Does economic policy uncertainty drive the dynamic connectedness between oil price shocks and gold price?

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\section*{ABSTRACT}

This study examines the dynamic connectedness between three identified structural oil price shocks and the gold price based on the time-varying parameter vector autoregression (TVP-VAR) combined with the spillover’s measures of Diebold and Yilmaz (2014). The three oil shocks are disentangled using the recent procedure of Ready (2018), which allows one to identify oil supply, oil demand, and oil risk shocks. Using daily data covering the period between January 2, 1997 and January 30, 2019, the results reveal a weak average of the total dynamic connectedness between the oil price shocks and the gold returns, manifesting sudden upsurges during turmoil periods. We also find that the oil supply shocks are the dominant transmitter of the time-varying spillovers from oil to the gold market, followed by the oil risk shocks, while the oil demand shocks are a net receiver of the spillovers from the gold market. Performing further analysis, we did not find any asymmetric patterns of dynamic connectedness between the oil shocks and the gold returns, regardless of the signs of the oil shocks. Besides, the results indicate a significant effect of the economic policy uncertainty on the connectedness between the oil shocks and the gold market in both the static and regime-switching framework. These findings have important implications for investors in regard to the hedging and safe-haven properties of gold against the identified oil shocks.

\section*{1. Introduction}

The years during and following the 2008 global financial crisis (GFC) have witnessed an increasing interest in precious metals for offering investors safe investment opportunities. This interest is due to their growing acceptability by the investment community and the increased financialization of commodity markets (Rehman et al., 2018). Precious metals, particularly gold, is considered as a suitable diversifier and a good hedge against different market risks such as inflation, recessions, foreign exchange fluctuations, oil price volatility, and monetary policy mishaps (Lucey, 2011; Ciner et al., 2012; Berdin et al., 2015; Lucey and Li, 2015; Salisu et al., 2019c). In fact, oil and gold are considered as two strategic commodities given their important roles in both production and consumption. Both are very liquid and as such very widely traded.

Given their major roles, the connections between the prices of these commodities (i.e., oil and gold prices) are of great interest for economic agents, since they have implications for both the real economy and financial markets (Tiwari et al., 2020). Moreover, the continuous co-movement between oil and gold prices has renewed the interest of researchers in examining the nature of this relationship and further assess the hedging and safe haven properties of gold against oil market risks.

The linkage between oil and gold prices can be explained through various channels. The first channel is related to inflation, which has strengthened due to the repeated spikes in oil prices. Thus, in periods of high inflation, gold moves up because it can protect the purchasing power of money during the accompanying episodes of high oil prices, and thereby causing a positive relationship between oil and gold prices.
Consequently, gold is considered a unique long-run inflation hedging instrument during those periods (Tiwari and Sahadudheen, 2015). The second is the exchange rate channel. In fact, oil and gold prices move in the same direction when the dollar value of other currencies change (Sari et al., 2010). They both move up when the US dollar depreciates and dive down when the US currency appreciates. The third channel is the oil export revenue channel in which any increase in the dollar-denominated oil price will augment the revenues in the domestic currencies of oil-exporting countries, which subsequently tend to buy more gold to consolidate their shares in their reserve portfolios. Then the increase in the demand for gold demand leads to an increase in the gold price (Tiwari and Sahadudheen, 2015).

In the literature, many studies find a weak connectedness between gold and oil prices, but they also confirm the ability of gold to hedge and diversify investment portfolios during times of economic and political uncertainty (Kanjilal and Ghosh, 2017; Mo et al., 2018; Mokni, 2018; Uddin et al., 2018; Das et al., 2019). All of these studies consider only one time-horizon, but the time-varying connectedness between oil and gold is largely ignored. This first approach is restrictive since investors and speculators have different time horizons, and thus are exposed to varying types of connectedness and information transmissions. Therefore, examining the whole patterns of information transmission and time-varying linkages is the aim of our study. In particular, we investigate the time-varying connectedness between three identified diversified oil price shocks (oil demand shocks, oil supply shocks, and oil risk shocks), which could change the connectedness between oil and gold returns.

Another limit of previous studies is that these stides ignore the effect of economic and political uncertainty measures on the oil-gold nexus. The economic policy uncertainty index, which was constructed by Baker et al. (2016), demonstrates that such an uncertainty can influence the economic recessions and subsequent recoveries. This index provides a measure of assessing the macroeconomic uncertainty by combining economic uncertainty related to public views and economic policy-making. Since oil shocks have an uncertain outcome, the uncertainty about economic outcomes and economic policy may coexist, given that economic policy can change according to different economic outcomes (Yang, 2019). In this context, many studies discussed the relationship between oil price shocks and economic policy uncertainty (Kang and Ratti, 2013; Yang, 2019). Since gold acts as a hedge against fluctuations in different financial variables including inflation, exchange rates, and oil prices during times of uncertainty, consequently changes in economic and political uncertainty may affect, at different extents, all these variables and, therefore, maybe the main driver of the linkage between gold and these macroeconomic variables. In this research, we fill the gap in the literature by trying to examine the role of economic policy uncertainty in driving the oil-gold nexus in both the static and changing economic uncertainty states, using the three identified oil shocks.

Greenwood-Nimmo et al. (2015) show that the oil supply shocks (e.g., production interruptions or accidents) could have a sudden large impact on oil prices and can change the connectedness between the oil and metal markets. As well, the global oil market shocks also have the ability to affect the spillover between different financial markets. Moreover, Fernández et al. (2016) show that the conditional correlation between the oil market and precious metals is time-varying and is connected to the crisis periods representing major structural breaks. In this context, the time-varying linkage between oil and precious metals may have important implications for investors based on the time-varying connectedness between different financial asset returns. Consequently, econometric models analyzing the impact of a one-time change in the un-disentangled oil price are likely to yield misleading results, regarding the underestimated impact of a particular oil price shock on other financial assets.

More formally, the main objective of our study is to investigate the time-varying connectedness between the three identified oil price shocks and gold returns, which may have different spillovers between these assets. We focus on gold because it is the main precious metal that is able to provide clear evidence on the connection between oil and precious metal prices, which both are strategic commodities priced in the US dollar. Also, we use the methodology of Ready (2018) to disentangle the oil price shocks into the three identified oil demand, oil supply, and oil risk-driven shocks. Moreover, as can be seen from previous studies, there is no consensus in the literature on the relationship between oil price shocks and gold price returns (see Hammoudeh and Yuan, 2008; Soytas et al., 2009; Sari et al., 2010; Bhar and Hammoudeh, 2011; Balcilar et al., 2015 among others).

