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Spillover and Drivers of Uncertainty among Oil and Commodity Markets

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Abstract: The paper aims to examine the spillover of uncertainty among commodity markets using Diebold–Yilmaz approach based on forecast error variance decomposition. Next, causal impact of global factors as drivers of uncertainty transmission between oil and other commodity markets is analyzed. Our analysis suggests that oil is a net transmitter to other commodity uncertainties, and this transmission significantly increased during the global financial crisis of 2008–2009. The use of linear and nonlinear causality tests indicates that the global factors have a causal effect on the overall connectedness, and especially on the spillovers from oil to other commodity uncertainties. Further segregation of transmissions between oil to individual commodity markets indicates that stock market implied volatility, risk spread, and economic policy uncertainty are the influential drivers of connectedness among commodity markets.

Keywords: uncertainty transmission; commodities; nonlinear causality; global factors

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1. Introduction

Amidst the financialization of commodities, understanding the dynamics of commodity markets, such as energy, precious metals, industrial metals, and agriculture, has become an important topic for investors, policymakers, and risk managers. This financialization, along with increased integration of global markets, has augmented the transmission between different markets [1–3]. The increased flow of capital between countries and substantial technological development are the key reasons contributing to globalization. Thus, it is essential to understand the extent and nature of linkages among different financial markets [4].

In global financial markets, oil is considered as an important commodity [5]. Despite being an underlying asset, oil is also considered as life support for profuse economies [6]. The focus of researchers is now moved more towards the transmission among commodities, especially with oil markets, after an increase in general trend for investment in commodity markets [7]. Empirical researchers have proposed several possible channels of connectedness between the oil and other commodity markets. Accordingly, an increase in the price of oil leads to inclination in commodity prices [8]. According to Jain and Ghosh [9], the exchange rate and inflation shock in countries that rely heavily on oil imports result due to the increase in global oil prices. Thereby, investors prefer to collect precious metals against inflation and currency risk in such a situation to hedge their portfolios. Hooker [10] proposed that due to expansion in economic activities, there is seen an increase in global demand for oil, which enhances the oil prices that result in more usage of precious and industrial metals, say tin and copper.

Furthermore, oil price shocks result in commodity market inflationary pressure. Because of this inflationary pressure, policymakers tighten the monetary policy, thereby increasing the interest rates, which in turn impact the consumer demand for durable goods [11]. Likewise, the increase in global oil prices also leads to an upward trend in metal or commodity prices due to their impact on production and transportation costs [12]. Additionally, oil prices also have an impact on the growth of an economy—a key driver of demand for agricultural commodities [13]. Recent studies suggested a bi-directional causal relation between agricultural commodity prices and global oil prices [14–16]. The increase in oil prices upshot the cost of essential agricultural inputs, which in turn increases the production costs of agricultural products, thus, affecting the cost of oil substitutes, such as bio-fuels [17].

Recently, various studies have analyzed the transmission mechanism between the oil and commodity markets [18–24]. Hammoudeh and Yuan [11] argued that oil prices act as a determinant of univariate volatilities of precious metals (gold, silver, and copper) in the US metals market. According to Huang et al. [25], there is a positive effect of exchange rates and the US dollar on precious metals. Sari et al. [26] find a short-term relationship between precious metals and crude oil in context of developed countries. Diebold et al. [20] find that there is a high connectedness between energy, precious metals, industrial metals, and agricultural commodities.

Along with the increased interest in the transmission dynamics, there has been considerable attention given by researchers to explore the influence of global factors on commodity markets [27–33]. Batten et al. [34] argued that returns are time-varying, that is, risk-adjusted returns were negative during the Asian financial crisis period, whereas the returns were positive during the global financial crisis (GFC) of 2008–2009. Poncela et al. [32] explore the role of uncertainty in determining co-movements among non-energy prices in the short-run. The study finds increased spillovers among raw materials. Prokopczuk et al. [35] find that there is a bidirectional relationship between volatility of the commodity market with financial and economic uncertainty during a recession period.

Despite a multitude of research concerning the impact of global factors on commodities and other financial markets in separate settings, however, the literature is silent on the effect of global factors on the transmission relationship between oil and commodity markets. In order to fulfill this theoretical void, this study aims to investigate the spillover connectedness among commodities. Additionally, the study seeks to examine the impact of global factors in driving uncertainty spillovers between oil and commodity markets.

Owning to the fact that the financialization of commodities has increased both the intra-commodity connectedness and the connectedness of commodities with other financial markets at a global level, one can assume that commodity markets are exposed to the risks associated with stock markets, currency markets, and uncertainty regarding economic policies. Additionally, in light of the recent literature providing evidence of causal impact of economic policy uncertainty on the connectedness across oil and financial markets [27,28,30], this paper contributes to the literature by (i) examining the transmission between oil and other commodity uncertainties using the Diebold and Yilmaz [36] framework, and (ii) providing evidence on the causal impact of global factors on the intra-commodity transmission using linear and nonlinear causality frameworks proposed by Granger [37] and Péguin-Feissolle and Teräsvirta [38].

In application, our results indicate strong bi-directional transmission between oil and metal (agriculture) markets, and this transmission became significantly more pronounced during the turmoil period, i.e., the global financial crisis. Our analysis also suggests that oil is a net transmitter to other commodity uncertainties, and this transmission significantly increased during the period of the global financial crisis. Additionally, our results indicate that the global factors in some way have a causal effect on the overall connectedness, especially on the spillovers from oil to other commodity uncertainties. Further segregation of transmissions from oil to individual commodity markets and vice versa indicate the S&P 500 volatility index (VIX), and to some extent, difference between the interest rate on short-term U.S. government debt and the interest rate on interbank loans (TED) spread and the U.S. economic policy uncertainty index (EPU), as the most influential drivers of connectedness among commodity markets.

The remainder of this paper is divided into five sections. Section 2 provides a review of previous literature. Section 3 outlines the methodology used to analyze the transmission between oil and other commodity uncertainties and examination of the impact of global factors on the transmission across commodity markets. Section 4 provides details of the data and summary statistics. The empirical findings are discussed in Section 5. Finally, Section 6 makes concluding remarks.

2. Literature Review

2.1. Oil and Commodity Markets

As indicated earlier, the empirical finance literature is rich in studies focusing on the linkage between the precious metals, industrial metals, and agricultural commodities with oil markets (such as [7,19,39–50]). Sari et al. [26] find a short-term relationship between precious metals and crude oil in the context of developed countries. Hammoudeh and Yuan [11] indicate that, in the US metal market, lagged crude oil prices drive univariate volatilities of precious metals like gold, silver, and copper. In the same way, high co-movement between gold and crude oil prices under long-term equilibrium is documented by Zhang and Wei [51]. Further, the study of Bildirici and Turkmen [52] found significant long-term association between crude oil prices and precious metals. In accordance with the findings of Kanjilal and Ghosh [31], the study also reported significant long-run influence of crude oil prices on gold and copper returns. Diebold et al. [20] characterize connectedness in 19 key commodity volatilities over the period 2011 to 2016 using high-dimensional generalized vector-autoregressive (VAR) and network analysis. The study finds apparent clustering of commodities into groups, and the energy sector is most important in sending shocks to other commodities. Moreover, there is high connectedness between energy commodities, precious metals, industrial metals, agricultural commodities, and soft commodities. Balli et al. [19] find that connectedness among 22 commodity uncertainty indexes increased during the global financial crisis (GFC) and the oil price collapse of 2014–2016 using spillover analysis. Furthermore, network graphs analysis shows that precious metals may have served as a safe-haven due to less spillover with other commodities during the crisis period. In that regard, the study tests the following hypotheses:

Hypothesis 1a (H1a). *There are no spillovers between oil and commodity markets.*

Hypothesis 1b (H1b). *There are no spillovers between oil and commodity markets during crisis period.*

2.2. Global Factors and Commodity Markets

Various studies have witnessed more synchronization in the oil prices movement with commodity returns including precious metals, agricultural commodities, and commodity futures for the current decade due to the increased financialization and inclusion of alternative investments within a portfolio of investors [39,53–56]. The crude oil and commodity market risk and return interactions are profoundly investigated in the earlier studies from both directions (say [57,58]). However, studies that examine the possible causal effect of different global factors on the connectedness of oil and commodities are scarce. Therefore, in this study, we argue that global factors can have direct economy-wide effects that ultimately cascade into financial markets.

The earlier research has shown that lenders react with a conservative approach in government lending practices when an augmented level of uncertainty regarding government economic policies exists and, by consequence, the interest rates increase in the market [59]. Rogoff [60] argues that higher oil consumption countries are less vulnerable to shocks than they were in the past due in part to increased energy efficiency. Bouoiyour et al. [61] explores the dynamic association between oil prices and geopolitical risk (low- and high-risk scenarios). The findings of the study indicate oil prices as a nonlinear-switching phenomenon. Prokopczuk et al. [35] explore the association between volatility of commodity markets and economic and financial uncertainty. They conclude that there is a bidirectional relationship between the volatility of a commodity market with financial and economic uncertainty during a recession period. Ordu-Akkaya and Soytas [62] finds that spillover from stocks to commodities during a period of financialization increased for all commodities. Moreover, one of the underlying reasons for increasing spillover between markets was quantitative easing, including default spread, current factors, or interest rate.

Several other factors have been shown to affect the commodity markets, such as financial stress or TED spread [63], Morgan Stanley Capital International (MSCI) World index, U.S. Dollar (USD) index, and financial stress, among others (say [32,64]). Huang et al. [25] investigate the relationship between US oil prices and the prices of gold, copper, and silver in Chinese market. The findings of the study unveil that the network of oil, silver, and gold prices have significant explanatory power in establishing silver and gold prices in the Chinese commodity market. Accordingly, Jebabli et al. [33] find that shocks to MSCI markets or crude oil had short-term and immediate impacts on food markets during the GFC of 2008–2009. De Boyrie and Pavlova [29] find that an increase in the Chicago Board Options Exchange (CBOE) volatility index (VIX) is related to higher agriculture commodities correlations.

Murray [65] finds evidence of Granger-causality from commodity prices to the geopolitical risk (GPR) index in the years preceding the GFC but not afterward. Liu et al. [66] find that GPR causes fluctuations in the oil market, where results strongly confirm the GARCH-MIDAS-GPRS model with serious GPR significantly outperforms the GARCH-MIDAS model in the out-of-sample results.

