [64]. In the generalized VAR framework, the H-step-ahead GFEVD in forecasting variable \( j \) that is due to the shocks of variable \( i \) is calculated as follow,

\[
\bar{\gamma}_{ij,t}^g(H) = \frac{\sum_{l=1}^{H-1} \Psi_{ij,t}^2}{\sum_{j=1}^{N} \sum_{l=1}^{H-1} \Psi_{ij,t}^2}
\]

where \( \bar{\gamma}_{ij,t}^g(H) \) represents the H-step ahead GFEVD. \( \Psi_{ij,t}^2 \) represents the square of the H-step ahead GIRF. With \( \sum_{j=1}^{N} \bar{\gamma}_{ij,t}^g(H) = 1 \) and \( \sum_{i,j=1}^{N} \bar{\gamma}_{ij,t}^g(H) = N \). Finally, the average dynamic spillover indexes from variable \( i \) to variable \( j \) are the average of the time-varying values of GFEVD:

\[
\text{average dynamic spillover index} = \frac{\sum_{t=1}^{T} \bar{\gamma}_{ij,t}^g(H)}{N \times T}
\]

where \( N \) represents the number of variables in the framework, \( T \) represents the sample size.

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