We, therefore, use the popular model of Diebold and Yilmaz (2014) to capture the spillovers over time, also combined with the time-varying parameter vector autoregression (TVP-VAR) approach recently employed by Antonomakis and Gabauer (2017). This methodology improves substantially the connectedness approach of Diebold and Yilmaz (2014) because it allows the variances to vary over time through a Kalman Filter estimation, which relies on decay factors. By doing so, the TVP-VAR approach overcomes the burden of the often arbitrarily chosen rolling-window-size which could lead to very erratic or flattened parameters as well as a loss of valuable observations (Antonomakis and Gabauer, 2017; Antonomakis and Gabauer, 2017; Gabauer and Gupta, 2018; Diebold and Yilmaz, 2009).

The contributions of this study over others are four-fold. First, it investigates the effect of disentangled changes in oil prices on gold returns using the novel method of Ready (2018) to isolate the oil shocks as driven by demand or supply. It tests whether the disentangled oil price shocks give a different insight into the connectedness between oil shocks and gold returns. In fact, Ready (2018)’s methodology is based on the fact that the gains of oil-producing companies increase with the oil demand augmentation, but they are immune to oil supply shocks. Also, Ready (2018) shows the empirical superiority of his methodology since it is based on daily data. Second, we investigate the asymmetric connectedness between positive and negative oil price shocks and gold returns. Moreover, the impact of a negative oil price shock on gold returns might be different from the impact of a positive oil shock. Third, we drive the effect of uncertainty on the connection between the oil and gold returns. Fourth, to the best of our knowledge, this paper is the first to apply the time-varying parameter vector autoregressive (TVP-VAR) methodology of Antonomakis and Gabauer (2017) to investigate the oil-gold nexus. This methodology improves the one provided by Diebold and Yilmaz (2012) because it allows for a measure of connectedness that adjusts immediately to events.

Our main findings indicate that the impact of the disentangled oil price shocks on gold returns is time-varying, and thus the static econometric models are not able to describe this dynamic pattern fully. Moreover, the oil supply and oil risk shocks are net transmitters of the dynamic spillowers to gold returns, but the oil demand shocks are net receivers of spillovers from gold returns. Generally, the results indicate a weak symmetric negative net connectedness between both the oil supply and oil risk shocks and the gold returns. This result indicates the insensitivity of gold returns to hedge the different risk factors driving the oil price shocks. Finally, our findings highlight a significant effect of the economic policy uncertainty (EPU) on the oil-gold connectedness on both the static and changing economic uncertainty states. Our findings have important implications for international investors for the hedging and diversifying properties of gold against the different oil market risks, depending on the economic uncertainty states.

The remainder of this study is organized as follows. Section 2 provides a brief review of the relevant literature. Section 3 discusses the methodology and presents the data. Section 4 presents and discusses the empirical results. Section 5 presents the relevant risk management implications and concludes.

2. Related literature

The studies exploring the interaction between oil and precious metal
prices are abundant and give mixed and often conflicting results. In this section, we provide a survey of the major empirical studies examining this relationship. Below, we focus on the different categorized areas of the relationships between the oil price and precious metals, including the co-movement, causality, and volatility regime dependencies.

Using the co-movement approach, the seminal work by Pindyck and Rotemberg (1990) provides a positive co-movement between oil and gold prices using monthly data. Lescaroux (2009) explores the correlation between oil and six metal prices. He finds a high level of correlation explained by common supply and demand shocks. Also, Turhan et al. (2014) report an increasingly positive correlation between oil and gold prices. Charlot and Marimoutou (2014) report a time-varying correlation between international oil markets and precious metal returns during extreme market conditions. Juvenal and Petrella (2015) use a dynamic factor model on a large dataset and report that shocks to oil demand drive the co-movements between international oil and precious metal prices. More recently, Chen and Xu (2019) used a multivariate GAS model to forecast volatility and correlation between gold and oil prices. The estimation results show that the multivariate GAS model captures the volatility persistence and the nonlinear interaction effect between gold and oil markets. In addition, the results show that the forecasting power of volatility and correlation in multivariate GAS models are better than the DCC-GARCH models.

More recently, Rehman et al. (2018) examine the impact of oil price shocks on precious metal returns using the structural autoregression (SVAR) model proposed by Kilian and Park (2009). They capture the variability in the effects through a rolling window impulse response function by extending the dynamic connectedness approach of Diebold and Yilmaz (2014) using the structural forecast error variance decomposition. They report a time-varying effect of the disintegrated structural oil shocks on precious metal returns with also a significant increase during the global financial crisis period of 2008–2009. Husain et al. (2019) investigate the connectedness among the crude oil price, stock index and metal prices for the US economy by applying the time domain spillover index of Diebold and Yilmaz (2012). Their investigation demonstrates that palladium, gold, platinum and silver are net contributors of volatility spillover, whereas crude oil, titanium, steel and silver are net receivers of volatility spillover.

In the same context, Tiwari et al. (2020) examine the dependence structures and dynamics between gold and oil prices and the effect of geopolitical risks on the dynamic dependence. More specifically, they study the hedge and safe-haven ability of gold against oil price shocks, using the time-varying Markov-switching copula models. Their results provide evidence of time-varying Markov tail dependence structure and dynamic between oil and gold. Moreover, their findings show that gold is a good hedge for oil returns and for short- and medium-term investors and provides evidence in support of the safe haven ability of gold for oil. Also, the results show that the inclusion of geopolitical risks in a pure oil-gold portfolio provides diversification benefits, since the former have mostly a negative effect on the dependence structure between gold and oil.