Robe and Wallen [64] reveal that short-term oil implied volatilities and West Texas Intermediate (WTI)-implied volatility term structure is significantly affected by VIX and the other constraints of oil output such as inflation. The authors' explanation regarding inflation channel suggests that higher oil prices not only imply higher energy and production costs, but also that the phenomena cause an interest rate hike. In addition, the positive impact of EPU on stock-commodity association is reported by Badshah et al. [30]. The effects were more pronounced in the case of energy and industrial metals. In the same way, Kanjilal and Ghosh [31] also report the linkages between oil and gold in two specific ways, either through an inflation channel for oil-importing countries or through a revenue channel for oil exporters. Considering the above literature, we test the following hypotheses:

Hypothesis 2a (H2a). *Global factors do not Granger-cause spillovers between oil and commodity markets in a linear setting.*

Hypothesis 2b (H2b). *Global factors do not Granger-cause spillovers between oil and commodity markets in a nonlinear setting.*

3. Methodology

The empirical analysis of this paper is divided into two parts. First, we follow the connectedness framework of Diebold and Yilmaz [36] to estimate the transmission between oil and other commodity uncertainties. After estimating the transmission measures, we then test the impact of global factors on the transmission measures between oil and other commodity uncertainties using linear and nonlinear causality tests.

3.1. Diebold and Yilmaz Transmission Approach

We follow the connectedness framework of Diebold and Yilmaz [36] to estimate the different transmission measures built from the forecast-error variance decomposition (FEVD) matrix centered on the generalized vector-autoregressive (VAR) model. Consider an n-variate covariance stationary VAR (p) model,

$$x_t = \sum_{i=1}^{p} \gamma_i x_{t-i} + \epsilon_t \tag{1}$$

where $\epsilon_t \sim N(0, \Sigma)$. The moving average component of the VAR process is represented by the following moving average (MA) (∞) process $x_t = \sum_{i=0}^{\infty} \omega_i \epsilon_{t-i}$, where ω_i is a $n \times n$ coefficient matrix and calculated recursively using $\omega_i = \gamma_1 \omega_{i-1} + \gamma_2 \omega_{i-2} + \cdots + \gamma_p \omega_{i-p}$, and ω_0 represents the identity matrix. Taking help from the MA coefficient, we utilize the generalized FEVD, which permits splitting the H-step-ahead forecast error of each variable and attributed to various shocks in the system.

We favor the generalized approach of Koop et al. [67] and Pesaran and Shin [68] to achieve orthogonality since the Cholesky factor depends upon the ordering of the variables. The contribution of variable j to the H-step-ahead generalized variance of forecast error of variable i is denoted as $\tau_{ij}(\mathrm{H})$ and computed as:

$$\tau_{ij}(\mathrm{H}) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' \omega_h \sum e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' \omega_h \sum \omega_h' e_i\right)^2} \tag{2}$$

where the jth diagonal component of the standard deviation is represented by σ_{jj}. $\sum$ represents the covariance matrix of errors. e_i has a value 1 for ith component and 0 otherwise. Finally, the coefficient matrix that multiplies h-lagged error in the infinite moving-average representation of non-orthogonalized VAR is represented by ω_h.

We measure the pairwise directional transmission, $\tau_{ij}(\mathrm{H})$, from j to i as:

$$\mathrm{T}_{i \leftarrow j}^{H} = \tau_{ij}(\mathrm{H}) \tag{3}$$

The ratio of the off-diagonal sum of rows to the sum of all the elements represents the total directional transmission from others to i as:

$$\mathrm{T}_{i \leftarrow \bullet}^{H} = \frac{1}{N} \sum_{\substack{j=1 \\ j \neq i}}^{N} \tau_{ij}(\mathrm{H}) \tag{4}$$

Furthermore, the ratio of the off-diagonal sums of columns to the sum of all the elements represents the total directional transmission to others from j as:

$$\mathrm{T}_{\bullet \leftarrow j}^{H} = \frac{1}{N} \sum_{\substack{i=1 \\ i \neq j}}^{N} \tau_{ij}(\mathrm{H}) \tag{5}$$

Finally, the total system-wide transmission is the ratio of the sum of the from-others (to-others) elements of the variance decomposition matrix to the sum of all its elements:

$$\mathrm{T}^{H} = \frac{1}{N} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tau_{ij}(\mathrm{H}) \tag{6}$$

3.2. *Causality Tests*

In the second part of our analysis, we empirically examine the impact of global factors on the transmission relationship between oil and other commodity uncertainties utilizing the linear and nonlinear causality tests.

3.2.1. Linear Causality Test

Based on the vector autoregressive (VAR) framework, we employ the linear causality test following Granger [37]. The test can be expressed as:

$$\begin{array}{c} x_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} x_{t-i} + \sum_{i=1}^{m} \alpha_{2i} y_{t-i} + \varepsilon_{1t} \\ y_t = \beta_0 + \sum_{i=1}^{m} \beta_{1i} y_{t-i} + \sum_{i=1}^{n} \beta_{2i} x_{t-i} + \varepsilon_{2t} \end{array} \tag{7}$$

where x_t and y_t represent global factors and transmission between oil and other commodity uncertainties, respectively. ε_{1t} and ε_{2t} are uncorrelated idiosyncratic terms. The null hypothesis tested using Granger [37] causality test is "x_t does not Granger-cause y_t". If the lags of x_t can predict y_t, we can reject the hypothesis and x_t "Granger-causes" y_t.

3.2.2. Nonlinear Causality Tests

The pioneering work by Granger [37] paved the way for other researchers to look deeply into the causal relationship between economic and financial time series. Péguin-Feissolle and Teräsvirta [38] proposed two nonlinear causality tests: (1) Taylor series approximation and (2) Artificial Neural Network (ANN)-based.

The Taylor series approximation causality test is based on the Taylor expansion of the nonlinear function:

$$x_t = f^*\left(x_{t-1}, \ldots, x_{t-q}, y_{t-1}, \ldots, y_{t-n}, \vartheta^*\right) + \varepsilon_t \tag{8}$$

where ϑ^* is a vector, x_t and y_t are weakly stationary series, and f^* is an unknown function but assumed to represent the causal relationship between y_t and x_t. Moreover, for every point of the sample (parameter) space $\vartheta^* \in \Theta$, f^* has a convergent Taylor expansion. In order to examine the non-causality hypothesis, i.e., y_t does not cause x_t, we have:

$$x_t = f^*\left(x_{t-1}, \ldots, x_{t-q}, \vartheta\right) + \varepsilon_t \tag{9}$$

To test Equation (9) against Equation (8), following Péguin-Feissolle and Teräsvirta [38] and later Péguin-Feissolle et al. [69], we linearize f^* and increase the function form into a kth order Taylor series around an arbitrary sample space. After the approximation and re-parameterization of f^*, we obtain:

$$\begin{array}{c} x_t = \theta_0 + \sum_{j=1}^{q} \theta_j x_{t-j} + \sum_{j=1}^{n} \gamma_j y_{t-j} + \sum_{j_1=1}^{q} \sum_{j_2=j_1}^{q} \theta_{j_1 j_2} x_{t-j_1} x_{t-j_2} + \sum_{j_1=1}^{q} \sum_{j_2=1}^{n} \varphi_{j_1 j_2} x_{t-j_1} y_{t-j_2} + \\ \sum_{j_1=1}^{n} \sum_{j_2=j_1}^{n} \gamma_{j_1 j_2} y_{t-j_1} y_{t-j_2} + \cdots + \sum_{j_1-1}^{q} \sum_{j_2=j_1}^{q} \cdots \sum_{j_k=j_k-1}^{q} \theta_{j_1 \ldots j_k} x_{t-j_1} \ldots x_{t-j_k} + \cdots + \theta_{j_1 j_2} x_{t-j_1} x_{t-j_2} + \\ \sum_{j_1=1}^{n} \sum_{j_2=j_1}^{n} \cdots \sum_{j_k=j_k-1}^{n} \gamma_{j_1 \ldots j_k} y_{t-j_1} \cdots y_{t-j_k} + \varepsilon_t^* \end{array} \tag{10}$$

where $\varepsilon_t^* = \varepsilon_t + R_t{}^{(k)}(y, x)$, $R_t{}^{(k)}$ represents the remainder with $n \leq k$ and $q \leq k$.

Péguin-Feissolle and Teräsvirta [38] indicate two possible difficulties related to Equation (10). One being multicollinearity due to large k, q, and n, and second is the small number of degrees of freedom, due to the rapid increase in the number of regressors with k. By replacing some observation matrices with their principal components, we can tackle both problems. Hence, we use the principal components and test the null hypothesis of zero coefficients of principal components, tested as:

$$General = \frac{(SSR_0 - SSR_1)/p^*}{SSR_1/(T - 1 - 2p^*)} \tag{11}$$

where we obtain SSR_0 and SSR_1 using the following methods. For SSR_0, we regress x_t on 1 and the first principal components p^* of the matrix of lags of x_t only, to estimate the residuals $\hat{\varepsilon}_t,\ t = 1, \ldots,$ T. The squared residuals are summed to obtain SSR_0. SSR_1 are obtained by regressing $\hat{\varepsilon}_t$ on 1 and all the terms of the two principal component matrices. The problem of degree of freedom can be tackled by assuming that the general model is "semi-additive":

$$x_t = f\left(x_{t-1}, \ldots, x_{t-q}, \vartheta_f\right) + g\left(y_{t-1}, \ldots, y_{t-n}, \vartheta_g\right) + \varepsilon_t \tag{12}$$

where $\vartheta' = \left(\vartheta'_f, \vartheta'_g\right)'$ is the parameter vector. If $g\left(y_{t-1}, \ldots, y_{t-n}, \vartheta_g\right) = constant$, then y_t does not cause x_t. In order to obtain the static called "additive", we linearize both functions into kth order Taylor series.

The artificial neural network causality test uses a logistic function. The approximation of the equation $g\left(y_{t-1}, \ldots, y_{t-n}, \vartheta_g\right)$ is obtained using:

$$\vartheta_0 + \tilde{\mu}_t' \alpha + \sum_{j=1}^{p} B_j \frac{1}{1 + e^{-\gamma_j' \mu_t}} \tag{13}$$

where $\vartheta_0 \in R$, $\mu_t = (1, \tilde{\mu}_t')'$ is a $(n+1) \times 1$ vector, $\tilde{\mu}_t = (y_{t-1}, \ldots, y_{t-n})'$, $\alpha = (\alpha_1, \ldots, \alpha_n)'$ are $(n \times 1)$ vectors, and $\gamma_j = \left(\gamma_{j0}, \ldots, \gamma_{jn}\right)'$ for $j = 1, \ldots, p$, are $(n+1) \times 1$ vectors. The null hypothesis of the test is $\{y_t\}$ does not cause $\{x_t\}$. The estimation of the ANN-based causality test serves as (1) comparative analysis for the Taylor-based nonlinear causality test, and (2) serves as a robustness check. The use of nonlinear causality tests also helps minimize possible estimation errors, since we use the estimated transmission measures. Additionally, we utilize the VAR stability tests to ensure the stationarity of residuals.

4. Data and Summary Statistics

In order to estimate the transmission between crude oil and other commodities, we use daily data of commodity uncertainties, namely crude oil WTI (WTI), gold (GLD), silver (SLV), platinum (PLT), palladium (PLD), aluminum (ALM), copper (CPR), zinc (ZNC), lead (LED), nickel (NKL), wheat (WHT), corn (CRN), soybean (SBN), coffee (COF), sugar (SGR), cocoa (COC), and cotton (COT) from January 2007 to December 2016. The sample period of commodity uncertainties developed by Balli et al. [19] covers several periods of uncertainty for commodities, including the GFC. Table 1 reports the descriptive statistics for crude oil WTI and other commodity uncertainty indices.

The summary statistics of uncertainty indices indicate that silver and gold have the highest mean uncertainty along with the highest standard deviation indicating the presence of extreme fluctuations. This can be related to the fact that investors use precious metals, such as gold, as a hedge against the inflationary and monetary policy uncertainty [70]. The results of the Jarque Bera test reject the null of normality for all uncertainty indices. Furthermore, the results of Augmented Dickey−Fuller (ADF) and Phillips−Perron (PP) indicate stationarity in all the uncertainty indices and hence, appropriate for the use of the Diebold–Yilmaz (DY) framework. Following Balli et al. [19], we analyze the uncertainty transmission between crude oil WTI and other commodity uncertainties using log-transformed uncertainty indices.

For our objective to analyze whether global factors impact the transmission between crude oil WTI and other commodity uncertainties, we employ a battery of six potential global factors, widely used in the literature. These include: (1) the U.S. economic policy uncertainty index (EPU) developed by Baker et al. [71], (2) the U.S. geopolitical risk index (GPR) developed by Caldara and Iacoviello [72], (3) the S&P 500 volatility index (VIX) developed by the Chicago Board Options Exchange (CBOE), (4) MSCI world index (MSCI) as a representative of the world stock market index, (5) TED spread (TED), which is the difference between the yield on 90-day Treasury Bill and London Interbank Offered Rate (LIBOR), and (6) the trade-weighted U.S. Dollar Index (USD). The summary statistics for six global factors indicate that EPU, GPR, VIX, and TED are stationary; hence, they are not transformed. Whereas MSCI and USD are transformed using the logarithmic first difference in order to achieve stationarity.

Table 1. Descriptive statistics for commodity uncertainties and global factors.

	Abbreviation	Mean	Std. Dev.	JB	ADF	PP
Crude oil WTI	WTI	1.87	1.42	13,915.90 ***	−3.66 ***	−4.31 ***
Gold	GLD	5.15	2.85	10,078.38 ***	−5.47 ***	−5.61 ***
Silver	SLV	7.88	3.69	8085.54 ***	−5.12 ***	−4.45 ***
Platinum	PLT	4.00	1.65	16,150.18 ***	−14.35 ***	−12.29 ***
Palladium	PLD	2.41	2.59	17,149.21 ***	−6.37 ***	−5.06 ***
Aluminum	ALM	0.63	0.94	147,332.80 ***	−6.36 ***	−22.20 ***
Copper	CPR	0.31	0.28	1,282,594.00 ***	−5.04 ***	−8.32 ***
Zinc	ZNC	0.72	0.52	741,914.00 ***	−7.49 ***	−14.49 ***
Lead	LED	0.66	0.51	589,331.20 ***	−14.79 ***	−15.00 ***
Nickel	NKL	0.52	0.45	1,130,079.00 ***	−14.40 ***	−15.91 ***
Wheat	WHT	2.02	1.83	153,832.00 ***	−7.20 ***	−5.58 ***
Corn	CRN	2.42	1.69	15,834.98 ***	−8.89 ***	−8.73 ***
Soybean	SBN	2.33	1.43	14,194.39 ***	−9.93 ***	−9.65 ***
Coffee	COF	0.58	0.37	302,365.70 ***	−12.50 ***	−6.71 ***
Sugar	SGR	3.67	2.11	4089.68 ***	−7.54 ***	−5.07 ***
Cocoa	COC	1.27	0.63	212,745.00 ***	−4.37 ***	−9.40 ***
Cotton	COT	4.50	2.68	12,522.60 ***	−5.83 ***	−7.52 ***
US EPU	EPU	115.3	71.04	3810.31 ***	−7.96 ***	−35.98 ***
US GPR	GPR	85.19	60.89	14,001.98 ***	−9.86 ***	−39.30 ***
VIX	VIX	21.05	9.98	6251.38 ***	−2.92 **	−3.87 ***
MSCI World	MSCI	0.004	1.15	6912.08 ***	−34.90 ***	−43.06 ***
TED Spread	TED	0.448	0.50	36,716.87 ***	−2.97 **	−3.27 **
USD index	USD	0.012	0.54	444.18 ***	−47.65 ***	−47.65 ***

Note: The table illustrates descriptive statistics of uncertainty series of Balli et al. (2019). The empirical statistics of Augmented Dickey–Fuller (1979) and the Phillips–Perron (1988) unit root tests are represented by ADF and PP. Whereas, JB represents Jarque–Bera test of normality. ** and *** denotes rejection of null hypothesis at 5% and 1% level of significance.

5. Empirical Findings

The empirical findings consist of two sections. First, we employ the DY framework to analyze the transmission between crude oil WTI and other commodities' uncertainties and provide evidence of significant transmission between them. Second, we apply linear and non-linear Granger causality models to analyze the impact of six global factors on the transmission between crude oil WTI and other commodity uncertainties.

5.1. Transmission between Oil and Other Commodity Uncertainties

Table 2 reports the transmission estimates between oil and other commodity uncertainties. Panel A and B report the estimates of the DY framework for full-sample and the global financial crisis (GFC). Analyzing Panel A, we find that metals, such as palladium, platinum, copper, aluminum, and lead, are the highest receivers of uncertainty from oil, whereas silver, palladium, and copper are the highest transmitters. Strikingly, most of the metals are the highest transmitters and receivers of uncertainty from oil. These findings indicate the strong bi-directional transmission between oil and metal markets, which are in line with the findings evidenced by Kang et al. [21] and Reboredo and Ugolini [57]. Additionally, we also find significant bi-directional transmission between oil and agricultural commodity uncertainties, consistent with the findings of Ji et al. [73] and Nazlioglu et al. [46]. Although the analysis of overall net spillovers (net spillover all uncertainties) between oil and other commodity uncertainties indicates that oil is mostly a net transmitter, additional examination of net pairwise spillovers between oil and other commodity uncertainties suggests oil is a net receiver from gold, silver, palladium, soybean, and cocoa. Similar to the findings of Albulescu et al. [27] about the heterogeneity in the relationship between oil and commodity currencies, we find additional evidence of heterogeneity in the relationship between oil and other commodities.

Table 2. Diebold–Yilmaz (DY) spillover results.

	From WTI	From All Uncertainties	To WTI	To All Uncertainties	Net Spillover WTI	Net Spillover All Uncertainties
Panel A: Full sample (January 2007 to December 2016)						
WTI	68.767	1.952	68.767	2.128	0.000	0.176
GLD	0.901	2.333	1.343	2.694	−0.441	0.361
SLV	0.854	1.361	8.237	5.198	−7.383	3.836
PLT	4.743	1.843	0.324	0.651	4.419	−1.192
PLD	5.214	2.105	8.292	3.081	−3.078	0.976
ALM	3.117	2.110	0.067	1.541	3.049	−0.568
CPR	3.825	2.249	3.674	3.847	0.151	1.598
ZNC	1.112	2.418	0.372	1.493	0.740	−0.925
LED	2.947	2.830	0.270	4.167	2.677	1.337
NKL	2.040	5.801	0.783	0.409	1.257	−5.391
WHT	0.660	2.084	0.628	2.459	0.032	0.375
CRN	1.528	2.590	2.389	2.518	−0.860	−0.072
SBN	2.275	2.430	0.645	2.035	1.630	−0.395
COF	1.259	2.429	1.116	0.914	0.144	−1.514
SGR	0.731	1.699	0.246	2.490	0.486	0.791
COC	2.088	1.784	2.742	1.987	−0.654	0.204
COT	0.756	1.952	0.106	2.357	0.650	0.404
Panel B: Global financial crisis (GFC) (January 2008–June 2009)						
WTI	51.759	3.015	51.759	3.709	0.000	0.694
GLD	0.240	2.549	0.439	2.192	−0.199	−0.357
SLV	0.625	2.828	1.908	2.879	−1.283	0.051
PLT	6.723	3.816	0.105	1.538	6.618	−2.279
PLD	4.820	2.197	7.294	3.753	−2.474	1.556
ALM	5.900	2.547	0.332	1.291	5.568	−1.255
CPR	0.221	2.623	0.811	2.699	−0.591	0.076
ZNC	0.281	2.099	0.190	2.118	0.091	0.019
LED	0.332	3.158	0.509	4.405	−0.177	1.247
NKL	0.481	4.447	1.810	3.586	−1.329	−0.861
WHT	24.671	3.760	6.656	2.870	18.015	−0.890
CRN	4.305	3.467	4.058	2.559	0.247	−0.908
SBN	5.537	2.859	3.435	2.581	2.102	−0.278
COF	1.077	2.433	6.606	3.035	−5.529	0.603
SGR	0.208	1.880	0.875	1.829	−0.667	−0.052
COC	2.578	2.757	9.109	6.788	−6.531	4.031
COT	1.340	3.007	4.104	1.612	−2.764	−1.396

Note: The table illustrates the estimates of the contribution to the variance of 100-day forecast error of asset i due to innovations in asset j. Panel A and B report the spillover results of Diebold and Yilmaz (2014) for full sample and global financial crisis (GFC), respectively.

We further analyze the transmission between oil and other commodity uncertainties during the period of the GFC (from January 2008 until June 2009) in Table 2 Panel B and find a substantial increase in the bi-directional transmission between oil and agricultural commodity uncertainties during this period. These results corroborate the findings of Shahzad et al. [74], who find symmetry in the upside and downside spillover impact between oil and agricultural commodities. We also find a significant increase in the overall net spillovers of oil uncertainty, indicating an increase in the overall transmission from oil to other commodity uncertainties. Using visual aid in Figure 1 provides additional support to the argument of a significant increase in the net spillovers of oil during the GFC period. Although we do not report the overall spillovers, the findings indicate a significant increase in the overall spillovers, implying a more pronounced dependence between oil and other commodities during the GFC.