Research using the Granger causality tests between oil and precious metal markets reports mixed findings. Sari et al. (2010), for example, report a significant unidirectional causality running from oil to gold prices and bidirectional causality between oil and silver prices. However, the causality relationship between oil and platinum prices is very weak. Moreover, Soytas et al. (2009) report a significant short-run impact running from gold returns to oil and silver prices. However, Chang et al. (2019) find an absence of causality between oil prices and gold prices. Lee et al. (2012) indicate a unidirectional long-run causality running from oil prices to gold. Zhang and Wei (2010) show a significant long-term (equilibrium) between the gold and crude oil markets, highlighting a unidirectional linear causality running from the oil price to the volatility of the gold price. However, no significant nonlinear Granger causality was detected between the two markets. Also, Narayan et al. (2010) suggest a bidirectional long-run relationship between gold and oil prices. By analyzing Johansen’s cointegration, Granger causality, and VECM, Simáková (2011) finds a long-run relationship between oil and gold prices. Bildirici and Turkmên (2015) use the nonlinear ARDL procedure and two other nonlinear tests and find clear evidence of bidirectional causality from the oil price to both the gold and silver prices. More recently, Singhal et al. (2019) studied the dynamic relationship among international oil prices, international gold prices, exchange rates and stock market index in Mexico using the ARDL bound-testing cointegration approach. Their findings show that gold prices positively affect the stock market of Mexico but do not have any significant impact on the exchange rate.

Many studies report mixed findings on the relationship between oil and precious metal prices, using volatility-regime dependencies. For example, Bhar and Hammoudeh (2011) find that oil returns have a more important impact on precious metal returns when uncertainty is in a high-volatility regime. Hammoudeh and Yuan (2008) examine the conditional volatility for three important metals (gold, silver, and copper) using GARCH-based models. They provide that oil shocks had calming effects on precious metals, excluding copper. Ewing and Malik (2013) use univariate and bivariate GARCH models with structural breaks in the variance to provide a significant volatility transmission between gold and oil price returns. Balellar et al. (2015) use a Bayesian Markov switching vector error correction model to report a positive impact from oil price shocks to precious metal prices, particularly in a high-volatility regime. Tiwari and Sahadudheen (2015) use types of GARCH models to investigate the relationship between oil and gold prices. They find that an increase in real oil prices has positive effects on gold. Lau et al. (2017) use an E-GARCH model, taking into consideration frequency dynamics and find a significant cointegration between oil and precious metal prices.

Using a bivariate DCC–FIAPARCH model with and without structural breaks, Mensi et al. (2015) report an asymmetry and long memory in the conditional volatility between oil and gold markets. Similarly, Mensi et al. (2018) provide a stronger correlation between oil and gold markets. Mokni et al. (2018) uses a FIEGARCH-copula framework to investigate the linkage between returns, volatilities, and market risks among crude oil and precious metals markets. He finds that the dependence between oil-silver and oil-gold is significant and time-varying for the returns and the volatilities. Uddin et al. (2018) use a Markov regime-switching regression to investigate the impact of the oil price shocks on precious metals returns but do not examine the connectedness between oil shocks and precious metals. The decomposing of oil price changes into oil supply, oil demand, and oil risk-driven shocks was conducted with the Ready (2018) approach. The authors report that the impact of the oil demand and supply shocks is significant and positive; however, the impact of the oil risk shocks on the precious metal returns is negative.

Other studies focus on the connectedness between oil price stocks, and economic policy uncertainty. Kang and Ratti (2013) find that oil supply-side shocks do not affect policy uncertainty. In contrast, the aggregate demand shocks have a significant negative effect on policy uncertainty. Yang (2019) investigates the causality and connectedness between oil price shocks and economic policy uncertainty. The findings show that the oil price behaves like receivers of information from economic policy uncertainty, regardless of the time scales. However, the causality between oil price shocks and economic policy uncertainty intensifies as time scales increase, and connectedness relationships is robust to time scales change. On the other hand, a recent research line studies the ability of different assets to hedge economic policy uncertainty, Wu et al. (2019) investigate the hedging and safe-have abilities of gold and Bitcoin against economic policy uncertainty. The findings from this study show that neither gold nor Bitcoin can serve as a strong hedge or a strong safe-haven against economic uncertainty (EPU) at the average conditions; however, both commodities may act as a weak hedge or a safe haven against (EPU) during the extreme bearish or bullish markets. In this research, we extend the previous literature by investigating the effect of economic policy uncertainty on the
connectedness between disentangled oil price shocks and gold. Given that investors aim to protect their portfolio wealth against different oil risks by incorporation gold, they should respond timely and appropriately to different causal relationships between oil price shocks, gold prices and economic uncertainty.

To the best of our knowledge, none of the previous studies in the literature which explore the impact of the disentangled oil shocks on the gold price has applied the TVP-VAR model combined with the popular methodology of Diebold and Yilmaz (2014) applied originally by Antonakakis and Gabauer (2017). Our study aims to fill this gap in the literature by using more recent data.

3. Data and methodology

3.1. Data

To disentangle the oil price shocks, we follow the procedure of Ready (2018). To do so, we employ a dataset of three variables following the literature. The first one is the World Integrated Oil and Gas Producer (equity) Index used as a proxy for the global stock price index of oil-producing firms. The second variable is the unexpected change in the CBOE Volatility (equity) Index (VIX) considered as a proxy for equity risk changes. The unexpected changes in the VIX index are estimated as residuals of an ARMA(1,1) process of the index (Uddin et al., 2018; Ready, 2018). The third variable includes the oil price represented by the NYMEX -Light Sweet Oil contracts, which are expressed in US dollars. Finally, to examine the effect of economic policy uncertainty (EPU) on the identified oil shocks-gold connectedness, we use the daily US EPU index developed by Baker et al. (2016) during the same period.1

To examine the dynamic asymmetric connectedness between gold returns and the identified oil shocks, we use the futures gold price, which is also expressed in the US dollar. All the used daily data is obtained from Datastream and spans from January 2, 1997, to January 30, 2019. This dataset covers a large period, which includes major economic and political events (e.g., the 1998 Asian financial crisis, the 2002 dotcom crisis, the 2008 global financial crisis, the 2010–2012 European debt crisis, and the 2014–2016 oil price collapse, among others). We compute the continuously compounded daily gold returns by taking the difference in the log values of two consecutive prices.

3.2. Methodology

The methodology adopted in this paper is threefold. Firstly, we identify the different oil shocks, including the oil supply, oil demand, and oil risk shocks based on the recent and sophisticated procedure of Ready (2018). Second, we proceed to examine the dynamic connectedness between these identified oil shocks and gold returns, using the refined measures of the dynamic connectedness recently applied by Antonakakis and Gabauer (2017). This approach combines the time-varying parameters autoregression vector (TVP-VAR) model of Koop and Korobilis (2014) with the connectedness approach of Diebold and Yilmaz (2014). This procedure is proposed to overcome certain shortcomings of the connectedness measures introduced originally by Diebold and Yilmaz (2009, 2012, 2014). The third step investigates the possibility that the economic policy uncertainty drives this dynamic spillover between the identified oil shocks and gold returns.