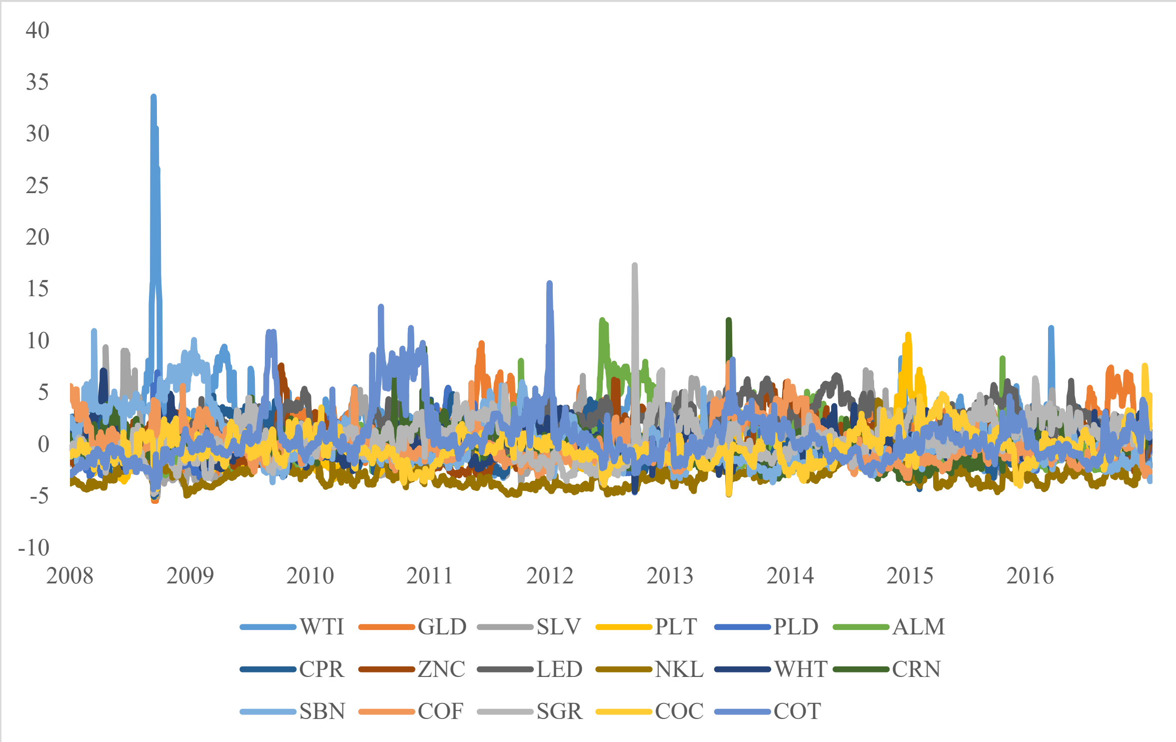

Figure 1. Dynamics of net directional connectedness of oil and other commodity uncertainties.

5.2. Impact of Global Factors

In the previous section, we observed bi-directional transmission between oil and other commodity uncertainties, with an increase in the overall transmission during the global financial crisis. Our analysis also points out the role of oil as a net transmitter of uncertainty shocks to the other commodities. In this section, we explore the impact of global factors on the connectedness of commodity markets. Indeed, with the world becoming a global village, stakeholders throughout the world have investments across different markets. Just as markets are open to investment opportunities, they also become prone to the risks associated with globalization, i.e., global liquidity conditions and the risk appetite of investors [27,75], the most notable example being the 2008 sub-prime mortgage crisis, which triggered a global financial meltdown.

We test the impact of global factors on the transmission between oil and other commodity uncertainties using three distinct methods of causality tests, i.e., a linear Granger-causality test proposed by Granger [37], along with two nonlinear (Taylor- and ANN-based) causality tests proposed by Péguin-Feissolle and Teräsvirta [38] and Péguin-Feissolle et al. [69] in Table 3. Panel A and B report the findings for the whole sample and GFC period, respectively. The null hypothesis of global factor does not Granger-cause (a) overall transmission, (b) transmission from oil uncertainty to other commodity uncertainties, and (c) transmission from other commodity uncertainties to oil uncertainty. These are tested.

Table 3. Linear and nonlinear causality tests for overall and unidirectional spillovers.

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
Panel A: Full sample (January 2007 to December 2016)												
A1: H0: Global factor −/→ overall spillovers												
Linear	3.5477	0.4707	4.7576	0.4462	4.5276	0.2098	0.5812	0.7478	**2.3654**	0.0509	2.5673	0.2770
Taylor-based	1.6579	0.1908	1.2495	0.2869	1.2478	0.2885	**2.3481**	0.0708	1.1532	0.2830	**1.6840**	0.0710
ANN-based	1.0184	0.4159	0.7018	0.6706	0.5621	0.7292	1.1202	0.3478	1.0622	0.3794	1.1660	0.3235
A2: H0: Global factor −/→ spillover FROM crude oil TO the other markets												
Linear	5.5983	0.3473	3.8061	0.5777	**5.5512**	0.0623	0.6598	0.8826	**19.7149**	0.0006	**9.7011**	0.0458
Taylor-based	**2.3048**	0.0986	**3.7839**	0.0229	**59.8155**	0.0000	**13.4252**	0.0000	**15.7838**	0.0001	**39.6647**	0.0000
ANN-based	0.2405	0.9752	1.1624	0.3212	**28.7543**	0.0000	**5.3966**	0.0000	**46.4748**	0.0000	**6.8233**	0.0000
A3: H0: Global factor −/→ spillover FROM other markets TO crude oil												
Linear	**9.1587**	0.0573	7.1653	0.2086	3.0813	0.2142	1.0881	0.5804	1.3590	0.7152	0.4477	0.5034
Taylor-based	**2.2803**	0.0585	**12.9045**	0.0000	1.8653	0.1138	0.9563	0.4686	0.9021	0.3423	**2.2701**	0.0595
ANN-based	0.9870	0.4388	**2.3820**	0.0199	0.8297	0.5284	1.3938	0.2132	**6.6518**	0.0000	**3.3619**	0.0050
Panel B: Global financial crisis (GFC) (January 2008–June 2009)												
B1: H0: Global factor −/→ overall spillovers												
Linear	1.6207	0.1841	1.3578	0.2554	1.0625	0.3649	0.9882	0.3208	0.0313	0.8596	0.1472	0.7015
Taylor-based	**2.4224**	0.0905	0.5475	0.5790	0.0825	0.7741	1.9579	0.1628	1.4666	0.2269	1.5912	0.2082
ANN-based	**2.7466**	0.0287	1.3996	0.2342	0.5213	0.7202	**5.3718**	0.0013	**5.8258**	0.0033	0.4788	0.6201
B2: H0: Global factor−/→spillover FROM crude oil TO the other markets												
Linear	**2.3023**	0.0767	1.7942	0.1477	1.5400	0.2037	0.4954	0.6857	2.2322	0.1360	1.0346	0.3772
Taylor-based	0.4639	0.6293	0.3813	0.6833	**2.7720**	0.0970	**2.9639**	0.0325	**28.1361**	0.0000	**8.4097**	0.0000
ANN-based	1.1195	0.3475	**2.4767**	0.0445	1.1649	0.3265	0.5222	0.7594	0.3314	0.7182	0.5033	0.7334
B3: H0: Global factor −/→ spillover FROM other markets TO crude oil												
Linear	0.6159	0.4330	**2.3182**	0.0998	1.2820	0.2802	**3.4551**	0.0638	0.7287	0.3938	0.3681	0.5444
Taylor-based	0.5880	0.4438	2.0656	0.1286	0.4847	0.4869	2.2490	0.1074	1.3217	0.2515	0.0032	0.9549
ANN-based	1.1663	0.3130	**2.2859**	0.0790	**2.0375**	0.0893	1.6793	0.1716	**2.3566**	0.0966	0.0016	0.9984

Note. The table reports the causality test results for linear and nonlinear (Taylor- and ANN-based) causality tests. Panel A and B report the findings for full sample and GFC, respectively. Each panel reports the causality tests for the null hypothesis that global factor does not Granger-cause (−/ →) overall spillover, spillover from oil to other commodity uncertainties, and from other commodity uncertainties to oil.

The results from Panel A indicate the impact of MSCI World, TED spread, and USD index on the overall connectedness of oil and other commodity uncertainties. We do not find the impact of EPU, GPR, and VIX on the overall connectedness. Interestingly, the results in sub-panel A2 indicate a substantial impact of the global factors on the transmission from oil to other commodity uncertainties, especially VIX, TED spread, and USD index, where linear and nonlinear tests show consistent evidence of causality. Consequently, we find evidence of the nonlinear causal impact of EPU, GPR, and MSCI World. The evidence from Panel A3 further indicates the bi-directional impact of EPU, GPR, TED spread, and USD index. The above findings provide evidence that nearly all the global factors in some way tend to drive the bi-directional connectedness of commodity markets. The evidence also suggests the intermediary role of oil to transfer the impact of global factors on other commodity markets. The above evidence can be related to the findings provided by Ciner et al. [42], and more recently, by Batten et al. [76] about the feasibility of oil as a hedge against market shocks. Indeed, if oil can be used as a hedge against market shocks, it is safe to assume that oil acts as a buffer against the impact of global factors on other commodity markets.

We further test the impact of global factors on the transmission between oil and individual commodity uncertainties. In Table 4, we present the results of linear and nonlinear causality tests for the spillovers running from oil to other commodity uncertainties for the whole sample. Although we generally find a significant impact of global factors, the results indicate a stronger impact of VIX, TED spread, and USD index on the transmissions running from oil to other commodity uncertainties. Additionally, a comparison of the linear and nonlinear causality tests yields that the relationship between the spillovers and the global factors is mostly nonlinear. In order to provide further insight into the impact of global factors on the transmission from oil to individual commodity uncertainties, we perform a sub-sample analysis during the period of the GFC. We report the results of the causality tests in Table 5. Compared with other global factors, the analysis indicates the significant impact of VIX, and to some extent, the nonlinear impact of TED spread and EPU on the transmission from oil to individual commodity uncertainties during the GFC period.

Finally, we report the results of linear and nonlinear causality tests for the transmissions running from individual commodity uncertainties to oil in Table 6. Comparing the results to Table 4, we find VIX and TED spread as the significant drivers of connectedness from individual commodity uncertainties to oil. We also find the nonlinear impact of the USD index across all commodity markets. Nevertheless, the analysis reported in Table 7 related to the transmission of individual commodity uncertainty to oil during the GFC sub-period points out the importance of VIX, and to a lesser extent, TED spread and EPU, as the drivers to cross-commodity connectedness.