3.2.1. Disentangling the oil price shocks

While almost all of the studies investigating the oil-gold nexus hypothesize that the effects of exogenous rises in oil prices are similar, regardless of the sources of the economic forces driving the oil prices, one of the tasks of this paper is to address this limitation. To do so, we disentangle the different oil shocks by following the procedure of Ready (2018), which suggests that the oil price should be disentangled into three orthogonal shocks namely the oil supply (s1), the oil demand (d1), and the oil risk (r1) shocks based on the following equation:

\[ Z_t = A^{-1} X_t \]  

where

\[ X_t = \begin{bmatrix} \Delta op_t \\ Pr_t \\ VIX_t \end{bmatrix} \]

\[ Z_t = \begin{bmatrix} s_1 \\ d_1 \\ r_1 \end{bmatrix} \]

and

\[ A = \begin{bmatrix} 1 & 1 & 1 \\ a_{22} & a_{23} \\ 0 & 0 & a_{33} \end{bmatrix} \]

Where \( Z_t \) is a vector that embraces the oil supply, oil demand, and oil risk shocks. The vector \( X_t \) includes \( \Delta op \), which denotes the change in oil prices, \( Pr_t \) is the returns on the index of global oil-producing firms (i.e., World Integrated Oil and Gas Producer Index), and \( VIX_t \) represents the innovations in the volatility index (VIX) derived based on the ARMA (1,1) process.

By following this approach, it can be observed that the oil demand shocks are the returns to the index of oil-producing companies, which are orthogonal to the unexpected changes in the equity volatility index (VIX). In contrast, the oil supply shocks identify the remaining variation in oil prices. In other words, the oil demand shocks are estimated based on the residuals term of regression of VIX index returns on the global index of oil-producing firms on the unexpected changes in the log of VIX index. On the other hand, the oil supply shocks are computed as the residuals of a contemporaneous regression where changes in oil prices are regressed on the oil demand shocks and unexpected changes in the VIX index. The oil demand and supply shocks are constructed in a manner such that the entire variations in the oil price changes are explained by the oil demand shocks, oil supply shocks, and unexpected oil changes in the VIX index.

3.2.2. Dynamic connectedness: TVP-VAR based approach

To extend and refine the connectedness measure between the variables, Antonakakis and Gabauer (2017) apply a time-varying parameter vector autoregression (TVP-VAR) to address the limitation of the previously used rolling-window VAR by allowing the variances to vary with time. To apply this procedure in our study, let \( Y_t \) be a \((N \times 1)\) vector (in our case, it consists of the three disentangled oil shocks and gold returns). The TVP-VAR model can be represented by the following set of equations:

\[ Y_t = \Phi_1 Y_{t-1} + u_t, \quad u_t \sim N(0, \Omega_1) \]  

\[ \Phi_1 = \Phi_{1,1} + \nu_1, \quad \nu_1 \sim N(0, R_1) \]  

where \( \Omega_1 \) represents the set of information available at \( t-1 \). \( Y_{t-1} \) is a lagged vector of the dependent variables. \( \Phi_1 \) is an \((N \times Np)\) matrix of coefficients, which is supposed to be time-varying, \( u_t \) and \( \nu_1 \) are two \((N \times 1)\) vectors of the error terms related to Eqs. (2) and (3), respectively. Further, \( S_t \) and \( R_t \) are \((Np \times Np)\) matrices that denote the time-varying variance-covariance matrices of the error terms \( u_t \) and \( \nu_1 \), respectively. Therefore, by allowing the VAR parameters and variances to vary over time, this model can estimate the generalized connectedness procedure of Diebold and Yilmaz (2014) based on the generalized impulse response functions (GIRF) and the generalized forecast error variance decompositions (GFEVD), by transforming the VAR to its vector moving average (VMA) (Koop et al., 1996; Pesaran and Shin, 1998) of Eq. (2) as follows:

\[ Y_t = \Phi_1 Y_{t-1} + u_t = A_t u_t \]  

where \( A_t = \begin{bmatrix} A_{1,1} & A_{2,1} & \cdots & A_{p,1} \end{bmatrix} \) is an \((N \times N)\) matrix of parameters verifying:

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1 Following Baker et al. (2016), EPU is defined as non-zero probability of changes in the existing economic policies that determine the rules of the game for economic agents in a country. For more details, see: https://www.policyuncertainty.com/.
Table 1
Different spillover indices and its interpretations.

<table>
<thead>
<tr>
<th>Index</th>
<th>Formulas</th>
<th>Interpretation</th>
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<tbody>
<tr>
<td>(1) Total connectedness index</td>
<td>$H_{ij}(J) = \sum_{j=1}^{N} A_{i,j} R_{ij}(J) \times 100$</td>
<td>Shows how a shock in one variable spills over to other variables.</td>
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<tr>
<td>(2) Total directional connectedness to others</td>
<td>$H_{iju}(J) = \sum_{j=1}^{N}</td>
<td>A_{i,j}</td>
</tr>
<tr>
<td>(3) Total directional connectedness from others</td>
<td>$H_{ijd}(J) = \sum_{j=1}^{N}</td>
<td>A_{i,j}</td>
</tr>
<tr>
<td>(4) Net total directional connectedness</td>
<td>$H_{ij}(J) = H_{iju}(J) - H_{ijd}(J)$</td>
<td>Examine the “power” of variable $i$, or its influence on the whole variables’ network. If $H_{ij}(J) &gt; 0$, the variable $i$ influences the network more than being influenced by that. If $H_{ij}(J) &lt; 0$, it means that variable $i$ is driven by the network.</td>
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Notes: This table presents the different connectedness measures developed by Diebold and Yılmaz (2014).

\[ A_{i,j} = \begin{cases} \delta_i & \text{if } i = 0 \\ \sum_{k=1}^{N} \Phi_{i,k} A_{k,j} & \text{if } i \neq 0 \end{cases} \]  

In this case, the generalized impulse response functions (GIRF) define the responses of all variables following a shock in variable $i$.