Interestingly, we find a heterogeneous impact of global factors across different commodity markets. Our findings provide further evidence in support of the idea of the "financialization" of commodity markets [75,77] through various channels. First, our analysis of inter-connectedness between oil and other commodity uncertainties provides evidence of the increase in connectedness, especially during the global financial crisis. These findings are consistent with previous literature on the bi-directional inter-connectedness among commodity markets (such as [19,22,46,73,74]). Second, the results related to VIX as the most influential driver of transmission between oil and other commodity uncertainties corroborate the findings of Silvennoinen and Thorp [78] and Yoon et al. [79], indicating the importance of the US stock market as the most significant contributor of spillovers across different asset classes. Finally, the relatively significant causal impact of TED spread, and EPU provides support to the evidence provided by Buyuksahin and Robe [80] and Albulescu et al. [27] for financial market stress (TED spread) and US monetary policy (EPU) as the drivers of financial market connectedness.

Table 4. Linear and nonlinear causality tests for spillovers from oil to individual commodity uncertainties (full sample).

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor −/→ spillover FROM crude oil TO gold												
Linear	0.8710	0.4996	**5.9034**	0.0000	0.4699	0.7990	**2.6677**	0.0461	**2.6953**	0.0444	**4.2863**	0.0000
Taylor-based	1.0077	0.3883	**2.8133**	0.0602	**14.7280**	0.0001	**2.0662**	0.0440	2.3609	0.1245	**11.8387**	0.0000
ANN-based	1.8283	0.1206	**2.4489**	0.0168	**14.3010**	0.0000	**5.3515**	0.0000	**29.6800**	0.0000	1.7658	0.1166
H0: Global factor −/→ spillover FROM crude oil TO silver												
Linear	0.4969	0.7788	**5.0657**	0.0001	0.5336	0.7510	**17.7453**	0.0000	**6.2423**	0.0003	0.3372	0.7984
Taylor-based	1.5600	0.2104	**17.2247**	0.0000	**94.1650**	0.0000	**4.3676**	0.0001	0.4990	0.4800	**16.5499**	0.0000
ANN-based	**6.3265**	0.0000	0.6425	0.7209	**43.7637**	0.0000	**11.1924**	0.0000	**16.2032**	0.0000	**9.2562**	0.0000
H0: Global factor −/→ spillover FROM crude oil TO platinum												
Linear	**1.9520**	0.0577	1.3830	0.1896	1.4211	0.1918	**2.0527**	0.0452	0.7224	0.6530	1.9196	0.1045
Taylor-based	1.7888	0.1472	**51.0005**	0.0000	**13.2123**	0.0003	**2.3438**	0.0293	**24.3331**	0.0000	**15.7756**	0.0000
ANN-based	0.9138	0.4549	**14.6384**	0.0000	**6.7743**	0.0000	1.7125	0.1141	**29.6308**	0.0000	**1.9994**	0.0758
H0: Global factor −/→ spillover FROM crude oil TO palladium												
Linear	0.2511	0.9091	0.3723	0.8679	1.7082	0.1291	**3.8372**	0.0093	**4.5799**	0.0033	**7.5449**	0.0000
Taylor-based	1.5862	0.2049	**3.5119**	0.0300	**11.0566**	0.0009	**4.2593**	0.0003	0.2601	0.6101	**10.4737**	0.0000
ANN-based	0.3651	0.9227	1.0353	0.4040	**20.6270**	0.0224	1.4707	0.1843	**15.1390**	0.0000	1.1743	0.3193
H0: Global factor −/→ spillover FROM crude oil TO aluminum												
Linear	0.2244	0.9249	1.7043	0.1300	0.8615	0.5061	1.1713	0.3213	1.7553	0.1350	1.6876	0.1501
Taylor-based	**5.8399**	0.0030	**7.7639**	0.0054	**66.5353**	0.0000	**1.9649**	0.0673	**4.6179**	0.0317	**6.9828**	0.0000
ANN-based	**11.0410**	0.0000	**10.4251**	0.0000	**22.0219**	0.0000	**6.7283**	0.0000	**28.7855**	0.0000	**6.7615**	0.0000
H0: Global factor −/→ spillover FROM crude oil TO copper												
Linear	1.3666	0.2059	0.9077	0.5249	0.3165	0.9287	**2.7122**	0.0056	1.0560	0.3912	**8.9293**	0.0000
Taylor-based	0.1401	0.8693	1.2701	0.2810	**27.8830**	0.0000	**3.0288**	0.0060	**17.0333**	0.0000	**8.9347**	0.0000
ANN-based	0.3411	0.9352	0.5291	0.8131	**9.7717**	0.0000	**3.2895**	0.0032	**16.6486**	0.0000	2.4563	0.0314
H0: Global factor −/→ spillover FROM crude oil TO zinc												
Linear	1.2261	0.2939	1.5267	0.1779	0.2293	0.9499	0.5766	0.6796	0.4732	0.7554	0.9708	0.4506
Taylor-based	**3.5515**	0.0288	0.0449	0.9561	**21.1715**	0.0000	1.8860	0.3667	0.0202	0.8871	**8.4231**	0.0000
ANN-based	3.8907	0.0087	0.6393	0.6344	**11.6719**	0.0000	**3.4005**	0.0024	**28.0229**	0.0000	**3.1977**	0.0070

Table 4. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO lead												
Linear	1.5391	0.1381	0.9741	0.4481	1.0533	0.3913	**3.5789**	0.0008	1.2507	0.2649	**9.0142**	0.0000
Taylor-based	**7.3626**	0.0007	0.1307	0.7178	**13.4060**	0.0003	**1.8092**	0.0935	1.3220	0.2504	0.4673	0.9431
ANN-based	**2.7422**	0.0272	1.0137	0.3855	**2.1832**	0.0535	0.6743	0.6705	**25.6573**	0.0000	0.2808	0.9238
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO nickel												
Linear	**3.1023**	0.0029	**1.8810**	0.0684	0.5805	0.7724	**5.5338**	0.0000	**2.8659**	0.0055	**2.4901**	0.0414
Taylor-based	0.4995	0.6069	**2.7478**	0.0975	**4.3340**	0.0017	1.7599	0.1035	0.6584	0.4176	**2.5119**	0.0015
ANN-based	0.5692	0.6353	**16.5900**	0.0000	**12.4093**	0.0000	**6.9391**	0.0000	**33.3496**	0.0000	**3.4895**	0.0038
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO wheat												
Linear	0.9868	0.4322	1.7429	0.1069	0.1421	0.9906	0.7651	0.5749	0.6987	0.6244	**5.4851**	0.0000
Taylor-based	**3.1870**	0.0744	0.2953	0.7443	**25.0459**	0.0000	0.6512	0.6893	0.1733	0.6772	**23.5971**	0.0000
ANN-based	0.4808	0.6183	0.7006	0.5915	**15.0613**	0.0000	**3.6814**	0.0012	**54.6548**	0.0000	**8.2629**	0.0000
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO corn												
Linear	1.4560	0.2009	1.3021	0.2599	0.4638	0.8034	0.0887	0.7658	1.4749	0.2289	0.9274	0.4469
Taylor-based	**3.5315**	0.0294	0.6393	0.4240	**25.6121**	0.0000	0.8283	0.5478	**20.4587**	0.0000	**15.2950**	0.0000
ANN-based	**6.1555**	0.0004	0.3717	0.7734	**8.6047**	0.0000	0.7207	0.6329	**7.8646**	0.0000	**6.2589**	0.0000
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO soybean												
Linear	1.3427	0.2343	**2.0056**	0.0747	**4.2398**	0.0003	**2.3241**	0.0304	1.2152	0.2950	**2.7128**	0.0038
Taylor-based	**13.8969**	0.0000	**56.4882**	0.0000	**16.4555**	0.0001	**2.6895**	0.0297	**18.4894**	0.0000	**8.3412**	0.0000
ANN-based	**17.6759**	0.0000	**28.4296**	0.0000	0.8032	0.5473	1.2743	0.2657	**16.1131**	0.0000	0.3351	0.8919
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO coffee												
Linear	1.1418	0.3351	1.7509	0.1052	**2.0131**	0.0605	1.1059	0.3310	1.8247	0.1211	**5.8454**	0.0000
Taylor-based	0.3265	0.7215	**18.0011**	0.0000	**2.7338**	0.0984	**13.2656**	0.0000	**2.7315**	0.0985	**13.0944**	0.0000
ANN-based	0.1419	0.9349	1.3030	0.2718	1.8020	0.1092	**2.2906**	0.0330	**28.7761**	0.0000	**4.2095**	0.0008
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO sugar												
Linear	1.4452	0.1932	0.4330	0.6486	0.3649	0.9015	0.1485	0.7000	1.8081	0.1434	**2.2569**	0.0210
Taylor-based	1.0333	0.3560	**7.4875**	0.0063	2.4626	0.1167	1.4398	0.1955	**17.5637**	0.0000	**5.5602**	0.0000
ANN-based	0.4111	0.7451	**2.6129**	0.0497	**2.0800**	0.0651	0.5306	0.7854	**5.8831**	0.0000	0.9720	0.4334

Table 4. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO cocoa												
Linear	1.5819	0.1762	3.6625	0.0026	**2.9011**	0.0128	1.6173	0.2035	1.5922	0.2036	**5.3742**	0.0000
Taylor-based	0.2980	0.7423	**89.8838**	0.0000	**12.0045**	0.0005	0.6071	0.7249	2.2374	0.1348	**8.8683**	0.0000
ANN-based	**3.2166**	0.0220	**21.6909**	0.0000	**10.1997**	0.0000	**4.7777**	0.0001	**13.5966**	0.0000	**3.3364**	0.0053
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO cotton												
Linear	**2.0676**	0.0436	**2.0425**	0.0464	0.6190	0.7407	**2.8635**	0.0055	**1.1970**	0.3006	**9.9179**	0.0000
Taylor-based	**5.0514**	0.0065	**6.3274**	0.0120	**223.8052**	0.0000	**8.8553**	0.0000	**128.4767**	0.0000	**18.7563**	0.0000
ANN-based	**6.8771**	0.0001	1.4842	0.2169	**94.0210**	0.0000	**7.9605**	0.0000	**58.8682**	0.0000	**7.3980**	0.0000

Note. The table reports the causality test results for linear and nonlinear (Taylor- and ANN-based) causality tests reporting the findings for full sample. Each panel reports the causality tests for the null hypothesis that global factor does not Granger-cause ($-/\rightarrow$) spillover from oil to individual commodity uncertainties.

Table 5. Linear and nonlinear causality tests for spillovers from oil to individual commodity uncertainties (GFC sub-sample).

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO gold												
Linear	**4.4579**	0.0354	0.0248	0.8748	1.5567	0.2129	**3.5815**	0.0592	**4.9691**	0.0264	0.1937	0.6601
Taylor-based	0.1232	0.7258	0.3159	0.5745	2.3378	0.1274	1.4502	0.2295	**4.7641**	0.0299	0.3339	0.7164
ANN-based	0.2373	0.7889	0.9207	0.3994	**6.6471**	0.0015	2.0564	0.1062	**4.1544**	0.0167	0.0185	0.9817
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO silver												
Linear	**3.3127**	0.0695	1.0051	0.3167	0.8032	0.3707	**7.9639**	0.0050	2.0013	0.1580	0.9704	0.3252
Taylor-based	1.7354	0.1888	0.2433	0.6222	0.3360	0.5626	**4.1434**	0.0427	1.9444	0.1643	2.2424	0.1081
ANN-based	2.1174	0.1222	0.9729	0.3793	**14.4260**	0.0000	**4.7816**	0.0029	3.1676	0.0248	0.3190	0.7271
H0: Global factor $-/\rightarrow$ spillover FROM crude oil TO platinum												
Linear	1.1630	0.2815	0.0331	0.8558	0.9920	0.3199	5.7417	0.0170	0.2809	0.5964	0.9070	0.3415
Taylor-based	0.2885	0.5916	0.2016	0.6538	2.0944	0.1489	0.0770	0.7816	0.5691	0.4513	0.5036	0.6049
ANN-based	1.1515	0.3176	0.6518	0.5219	**3.5038**	0.0314	0.1728	0.9147	**2.9054**	0.0563	0.2601	0.7712

Table 5. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor −/→ spillover FROM crude oil TO palladium												
Linear	0.0013	0.9711	**4.2638**	0.0396	**2.3240**	0.0993	0.7904	0.3745	1.8784	0.1542	0.5071	0.6027
Taylor-based	0.6660	0.4151	**5.4104**	0.0207	1.0176	0.3139	**3.5006**	0.0624	0.2558	0.6134	0.8411	0.5000
ANN-based	0.0749	0.9279	**3.7166**	0.0255	0.6453	0.5865	1.1465	0.3307	**5.0888**	0.0019	0.8479	0.4687
H0: Global factor −/→ spillover FROM crude oil TO aluminum												
Linear	1.1744	0.3101	**3.5215**	0.0305	0.8762	0.4172	0.7334	0.4810	0.1741	0.8403	0.4021	0.6692
Taylor-based	0.1152	0.8912	0.8317	0.4364	1.0421	0.3082	0.9555	0.3859	0.0002	0.9894	1.1176	0.3484
ANN-based	2.0870	0.1021	2.0881	0.1020	**3.8217**	0.0104	1.3113	0.2659	0.3463	0.7918	1.5545	0.2007
H0: Global factor −/→ spillover FROM crude oil TO copper												
Linear	0.1889	0.8279	0.9894	0.3728	**2.5380**	0.0803	**3.3991**	0.0660	0.5871	0.5564	2.4518	0.0875
Taylor-based	0.2542	0.7757	0.5865	0.5569	0.1972	0.6573	1.2961	0.2559	1.9775	0.1607	0.3123	0.8696
ANN-based	1.2786	0.2819	1.9588	0.1204	0.8161	0.4858	1.9088	0.1283	0.4726	0.7016	0.2778	0.8414
H0: Global factor −/→ spillover FROM crude oil TO zinc												
Linear	**2.9735**	0.0523	0.7906	0.4543	**2.9779**	0.0521	1.0800	0.3406	2.0918	0.1249	0.3088	0.7345
Taylor-based	1.9094	0.1501	0.0836	0.9198	**27.0131**	0.0000	0.3987	0.6716	**15.0899**	0.0001	0.3293	0.8582
ANN-based	**7.7015**	0.0001	1.4391	0.2316	**14.9703**	0.0000	1.0547	0.3793	**15.5111**	0.0000	0.0397	0.9894
H0: Global factor −/→ spillover FROM crude oil TO lead												
Linear	0.9604	0.3837	1.8877	0.1528	**2.7977**	0.0622	0.4284	0.6519	0.5804	0.5601	0.8206	0.4409
Taylor-based	1.6344	0.1969	1.1500	0.3181	**20.6166**	0.0000	1.0624	0.3470	1.3575	0.2449	0.6314	0.5953
ANN-based	**3.0892**	0.0275	1.4262	0.2353	**11.6298**	0.0000	0.1239	0.9738	2.0109	0.1126	0.3142	0.8151
H0: Global factor −/→ spillover FROM crude oil TO nickel												
Linear	0.5950	0.5521	1.0394	0.3547	1.0425	0.3536	1.7596	0.1735	1.3775	0.2534	0.1764	0.8383
Taylor-based	0.1266	0.8811	0.1267	0.8810	**6.9483**	0.0088	1.6785	0.1885	0.0448	0.8326	0.1095	0.9545
ANN-based	0.3130	0.8160	0.2319	0.8741	**2.1721**	0.0915	1.0371	0.3883	1.4059	0.2413	1.0813	0.3574
H0: Global factor −/→ spillover FROM crude oil TO wheat												
Linear	2.1073	0.1230	0.4236	0.6550	0.5032	0.6803	0.1343	0.8744	1.3753	0.2540	0.1110	0.8950
Taylor-based	0.1436	0.8663	0.6182	0.5397	**7.2289**	0.0076	0.6362	0.5300	7.9758	0.0051	1.0394	0.3947
ANN-based	0.9423	0.4206	0.3033	0.8230	**2.1252**	0.0778	0.3164	0.8669	9.4944	0.0000	0.3717	0.7735

Table 5. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor −/→ spillover FROM crude oil TO corn												
Linear	2.2643	0.1053	0.7066	0.4939	1.5678	0.2098	1.1141	0.3293	2.8131	0.0613	1.0090	0.3655
Taylor-based	0.1390	0.8703	0.0573	0.9443	**3.9452**	0.0480	0.3415	0.7110	0.1936	0.6602	1.1388	0.3384
ANN-based	**2.3449**	0.0731	0.5699	0.6353	**4.9415**	0.0023	0.2803	0.8906	6.2476	0.0004	1.1939	0.3123
H0: Global factor −/→ spillover FROM crude oil TO soybean												
Linear	2.1177	0.1217	**2.758**	0.0647	**2.3294**	0.0987	0.2983	0.7423	2.1196	0.1215	1.1597	0.3147
Taylor-based	2.2474	0.1075	1.7454	0.1764	**25.7614**	0.0000	0.4707	0.6251	**6.3435**	0.0123	1.5713	0.1820
ANN-based	**3.8891**	0.0095	**2.2871**	0.0788	**9.8874**	0.0000	0.4177	0.7958	**4.1339**	0.0069	0.4854	0.6927
H0: Global factor −/→ spillover FROM crude oil TO coffee												
Linear	0.5948	0.5522	1.1347	0.3226	0.3914	0.5319	0.2807	0.7554	3.6825	0.0260	**2.7715**	0.0638
Taylor-based	0.1268	0.8810	0.6092	0.5445	0.2305	0.6316	1.0686	0.3448	14.6356	0.0002	**2.8780**	0.0232
ANN-based	0.4277	0.7333	0.6272	0.5980	**8.5501**	0.0002	0.1777	0.9498	5.5274	0.0011	1.2700	0.2849
H0: Global factor −/→ spillover FROM crude oil TO sugar												
Linear	**2.8093**	0.0615	0.3586	0.6989	1.5528	0.2130	0.2193	0.8032	1.5069	0.2229	1.6879	0.1863
Taylor-based	1.6930	0.1858	1.2182	0.2973	**24.7171**	0.0000	0.0105	0.9895	**11.7511**	0.0007	**5.6850**	0.0001
ANN-based	**4.7279**	0.0031	1.5323	0.2063	**12.7856**	0.0000	0.2252	0.9242	**9.6734**	0.0000	2.0541	0.1065
H0: Global factor −/→ spillover FROM crude oil TO cocoa												
Linear	**3.8810**	0.0214	**2.3738**	0.0945	**4.9707**	0.0074	**2.6543**	0.0716	**6.8363**	0.0012	1.3764	0.2537
Taylor-based	0.2158	0.8060	**6.2279**	0.0023	**6.0169**	0.0148	0.1717	0.8423	1.2591	0.2628	1.2514	0.2853
ANN-based	0.1607	0.9227	**6.4393**	0.0003	**3.1426**	0.0257	0.1923	0.9423	**15.0651**	0.0000	1.4380	0.2319
H0: Global factor −/→ spillover FROM crude oil TO cotton												
Linear	1.4136	0.2445	**2.3660**	0.0952	0.1440	0.8659	1.9120	0.1492	1.4759	0.2298	0.2480	0.7805
Taylor-based	**2.9424**	0.0543	1.3251	0.2674	**14.6169**	0.0002	0.7717	0.4632	**21.7886**	0.0000	1.8506	0.1031
ANN-based	**8.6847**	0.0000	1.3205	0.2679	**8.9606**	0.0000	1.0227	0.3958	**10.7312**	0.0000	1.2016	0.3095

Note: The table reports the causality test results for linear and nonlinear (Taylor- and ANN-based) causality tests reporting the findings for GFC sub-sample. Each panel reports the causality tests for the null hypothesis that global factor does not Granger-cause spillover from oil to individual commodity uncertainties.

Table 6. Linear and nonlinear causality tests for spillovers from individual commodity uncertainties to oil (full sample).