In the absence of a structural model, Antonakakis and Gabauer (2017) compute the differences between a J-step-ahead forecast where once variable $i$ is shocked and once it is not shocked. Formally, let $J$ be the forecast horizon and $\delta_i$ be the selection vector equal to 1 on the $i^{th}$ position, and 0 otherwise. Then the GIRF, which is denoted by $\Psi_{ij}(J)$, can be calculated by:

\[ \text{GIRF}(J, \delta_i, \Omega_{-1}) = E(Y_{i,t}|u_{j} = \delta_j, \Omega_{-1}) - E(Y_{i,t}|\Omega_{-1}) \]  

\[ \Psi_{ij}(J) = S_{i,j} A_{i,j} \]  

Besides, the GFEVD for the horizon $J$, denoted by $\Pi_{ij}(J)$, can be calculated by:

\[ \Pi_{ij}(J) = \sum_{j=1}^{N} \Psi_{ij}^{2} \sum_{j=1}^{N} \Psi_{ij}^{2} \]  

$\Pi_{ij}(J)$ can be interpreted as the variance share one variable has on others.\(^3\) The GFEVD verifies $\sum_{j=1}^{N} \Pi_{ij}(J) = 1$ and $\sum_{j=1}^{N} \Pi_{ij}(J) = N$. Using the GFEVD, we can construct the different connectedness indices presented in Table 1.

3 These variance shares are normalized in the sense that each row sums up to 1. This means that all variables together explain 100% of variable i ’s forecast error variance (Antonakakis and Gabauer, 2017).
and is negatively skewed, which means that the peak leans more to the left. However, both oil supply and oil demand shocks present negative average returns and are negatively skewed, while the oil risk shocks present positive average returns and are positively skewed. Comparing the oil price shocks, we notice that the oil risk shocks exhibit the largest variance value. Moreover, all the series (oil shocks and gold return series) are characterized by excess kurtosis, suggesting a leptokurtic distribution with fat tails, and the null hypothesis of normality is rejected for all series at the 1% level.

In addition, it’s necessary to explore the time-series properties of the variables in order to test for the existence of unit root on the data. Three tests are conducted, including the Augmented Dickey-Fuller (ADF) and the Philippe Perron (PP), and the Elliot- Rothenberg-Stock (ERS) tests. The results of these tests show that all series are integrated of order zero. In other words, we reject the presence of unit root in all the series. Besides, the results suggest that all series are autocorrelated and exhibit ARCH errors, which support choosing the TVP-VAR model with time-varying covariances.

4.2. Dynamic connectedness between oil shocks and gold returns

Table 3 reports the average dynamic connectedness between gold returns and the different disintegrated oil price shocks. Summarizing the information in Table 3, the own-oil shocks and own-gold return series spillovers explain the highest share of the forecast error variance, as the diagonal elements receive the highest values compared to the off-diagonal elements. For instance, the oil supply shocks explain 1.842% of the 10-day ahead forecast error variance of the gold returns. However, oil demand shocks and oil risk shocks explain 5.26% and 2.3% of gold returns’ 10-day forecast error variance, respectively. Contrarily, gold returns explain 1.33%, 4.94% of the 10-day forecast error variance of the oil supply and demand shocks, respectively, but only 1.98% of the oil risk shocks. The results highlight the low average connectedness between the oil shocks and gold returns, which may have important implications for investors regarding the low sensitivity of gold price returns to different extraneous oil shocks.

The results also show that both the oil price shock and gold returns are net pairwise transmitters of spillovers to each other. Moreover, the

<table>
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<th>Table 2 Descriptive statistics of the gold returns and the disentangled oil shocks.</th>
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<tbody>
<tr>
<td><strong>Supply shocks (SS)</strong></td>
</tr>
<tr>
<td>Mean</td>
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<tr>
<td>Variance</td>
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<tr>
<td>Skewness</td>
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<td>Kurtosis</td>
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<td>Q2(20)</td>
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<td>LM(20)</td>
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</tbody>
</table>

Notes: This table reports the descriptive statistics of gold and the different oil shocks. JB is the Jarque-Bera normality test statistics. ADF and PP are respectively, the statistics of Dickey-Fuller and Phillip-Perron tests. ERP is the Elliot-Rothenberg-Stock unit root tests. Q(10) and Q2(10) are the Ljung-Box tests for 20th order serial correlations for returns and squared returns, respectively. LM(20) is the LM heteroscedasticity test at order 20. (***), (**) and (*) indicate the statistical significance, respectively, at the 1%, 5%, and 10% levels.

<table>
<thead>
<tr>
<th>Table 3 Dynamic connectedness.</th>
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<tbody>
<tr>
<td><strong>From</strong></td>
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<tr>
<td>SS</td>
</tr>
<tr>
<td>SS</td>
</tr>
<tr>
<td>DS</td>
</tr>
<tr>
<td>RS</td>
</tr>
<tr>
<td>Gold</td>
</tr>
<tr>
<td>Contribution To others</td>
</tr>
<tr>
<td>Cont. including own</td>
</tr>
<tr>
<td>Net spillovers</td>
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</table>

Notes: This table reports the variance decompositions for the estimated TVP-VAR model addressing the gold returns and oil price shocks identified by the procedure of Ready (2018). Variance decompositions are based on 10-step-ahead forecasts and a TVP-VAR lag length of order 1. SS, DS, and RS denote the supply, demand, and risk shocks, respectively.
most important net transmitters of spillovers are the oil risk shocks followed by the oil supply shocks, but the oil demand shocks are net receivers of spillovers from gold returns throughout the period of analysis. This may be the result of the fact that the demand for gold, which is a good hedge, rises dramatically in uncertain times. These findings are contradictory to previous studies measuring the connectedness between oil shocks and traditional assets, which have revealed more emphasis is attributed to the oil demand shocks as opposite to the oil supply and risk shocks due to the differences in the asset classes such as equities and precious metals (see, Lippi and Nobili, 2012; Baumeister and Peersman, 2013). According to the total connectedness index (TCI) (index 1 in Table 1), the average influence all other variables have on one variable’s forecast error variance throughout time is 11.7%. Put differently, oil price shocks and gold returns are not independent of each other since the average influence of oil risk shocks is approximately 12%. Even though this value is not very large, it does show that the transmission of oil price shocks and gold price spillovers are important sources of the fluctuations in the oil-gold linkage. In order to see if this number changes over time, we proceed to do the estimation of dynamic connectedness, as outlined in Fig. 2.