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor $-/\rightarrow$ spillover FROM gold market TO crude oil												
Linear	**2.5463**	0.0376	1.2626	0.2771	1.2216	0.2960	1.1192	0.3266	**2.4369**	0.0875	0.4159	0.7416
Taylor-based	**3.6286**	0.0267	0.8308	0.3621	**6.4024**	0.0115	0.4488	0.8462	**9.0302**	0.0027	1.0979	0.3556
ANN-based	**2.5192**	0.0564	0.4024	0.7513	**2.8510**	0.0143	0.8978	0.4955	**3.9610**	0.0014	0.3678	0.8709
H0: Global factor $-/\rightarrow$ spillover FROM silver TO crude oil												
Linear	0.7789	0.5648	1.7541	0.1188	0.6988	0.6506	0.2830	0.5948	**4.4819**	0.0114	**0.3974**	0.7549
Taylor-based	**2.7037**	0.0672	1.5391	0.2149	**14.6086**	0.0001	0.4105	0.8725	**2.7730**	0.0960	**1.6356**	0.0754
ANN-based	**2.3208**	0.0734	1.9355	0.1217	**7.9589**	0.0000	**2.0167**	0.0602	1.4527	0.2022	**2.9420**	0.0119
H0: Global factor $-/\rightarrow$ spillover FROM platinum TO crude oil												
Linear	0.7078	0.6175	1.4582	0.2001	1.4059	0.2187	0.6327	0.4264	0.3246	0.8617	0.2408	0.9153
Taylor-based	0.3349	0.7154	1.4555	0.2278	**2.8752**	0.0901	0.0446	0.7756	1.7180	0.1901	0.3453	0.9806
ANN-based	1.0272	0.3794	**2.1926**	0.0870	1.1101	0.3528	0.5376	0.7800	**2.0508**	0.0688	0.4528	0.8115
H0: Global factor $-/\rightarrow$ spillover FROM palladium TO crude oil												
Linear	0.7236	0.5757	**3.5128**	0.0036	1.6055	0.1550	0.5220	0.4700	0.5014	0.4789	0.2229	0.9695
Taylor-based	**7.2218**	0.0007	**4.6478**	0.0312	0.0020	0.9646	1.0360	0.3997	0.2323	0.6299	**1.8908**	0.0268
ANN-based	1.4444	0.2280	1.8862	0.1298	**2.9725**	0.0111	1.0107	0.4164	1.7862	0.1123	**2.3967**	0.0353
H0: Global factor $-/\rightarrow$ spillover FROM aluminum TO crude oil												
Linear	0.5298	0.7539	0.4175	0.8369	0.4439	0.8180	1.3064	0.2709	1.7434	0.1750	0.1824	0.9084
Taylor-based	1.8429	0.1747	0.8167	0.3662	**5.0610**	0.0246	0.5378	0.7798	**5.9429**	0.0149	0.2138	0.9986
ANN-based	0.3483	0.7060	0.5521	0.6467	0.6926	0.6291	0.6287	0.7074	**4.0515**	0.0012	0.7231	0.6061
H0: Global factor $-/\rightarrow$ spillover FROM copper TO crude oil												
Linear	0.8401	0.4995	0.3255	0.8979	2.8305	0.0148	0.9063	0.3412	0.9703	0.3790	0.4408	0.7238
Taylor-based	0.0645	0.7996	**3.0005**	0.0834	**24.9853**	0.0000	0.0256	0.8730	**11.2288**	0.0008	**2.7059**	0.0670
ANN-based	**5.0885**	0.0062	**2.7896**	0.0617	**24.1857**	0.0000	**2.6963**	0.0677	**28.8469**	0.0000	**3.0171**	0.0491
H0: Global factor $-/\rightarrow$ spillover FROM zinc TO crude oil												
Linear	0.5857	0.7110	0.4593	0.8067	0.2659	0.9319	0.5594	0.5716	0.5590	0.5718	1.9098	0.1257
Taylor-based	0.4094	0.5223	0.1434	0.7050	**14.7733**	0.0000	0.0001	0.9912	**6.3992**	0.0115	0.9289	0.3951
ANN-based	1.5976	0.2026	0.1820	0.8336	**11.0464**	0.0000	**3.1605**	0.0426	**25.4532**	0.0000	1.3158	0.2685

Table 6. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor −/→ spillover FROM lead TO crude oil												
Linear	0.3251	0.8613	0.1421	0.9824	1.4028	0.2400	0.2741	0.6006	0.1933	0.8243	0.5681	0.6360
Taylor-based	1.0661	0.3019	**2.9192**	0.0877	**15.8192**	0.0001	0.8060	0.3694	2.0017	0.1573	0.6943	0.4995
ANN-based	1.6191	0.1983	0.2438	0.7836	**10.7244**	0.0000	2.1816	0.1131	1.2114	0.2980	0.9628	0.3820
H0: Global factor −/→ spillover FROM nickel TO crude oil												
Linear	0.7725	0.5429	0.8914	0.4858	1.6156	0.1522	1.2158	0.2966	2.0001	0.1354	0.4759	0.6991
Taylor-based	0.1222	0.7267	0.0130	0.9094	0.1454	0.7030	1.3066	0.2531	0.0499	0.8233	1.1939	0.3032
ANN-based	0.8022	0.4485	0.4846	0.6160	**7.4321**	0.0006	1.0629	0.3456	0.2938	0.7455	1.7040	0.1822
H0: Global factor −/→ spillover FROM wheat TO crude oil												
Linear	**2.2945**	0.0570	3.9294	0.0015	1.1774	0.3176	0.0112	0.9159	2.0341	0.1309	0.3019	0.8240
Taylor-based	0.0509	0.8215	**5.1311**	0.0236	0.4847	0.4864	**8.4515**	0.0000	**10.1655**	0.0015	**2.1873**	0.0082
ANN-based	0.9839	0.3740	**5.0694**	0.0064	1.7740	0.1699	0.8199	0.5543	**9.5223**	0.0000	**2.0154**	0.0735
H0: Global factor −/→ spillover FROM corn TO crude oil												
Linear	1.4668	0.2095	0.4252	0.8314	0.4319	0.8266	**2.5221**	0.0804	1.0694	0.3433	0.5874	0.6232
Taylor-based	1.2311	0.2673	0.5975	0.4396	**14.2624**	0.0002	**3.9372**	0.0473	**5.4339**	0.0198	**6.7727**	0.0012
ANN-based	**2.8177**	0.0600	0.0336	0.9669	**8.8246**	0.0002	1.8167	0.1628	**5.2883**	0.0051	**7.2035**	0.0008
H0: Global factor −/→ spillover FROM soybean TO crude oil												
Linear	0.1230	0.9873	**2.5602**	0.0255	0.7850	0.5603	0.0000	0.9952	0.8804	0.3482	0.7356	0.5306
Taylor-based	1.4787	0.2241	**4.1616**	0.0415	**3.1446**	0.0763	**2.0225**	0.0595	0.0921	0.7615	**1.6979**	0.0551
ANN-based	0.3691	0.6914	**5.3245**	0.0012	**1.8706**	0.0963	**2.6492**	0.0146	1.1160	0.3496	**1.8952**	0.0920
H0: Global factor −/→ spillover FROM coffee TO crude oil												
Linear	1.3738	0.2403	1.0921	0.3625	0.2994	0.9134	0.2563	0.6127	0.1107	0.9539	1.0771	0.3574
Taylor-based	0.0849	0.7708	0.3653	0.6941	2.3349	0.1266	0.5752	0.7504	0.0005	0.9815	0.8890	0.5577
ANN-based	0.1296	0.8784	0.3762	0.9166	0.3557	0.8788	1.4022	0.2099	1.1146	0.3504	0.4008	0.8485
H0: Global factor −/→ spillover FROM sugar TO crude oil												
Linear	0.5325	0.7519	0.4831	0.7891	1.2370	0.2888	**6.1503**	0.0022	0.3019	0.7394	0.5316	0.6606
Taylor-based	0.5101	0.4752	1.6402	0.2004	**3.4481**	0.0081	**7.9170**	0.0000	**11.1397**	0.0009	0.9147	0.5368
ANN-based	0.0966	0.9079	1.2609	0.2836	**4.1431**	0.0009	**4.3244**	0.0002	**4.5370**	0.0004	0.1373	0.9837

Table 6. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor −/→ spillover FROM cocoa TO crude oil												
Linear	0.4491	0.7732	0.2735	0.9278	0.8575	0.5089	0.0021	0.9636	0.5331	0.5868	0.1782	0.9112
Taylor-based	0.0805	0.7766	1.2954	0.2740	**13.9516**	0.0002	0.4328	0.8574	**14.1409**	0.0002	**2.5138**	0.0015
ANN-based	0.1527	0.8584	0.5708	0.7802	1.6207	0.1511	0.9953	0.4266	**14.1446**	0.0000	0.2949	0.9159
H0: Global factor −/→ spillover FROM cotton TO crude oil												
Linear	1.3833	0.2370	0.4944	0.7807	0.8120	0.5408	**4.5693**	0.0104	1.1853	0.3057	0.3463	0.7919
Taylor-based	0.5274	0.4678	1.4633	0.2265	**16.7058**	0.0000	**4.6880**	0.0093	**14.5232**	0.0001	1.3881	0.2355
ANN-based	1.8427	0.1586	**11.0690**	0.0000	**7.3390**	0.0007	1.7160	0.1616	**10.8483**	0.0000	1.1197	0.3398

Note: The table reports the causality test results for linear and nonlinear (Taylor- and ANN-based) causality tests reporting the findings for full sample. Each panel reports the causality tests for the null hypothesis that global factor does not Granger-cause spillover from individual commodity to oil uncertainties.

Table 7. Linear and nonlinear causality tests for spillovers from individual commodity uncertainties to oil (GFC sub-sample).

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor −/→ spillover FROM gold TO crude oil												
Linear	**6.6873**	0.0014	0.0247	0.9756	0.2400	0.7868	1.8050	0.1659	0.5736	0.5640	**4.8294**	0.0085
Taylor-based	0.1286	0.8793	0.2749	0.7599	1.6639	0.1981	0.3293	0.7197	0.4903	0.4844	**2.6751**	0.0475
ANN-based	0.8151	0.4864	0.2228	0.8805	0.2954	0.8287	1.1327	0.3413	0.4107	0.7455	**2.8753**	0.0365
H0: Global factor −/→ spillover FROM silver TO crude oil												
Linear	2.6290	0.1057	0.9477	0.3309	**3.3334**	0.0687	0.1356	0.8732	0.2525	0.7770	0.3792	0.6847
Taylor-based	0.6202	0.4316	1.2191	0.2705	1.9467	0.1640	0.2889	0.7493	0.3641	0.5467	0.2170	0.8846
ANN-based	1.1167	0.3288	0.4303	0.6507	1.2893	0.2771	1.4085	0.2312	0.1389	0.9367	0.4174	0.7406
H0: Global factor −/→ spillover FROM platinum TO crude oil												
Linear	0.3482	0.7062	1.6547	0.1991	**3.2449**	0.0724	1.2931	0.2562	0.0294	0.8638	0.1801	0.6715
Taylor-based	0.3748	0.6878	0.3281	0.5672	1.1185	0.2911	0.0369	0.8478	0.0492	0.8247	0.0285	0.8660
ANN-based	0.4594	0.7109	0.6075	0.5454	0.9215	0.3991	1.6897	0.1694	0.0537	0.9478	0.1460	0.8641