We now focus on the interpretation of the spillover plots based on the time-varying estimates of the various connectedness measures. Fig. 2 presents the results of the dynamic total connectedness (index) between the disentangled oil price shocks and gold returns. We observe a large variation in the total connectedness index, which turns very responsive to extreme economic events such as the 1997 Asian Financial crisis, the 2003 Iraq War, the 2008–2009 Great Recession, the 2010–2012 European sovereign debt crisis and the Arabic spring turmoil that started in 2011 and continued until the end of the sample period. Particularly, the total dynamic connectedness reached unprecedented heights during the year 2002, near the end of the year 2007, which corresponds to the 2007 subprime crisis and before the onset of the 2008 global financial crisis (GFC). A sharp decline in the total connectedness between the two markets is observed during the 2008 GFC, but in the post-crisis period, total connectedness shows a sharp escalation.

Overall, despite the low connectedness between oil shocks and gold returns, the increasing connectedness during the financial crises suggests that even the low connectedness can increase in periods of financial and economic turmoil. Note that this dynamic provides evidence that (static) TCI is masking specific episodes (e.g., economic and financial shocks) that have had a distinct impact on its interconnectedness. This points out that analyzing the time-varying behavior of the connectedness measure is of particular importance to understand the transmission of the spillover mechanism between the oil shocks and gold returns in detail.

Fig. 3 depicts the total pairwise connectedness from gold to all oil shocks and from the different oil shocks to gold and net gold. One can notice from this figure that directional spillovers from or to gold range between 0% and 8% and are of a bilateral nature. Nevertheless, these spillovers behave rather heterogeneously over time and follow a similar pattern for the dynamic total connectedness.

Regarding the pairwise connectedness between oil shocks and gold returns, as shown in the plots of Fig. 3, we notice that both the disentangled oil shocks and gold returns show significant time-varying transmission patterns. Regarding the oil supply shocks, we see that the transmission of spillovers to gold returns is positive for the majority of the sample period and increases during the Iraqi war (2003), the global financial crisis (2008), and before the onset of the European sovereign debt crisis (2012). This result means that the oil supply shocks are a net transmitter of spillovers to gold returns and that the connectedness between the supply shocks and gold returns increases during periods of market turmoil. But it’s clear from the figure that gold returns can transmit spillovers to the supply shocks in the same periods.

Demand shocks have an observable negative value, indicating a low connectedness with gold returns for the first ten years of the sample period (i.e., 1997–2005). Then, we observe positive values that increase sharply during the onset of the GFC and a second spike during the year 2014. This result highlights that generally, oil demand shocks act as a net recipient of spillovers from gold returns. Regarding the oil risk shocks, the plots show a very weak positive connectedness between this disintegrated oil shock and gold returns, but we notice a sharp increase in its value during the recent financial crisis and a sharp decline following the GFC. This result suggests a degree of the insensitivity of gold returns to different risk factors affecting the oil market, which have important implications for investors concerning the capacity of gold as a hedge and a safe-haven against different financial risks.

The last plot in Fig. 3 depicts the net time-varying spillovers from gold to the different oil shocks. We observe a weak negative net connectedness between gold returns and the different oil shocks for the majority of the sample period; however, with two sudden spikes, the first takes place during the 1997 Asian financial crisis, and the second one coincides with the beginning of the GFC in 2007, followed by a sharp decline at the end of the year 2008 and during the sovereign debt crisis (2012). The total net connectedness maintains a weak negative value.
until the end of the sample period. This result suggests that gold acts as a net transmitter of spillovers to the oil market during financial crises, while a net receiver of spillovers from oil shocks for the remaining periods.

4.3. Asymmetric dynamic connectedness

In an attempt to examine whether the transmission of spillovers between oil shocks and gold returns differs between positive and negative oil shocks, we separate the positive and negative shocks from the three disintegrated oil shocks and re-estimate the time-varying spillovers and the dynamic connectedness paths. We then separate the dynamic connectedness of the positive oil shocks from the negative ones.

To do so, we define the positive and negative oil price shocks (OS) as:

$OS^+_t = \max(0, OS_t)$ and $OS^-_t = \min(0, OS_t)$, verifying $OS_t = OS^+_t + OS^-_t$, where $OS_t$ is the oil supply, oil demand, or oil risk shocks.

The results reported in Table 4 generally show a similar pattern of connectedness between gold returns and the positive and negative oil shocks. In fact, we notice the following regularities: (i) the positive and negative supply and risk shocks act as net transmitters of spillovers to gold returns. In contrast, the negative and positive demand shocks act as a net recipient of spillovers from gold returns. Those results are similar to those found in Table 3 and highlight a symmetric dynamic connectedness between the two markets. (ii) The positive risk shocks have a greater spillover effect on gold returns compared to the negative ones. (iii) The negative demand shocks are more vulnerable to spillover transmissions from gold returns, while the spillovers from positive and negative supply shocks to gold returns are approximately of the same magnitude. Similar results are observed for the net total connectedness (NTC), as the average influence of all other variables has on one variable’s forecast error variance throughout time is 8.612% and 8.028% for the positive and negative shocks, respectively. This result suggests that the average influence of the negative and positive oil shocks on gold returns is approximately equal, and consequently, the disintegrated oil shocks and gold returns have symmetric total connectedness.

We turn now to examine the asymmetric dynamic total connectedness patterns reported in Fig. 4, while Fig. 5 depicts the asymmetric total directional connectedness from others and to others. As we can see in Fig. 4 that there are no important differences in the dynamic total connectedness between the positive and negative oil shocks and gold returns during the whole sample period. In fact, the positive and negative oil shocks and gold returns exhibit similar time-varying behavior of

<table>
<thead>
<tr>
<th>Positive shocks</th>
<th>Negative shocks</th>
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<tbody>
<tr>
<td>SS</td>
<td>93.225</td>
</tr>
<tr>
<td>DS</td>
<td>4.444</td>
</tr>
<tr>
<td>RS</td>
<td>1.786</td>
</tr>
<tr>
<td>Gold</td>
<td>1.347</td>
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<tr>
<td>CTO</td>
<td>7.578</td>
</tr>
<tr>
<td>CIO</td>
<td>100.80</td>
</tr>
<tr>
<td>Net sp</td>
<td>0.802</td>
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</tbody>
</table>

$CTO = 100.86$ 99.597 100.26 99.284 TCI $Net sp = 0.802 \ -0.789 \ 0.716 \ -0.730 \ 8.612$ $From \ SS \ DS \ RS \ Gold \ From \ SS \ DS \ RS \ Gold \ From$

K. Mokni et al.
the spillovers. This result confirms the early result by suggesting a symmetric static and dynamic total connectedness between the oil shocks and gold returns. Similar results are also observed for the total connectedness from gold and to gold, as shown in Fig. 5. Regarding the asymmetric time-varying spillovers from the different oil price shocks to gold returns, we notice weak positive spillovers from negative supply shocks to gold returns, which means that the negative supply shocks act as a net transmitter of spillovers to gold returns, but the positive side of these shocks acts as a net recipient of spillovers from gold returns as shown by a negligible negative connectedness for the majority part of the sample period. The positive and negative demand (risk) shocks have similar paths of time-varying spillovers to the gold market, indicating a symmetric behavior of spillovers from the oil shocks to gold returns and a low sensitivity to gold returns to the direction of oil price shocks.

4.4. Effect of EPU on the dynamic connectedness

In this subsection, we investigate the role of the endogenous economic policy uncertainty (EPU) on driving the dynamic total connectedness between oil shocks and gold returns on both the static and changing environments. Estimates of the regression coefficients in Eqs. (9) and (10) are reported in Table 5. As we can see from this table, EPU has a significant effect on the time-varying transmission of the spillovers on both the static and regime-switching parameter models. For the static parameters model, all regression coefficients are statistically significant and positive at the 1% level for the total connectedness from gold to gold.
and for the pairwise dynamic connectedness between the disintegrated oil shocks and gold returns, except for the oil risk shocks when the effect of the EPU on transmission spillovers to gold returns turns to negative.

Given that the states of the economy are dynamic rather than static, and the selected commodities are connected, so the effect of the EPU may vary under different economic states. So, it’s interesting to examine the effect of the EPU on the time-varying directional connectedness between oil and gold markets in a regime-changing environment. We consider two regimes, the high and low uncertainty regimes, and re-estimate the regression coefficients (Table 5). The results reported in this table reveal a positive and significant effect of the EPU for the majority of transmissions of spillovers. In fact, we observe that total dynamic spillovers between the variables are positively influenced by EPU, and this effect becomes more pronounced in the low uncertainty regime (regime 1) when economic uncertainty is low. Total dynamic spillovers from gold to oil markets are negatively influenced by the EPU in the high uncertainty regime, but this effect turns to positive in a low uncertainty regime. Besides, the total dynamic spillovers from the oil shocks to gold returns are positively affected by EPU, and this effect is more pronounced in regime 1 when the economic uncertainty is low.

Regarding the dynamic spillovers from the disintegrated oil shocks to gold markets, the results reported in Table 5 show that the dynamic spillovers from the supply shocks are positively affected by the EPU, and this effect is more important in the low economic uncertainty state, and the transmission of the spillovers from the oil demand shocks to gold returns is significantly positive only in regime 1 (low uncertainty), while the transmission of spillovers from the oil risk shocks to the gold market is negatively influenced by EPU in the low uncertainty regime and this effect turns to positive and significant in the high economic uncertainty state.

The bottom line in Table 5 shows that the net transmissions of the spillovers are significantly influenced by EPU; the effect of EPU is negative in the low uncertainty regime but turns positive in the high economic uncertainty. In the last column of Table 5, we report the results from the Wald test (Wald-T) in order to justify the use of different regimes of economic uncertainty. The results from this test show that all estimated statistics are statistically significant at the 1% level. These results reject the null hypothesis of the equality of regression coefficients for different regimes and support the use of different economic uncertainty states when analyzing the effect of EPU on the dynamic connectedness between these variables. Consequently, considering a static economic uncertainty state may misspecify the effect of EPU on the different financial variables.

Similarly, we examine the effect of EPU on the total dynamic asymmetric connectedness between the oil price shocks and gold returns, and the results are reported in Table 6. In a static economy state, we find that EPU doesn’t affect the total dynamic asymmetric time spillovers between the two markets. Generally, EPU influences the dynamic transmissions of spillovers from gold to both the negative and positive oil price shocks, and from the positive oil shocks to gold returns. More specifically, EPU has a positive and significant effect on the transmission of spillovers from the positive and negative oil supply shocks to gold returns and this effect is greater for spillovers from the positive shocks to gold returns, whereas EPU affects significantly and positively the transmission of spillovers from the negative demand shocks to gold returns and have a negative effect on the transmission of spillovers from the positive risk shocks to gold returns.

Regarding the effect of EPU on the dynamic asymmetric connectedness in a changing economy state, the results show that in the considered regimes, the high and low economic uncertainty, the effect of EPU on the asymmetric dynamic connectedness is always significant and switches between negative and positive values. We report a statistically significant positive effect of EPU on the dynamic total connectedness between the variables in the low economic uncertainty regime, which turns to a significant negative effect on the high economic uncertainty state. Dynamic spillovers from gold to the different oil price shocks are significantly and positively influenced by EPU in both the high and low economic uncertainty states, but the dynamic asymmetric spillovers to gold are significantly affected by EPU only in the low economic uncertainty regime where the effect is positive on the transmission of spillovers from the positive shocks and negative from the negative ones.

The results also reveal that the asymmetric dynamic spillover from the demand shocks to gold returns is influenced by EPU, the effect is significantly negative and very weak from both the negative and positive oil demand shocks in regime one (low uncertainty) but turn positive, and greater from the negative oil demand shocks to gold returns in the high economic uncertainty state. Moreover, the dynamic transmission of spillovers from the positive and negative oil risk shocks is positively influenced by EPU in the low uncertainty regime. But in the high economic uncertainty state, the effect of EPU is significantly negative on the transmission of spillovers from only the positive oil risk shocks to the gold market.

These results suggest that the oil-gold connectedness is state-dependent. Moreover, this regime-dependency varies in magnitude and sign, depending on the sources of oil shocks. That is, what is good for the oil prices may be good or bad for the gold market, depending on the prevailing regime. For example, in a low economic uncertainty state, only the positive oil supply shocks are good for the gold market, while in
The high uncertainty state, both negative and positive oil supply shocks are good for the gold market, and the impact of this shock on the gold market is greater in the low economic uncertainty state. Further, we notice a bidirectional information transmission between the oil and gold markets, which is also state-dependent. These results imply that the oil shocks are inversely responsive to gold returns, depending on the economy states. This shows how gold is strongly tied to the real economy and underscores its great sensitivity to political news and geopolitical conflicts. In this context, policymakers may rely on oil shocks in order to predict future fluctuations in gold prices, depending on the state of the economy.