Table 7. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor $-/\rightarrow$ spillover FROM palladium TO crude oil												
Linear	**7.2474**	0.0074	0.3978	0.5286	1.8911	0.1699	1.5476	0.2142	**9.9311**	0.0018	0.2689	0.6044
Taylor-based	**14.6447**	0.0002	0.3344	0.5635	1.1237	0.2900	1.5659	0.2118	1.8037	0.1803	0.4062	0.5244
ANN-based	**2.8239**	0.0610	**2.5265**	0.0817	1.1371	0.3222	**2.3562**	0.0721	**3.3952**	0.0349	0.3290	0.7199
H0: Global factor $-/\rightarrow$ spillover FROM aluminum TO crude oil												
Linear	0.1509	0.6979	0.3782	0.5389	2.0756	0.1505	0.1627	0.6869	0.6246	0.4298	0.3378	0.5614
Taylor-based	0.3149	0.5751	0.0935	0.7600	0.8588	0.3548	0.0054	0.9414	0.2392	0.6252	0.0800	0.7775
ANN-based	0.3807	0.6837	0.8067	0.4474	2.3810	0.0943	1.5627	0.1986	0.2801	0.7559	0.2642	0.7680
H0: Global factor $-/\rightarrow$ spillover FROM copper TO crude oil												
Linear	**5.1042**	0.0244	0.2301	0.6318	**10.2814**	0.0015	0.2774	0.5987	1.6092	0.2054	0.4268	0.5140
Taylor-based	0.3529	0.5530	0.4680	0.4945	2.6273	0.1061	0.0225	0.8809	0.6680	0.4144	0.0332	0.8555
ANN-based	**3.9242**	0.0208	0.0975	0.9071	**2.7403**	0.0662	1.3369	0.2626	0.4576	0.6333	0.5546	0.5749
H0: Global factor $-/\rightarrow$ spillover FROM zinc TO crude oil												
Linear	0.0289	0.8651	0.1891	0.6639	0.6399	0.5279	0.1286	0.8794	1.1737	0.3103	0.4065	0.6663
Taylor-based	0.0552	0.8145	0.0225	0.8808	0.7578	0.3847	0.2044	0.8153	0.0045	0.9466	0.2369	0.8706
ANN-based	0.0179	0.9822	0.0813	0.9219	0.5549	0.6452	0.5052	0.7319	0.9641	0.4100	0.9860	0.3997
H0: Global factor $-/\rightarrow$ spillover FROM lead TO crude oil												
Linear	**2.3690**	0.0949	**2.9176**	0.0553	1.8486	0.1588	0.3329	0.7170	**4.1145**	0.0171	0.6111	0.5433
Taylor-based	1.4634	0.2332	0.3759	0.6870	**8.2337**	0.0044	0.6839	0.5055	1.1119	0.2925	1.9047	0.1290
ANN-based	**2.1089**	0.0993	0.8872	0.4481	**3.3878**	0.0185	**4.1859**	0.0026	**3.9248**	0.0091	1.6112	0.1869
H0: Global factor $-/\rightarrow$ spillover FROM nickel TO crude oil												
Linear	0.2796	0.5972	0.0959	0.7570	1.7964	0.1673	1.2845	0.2780	0.1098	0.8960	**2.4834**	0.0848
Taylor-based	0.0211	0.8845	**6.5693**	0.0109	1.1743	0.2794	**2.4563**	0.0876	0.0201	0.8874	1.0595	0.3667
ANN-based	0.0313	0.9692	1.2095	0.2999	0.4496	0.7178	1.8882	0.1126	2.0077	0.1130	0.6990	0.5533
H0: Global factor $-/\rightarrow$ spillover FROM wheat TO crude oil												
Linear	**7.9421**	0.0004	0.1987	0.8199	**3.6339**	0.0273	**5.9703**	0.0028	**6.7822**	0.0013	1.9061	0.1501
Taylor-based	**8.4740**	0.0003	0.1377	0.8714	**21.2606**	0.0000	**2.5399**	0.0807	**34.8651**	0.0000	**5.9021**	0.0006
ANN-based	**3.7853**	0.0109	0.5091	0.6763	**6.2896**	0.0004	0.8162	0.5157	**14.4067**	0.0000	0.7274	0.5364

Table 7. *Cont.*

	EPU		GPR		VIX		MSCI World		TED		USD	
	Stat	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**	**Stat**	***p*-Value**
H0: Global factor −/→ spillover FROM corn TO crude oil												
Linear	0.2648	0.6071	0.5532	0.4575	2.4653	0.1172	0.0150	0.9851	0.4998	0.6071	1.7389	0.1771
Taylor-based	0.0856	0.7700	0.0788	0.7791	1.0193	0.3135	0.0133	0.9869	0.2400	0.6246	0.5134	0.6733
ANN-based	0.4800	0.6193	0.0079	0.9922	0.8873	0.4129	0.5566	0.6944	0.7599	0.5174	1.6821	0.1710
H0: Global factor −/→ spillover FROM soybean TO crude oil												
Linear	0.4129	0.5209	0.5817	0.4461	0.6305	0.4277	0.0245	0.8757	0.1987	0.6560	**5.4783**	0.0198
Taylor-based	0.0214	0.8838	0.3379	0.5615	2.0935	0.1490	0.6002	0.4391	0.0611	0.8049	**3.1554**	0.0767
ANN-based	0.0224	0.9778	1.4816	0.2290	**3.0569**	0.0486	0.9054	0.4389	**3.6536**	0.0271	2.1741	0.1156
H0: Global factor −/→ spillover FROM coffee TO crude oil												
Linear	**6.5146**	0.0111	0.2425	0.6227	1.8421	0.1755	2.4073	0.1216	0.2300	0.6318	0.4226	0.5160
Taylor-based	**2.7819**	0.0965	0.1289	0.7198	2.2772	0.1324	0.1551	0.6940	0.0804	0.7770	0.2366	0.6271
ANN-based	**4.6430**	0.0104	0.2977	0.7428	1.7828	0.1700	1.5496	0.2019	1.9644	0.1420	0.1717	0.8423
H0: Global factor −/→ spillover FROM sugar TO crude oil												
Linear	0.7557	0.3852	**6.1963**	0.0132	0.8153	0.3671	**6.3019**	0.0125	**3.4366**	0.0645	0.6683	0.4142
Taylor-based	0.0858	0.7697	1.3323	0.2494	**4.0137**	0.0461	**14.9712**	0.0001	**11.5562**	0.0000	0.3172	0.5737
ANN-based	0.2788	0.7569	1.6590	0.1922	1.1815	0.3083	**4.3115**	0.0054	**28.5011**	0.0000	0.0586	0.9431
H0: Global factor −/→ spillover FROM cocoa TO crude oil												
Linear	0.0727	0.7876	0.2634	0.6081	0.0244	0.8760	0.5758	0.4484	1.0869	0.2978	0.7312	0.3930
Taylor-based	0.0964	0.7565	0.0368	0.8480	1.4858	0.2239	0.0778	0.7805	1.5105	0.2201	0.0005	0.9814
ANN-based	0.4809	0.6187	0.0175	0.9827	1.9466	0.1446	0.4400	0.7245	**9.2613**	0.0001	1.5288	0.2186
H0: Global factor −/→ spillover FROM cotton TO crude oil												
Linear	2.2028	0.1386	1.1079	0.2932	**4.7976**	0.0291	0.3255	0.5686	1.1729	0.2795	1.0565	0.3047
Taylor-based	0.2793	0.5976	0.2568	0.6127	1.6092	0.2056	0.0048	0.9451	0.4275	0.5138	0.0003	0.9869
ANN-based	0.8714	0.4195	0.5370	0.5851	1.6214	0.1994	1.0831	0.3566	0.4615	0.6308	0.2908	0.7479

Note: The table reports the causality test results for linear and nonlinear (Taylor- and ANN-based) causality tests reporting the findings for GFC sub-sample. Each panel reports the causality tests for the null hypothesis that global factor does not Granger-cause spillover from individual commodity to oil uncertainties.

6. Conclusions

In this study, we investigate the impact of global factors on the connectedness of commodity uncertainties from January 2007–December 2016. To this end, we first employ the methodology proposed by Diebold and Yilmaz [36] to estimate the transmission between oil and other commodity uncertainties. Moreover, we make use of the linear and nonlinear (Taylor- and ANN-based) causality tests to estimate the impact of global factors on the connectedness of commodity uncertainties. Performing additional sub-sample analysis, during the global financial crisis, helps us obtain an in-depth insight into the relationship among commodity markets and their interaction with the global factors.

In our study, we find strong bi-directional transmission between oil and metal (agriculture) markets, and this transmission became significantly more pronounced during the turmoil period, i.e., the GFC. Our analysis suggests that oil is a net transmitter to other commodity uncertainties, and this transmission of oil significantly increased during the period of the GFC (2008–2009), which originated as the sub-prime mortgage crisis in the U.S. and consequently resulted in the meltdown of financial markets globally. Additionally, our results indicate that the global factors in some way have a causal effect on the overall connectedness, especially on the spillovers from oil to other commodity uncertainties. Further segregation of transmissions from oil to other commodity markets and vice versa indicate VIX, and to some extent, TED spread and EPU, as the most influential drivers of connectedness among commodity markets.

Amidst the "financialization" of commodities, resulting in a sharp upsurge in the connectedness of commodity markets and their interaction with other financial and macroeconomic determinants, we find that the price of commodities is not only dependent on the supply and demand channel but also determined by the risk appetite of stakeholders. Thus, investors can be watchful of the global factors, such as VIX, which is considered as a proxy for investor sentiment and risk aversion [81] and also regarded as a good predictor of commodity and equity markets [82,83] to better forecast the price changes in commodity markets. Additionally, investors in the commodity market can utilize the insights from our analysis to formulate better portfolio diversification and hedging strategies. In this way, they would be better placed to get through the environment of high-contagion risk. Additionally, policymakers and regulators should carefully assess the risk associated with financial stress and economic policy. This way, they would be able to provide better avenues of risk-sharing for the producers and will be able to incentivize the commodity markets to provide relief to the consumers against the inflationary effects.

Among the limitations of our analysis is that it only uses Diebold and Yilmaz [36] time-domain approach to estimate total static connectedness. A possible direction for future research can be the further segregation of total connectedness into frequencies (i.e., short-, medium-, and long-term). This would provide a more in-depth insight into the causal impact of global factors on different frequency scales. In addition, although the static analysis effectively unveils the structure of connectedness spillovers among commodities, still, time-varying analysis of spillover patterns would also add important insights; hence, the future research can look into this matter.

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