The bottom line in Table 5 shows that the net connectedness between the positive and negative oil shocks and gold returns is negatively affected by EPU only in the high economic uncertainty state.

5. Conclusion

The objective of this paper is to investigate the dynamic connectedness between oil price shocks and gold returns and analyze the role of economic policy uncertainty (EPU) in driving these interconnections between these variables. To this finality, we first use the methodology of Ready (2018) to disentangle the oil price into different structural shocks depending on factors driving oil price changes. This process has given us a more accurate dataset that includes series on the oil supply shocks, oil demand shocks, and oil risk shocks. Second, we use a new methodology based on the TVP-VAR model of Antonakakis and Gabauer (2017) to examine the total dynamic connectedness between the disintegrated oil price shocks and gold returns. Third, given that changes in economic and political uncertainty are likely to affect in different extent, the macroeconomic variables, including oil prices, exchange rates, and inflation, and they may be fundamental drivers of the oil-gold interconnectedness. Thus, in this study, we investigate the effect of EPU on the dynamic connectedness between the oil price shocks and gold returns, considering the different states of the economic uncertainty.

These findings reveal different regularities. First, there is a weak average of total dynamic connectedness between oil price shocks and gold returns, with sudden upsurges during financial crises and market turmoil (i.e., the Asian financial crisis (1997–1998), the GFC (2008–2009) the sovereign debt crisis (2010–2012)). This finding suggests that even regularly low connectedness levels may increase during periods of financial end economic events. Further, the oil supply shocks are the dominant transmitters of the time-varying spillovers from the oil market to gold returns followed by the oil risk shocks, while oil demand shocks are net receivers of spillovers from gold market. This result may be explained by the fact that oil supply shocks are caused by sudden supply interruptions due to geopolitical conflicts, natural disasters, economic events, which matter most for investors and policy makers who search out for safe refuges to protect their portfolios against oil market risks. Another explanation may be related to the US dollar channel, given that both oil and gold are traded using the US dollar, and as a result central bank’s policy, such as selling or buying dollars, are likely to affect US dollar.

Overall, our findings highlight a weak negative net connectedness between the oil supply and oil risk shocks and gold, which suggests a low sensitivity of gold returns to the different risk factors driving oil price fluctuations. This result maybe explained by the fact that oil and gold are two commodities that have different characteristics. In fact, oil is a cyclical commodity that is regulated to some degree by OPEC and OPEC+, while gold is generally considered as a refuge asset. These findings suggest that investors should be more concerned with the oil supply interruptions than with changes in the oil demand and risk shocks.

Second, in order to examine if the positive and negative oil shocks impact the dynamic transmission of spillovers between oil and gold markets differently, we have separated the positive oil shocks from the negative ones and re-estimated the total asymmetric dynamic connectedness between the variables. The results didn’t show any asymmetric patterns of total dynamic connectedness, total connectedness from gold to gold or net gold. This result may be due to the low connectedness between the oil shocks and gold returns because of the gold monetary value to central banks and other particular economic uses (Bhar and Hammoudah, 2011).

Third, we have investigated the effect of EPU on transmission of spillovers between oil and gold markets. We find a significant effect of EPU on driving dynamic connectedness between these two markets in the both static and changing economic uncertainty states. Overall, we find a positive effect of EPU on transmission of spillovers between all variables and the effect is more important in the low economic uncertainty regime (regime 1), except for the spillovers from gold and from the oil risk shocks to gold returns for which the effect of EPU turns significantly negative. This is not surprising since gold can be called the uncertainty precious metal.

The changing of sign and size of the effect of EPU on the transmission of spillovers between gold and the oil shocks implies that the responses of the oil-gold connectedness to economic and policy uncertainty are regime-dependent and one regime is not the right recipe for correctly...
analyzing the effect of EPU. Consequently, different economic uncertainty states are drivers of the oil-gold connectedness level and may help investors in predicting the capacity of gold as a hedge or a diversifier depending on the economic uncertainty level, which means that there are times when gold stands as a refuge asset and there are other times when it is not. Our findings are in line with Balciar et al. (2016) who find that different uncertainty measures help to predict gold prices but are contradictory to those of Salisu and Adepitan (2020) who find that policy uncertainty plays no role to enable gold to hedge different oil market risks.

Our findings suggest that the oil-gold relationship is highly sensitive to crises, political news and inflation. This relationship is also affected by the central bank’s interventions, which gives gold a higher monetary value. Interestingly, the impact of the oil shocks on the gold market returns varies in the high and low economic uncertainty states. This result suggests that what is good for the oil market may be good or bad for gold, market, depending in both the sources of oil shocks and the prevailing regime. Thus, both oil shocks and gold returns seem to have strong information for the economic policymakers. This is more relevant under high economic uncertainty state. Oil shocks transmit more information to the gold market than the reverse direction. This suggests that policymakers can rely on oil shocks to predict future fluctuations on gold prices in the high uncertainty state in order to make suitable hedging strategies.

The various findings of this study have several implications for investors as well as for policymakers. First, we find a weak connectedness between oil shocks and gold with the sudden upsurge during tumultuous periods. This finding suggests that gold can act as a hedge and a safe haven against oil shocks especially during the normal oil market conditions. However, during market stress periods, gold has no beneficial hedging. Second, policymakers and investors should specify whether the oil price fluctuations are driven by oil supply, oil demand, and risk shocks when analyzing the gold price. At this point, the most noticeable connectedness with the gold price is associated with the oil supply shocks compared to other shocks. Therefore, more attention should be attributed to the oil supply shocks occurring in the oil markets, as a result of geopolitical events. In this case, investors should have no interest in using gold to hedge against those oil supply shocks under bear market conditions. Third, a significant and regime-dependence effect of the EPU on the dynamic connectedness between the oil shocks and gold implies that policymakers and investors should consider the factor of economic policy uncertainty in analyzing the oil-gold relationship.

As a following research, we suggest to considering other energy markets in the same framework and then to examine the ability of gold in hedging and safe havening against energy price variations.

Authors’ contributions

Authors contribute equally in this paper.

Declaration of competing interest

We declare that there are no conflicts of interest

References


