Dynamic spillovers between U.S. climate policy uncertainty and global foreign exchange markets: the pass-through effect of crude oil prices

Xin Li

Received: 5 August 2022 / Accepted: 30 August 2022 / Published online: 12 September 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
This study aims to investigate the time-varying spillover effects of the U.S. climate policy uncertainty (U.S. CPU) shock on crude oil prices and exchange rates by utilizing the DCC-GARCH connectedness approach. The results show that U.S. CPU is the largest net transmitter, followed by the crude oil price. Our outcomes also indicate that the Italian currency is the main net recipient and further reveal the pass-through effect of crude oil prices between U.S. CPU and exchange rates.

Keywords  Real effective exchange rate · Climate policy uncertainty · Crude oil · Dynamic connectedness

JEL Classification  F31 · G15 · Q54

1 Introduction
In response to climate change, international negotiations have been around for nearly two decades, and governments around the world have adopted several important policy measures to address climate change. The Paris Agreement has provided a new framework for climate policy, such as promoting the use of clean energy, carbon emission allowances, and green bonds. Nevertheless, there are still major uncertainties in the implementation path of such policies. The most recent example is that the U.S. withdrew from the Paris Agreement in 2017, which arises considerable uncertainties about the implementation of climate policy. These uncertainties might have far-reaching impacts across the macroeconomy. Indeed, the economic impacts of climate policy uncertainty (CPU) have been noted in recent studies (Monasterolo et al. 2019; Barnett et al. 2021; Fried et al. 2021).
The Real Effective Exchange Rate (REER), as one of the important macroeconomic indicators in the international financial market, reflects the international competitiveness of a nation in comparison with its trade partners. Understanding the characteristics of REER dynamics and investigating the determinants and connectedness between REER is very important for policymaking and market participants. Existing studies have considered the role of policy uncertainty in international financial markets, with a particular focus on the impact of economic policy uncertainty (EPU) on exchange rates (Kido 2016; Li et al. 2020; Nilavongse et al. 2020). Unfortunately, none of the papers in the literature consider the role of the CPU when investigating the determinants of exchange rates. In particular, central banks start to recognize climate-related financial risks as having a significant impact on their financial stability mandates (Barnett et al. 2020; Chenet et al. 2021; Hansen 2022).

The link between CPU and REER can be theoretically explained by the real-option effect of uncertainty (Handley and Limao 2015) and the transition risk effect of climate change (Chenet et al. 2021). That is, climate policy-induced uncertainty can affect firms’ productive asset investments, which brings risks to the decision to invest in the capital used with fossil energy (such as crude oil) and further leads to a negative macroeconomic supply shock. As one of the vital transmission channels for macroeconomic adjustment, the exchange rate has a potential response to this threat of CPU and macro-economy shock.

The main contributions of our article to the literature are listed as follows. First, the existing study rarely considers the impact of climate policy-induced uncertainty when detecting the determinants of crude oil prices. Therefore, we are motivated to investigate the connectedness between CPU and REER in order to bridge the gap. Second, this paper contributes to the existing literature by applying the novel DCC-GARCH connectedness approach developed by (Gabauer 2020) to identify the time-varying spillover effects between CPU and REER. To the best of our knowledge, a few studies have utilized the dynamic analysis method to capture the underlying impact of CPU. Third, the outcome of this study also reveals the pass-through effect of crude oil prices between CPU and exchange rate changes. Therefore, the time-varying analytical framework used in the study may help to better understand the relationship between the variables and provide corresponding policy recommendations.

2 Methodology and material

2.1 DCC-GARCH dynamic connectedness method

The idea of the novel DCC-GARCH connectedness approach (Gabauer 2020) is based on conditional variance–covariance forecasting associated with the volatility impulse

---

1 Climate transition risk is the risk rooted in the uncertainty of climate change and low-carbon economic transition. One source is policy uncertainty, such as unanticipated changes in climate policy that could devalue energy-based assets, adversely impacting firm’s production and total social output.
response function (VIRF). Specifically, the conditional volatilities \( Q_{t+h} | F_t \) can be predicted with the GARCH (1, 1), as follows:

\[
E(Q_{t+1} | F_t) = (1 - a - b) \bar{Q} + a u_t u_t' + b Q_t h = 1
\]

\[
E(Q_{t+h} | F_t) = (1 - a - b) \bar{Q} + aE(u_{t+h-1} u_{t+h-1}' | F_t) + bE(Q_{t+h-1} | F_t) h > 1
\]

where \( E(u_{t+h-1} u_{t+h-1}' | F_t) \approx E(Q_{t+h-1} | F_t) \) allows predicting the dynamic conditional correlations and the final dynamic conditional variance–covariance are forecasted by

\[
E(R_{t+h} | F_t) \approx \text{diag} \left[ E(q_{i_{i+h}}^{-1/2} | F_t), ..., E(q_{NNN+h}^{-1/2} | F_t) \right]
\]

\[
E(Q_{t+h} | F_t) \text{diag} \left[ E(q_{i_{i+h}}^{-1/2} | F_t), ..., E(q_{NNN+h}^{-1/2} | F_t) \right]
\]

\[
E(H_{t+h} | F_t) \approx E(D_{t+h} | F_t) E(R_{t+h} | F_t) E(D_{t+h} | F_t)
\]

The VIRF is then used to calculate the generalized forecast error variance decomposition (GFEVD), which is regarded as the variance share of one variable explained by others. The normalized variance share is calculated as follows:

\[
\tilde{\phi}_{ij}^g (J) = \frac{\sum_{T=1}^{J-1} \psi_{ij,t}^g 2^{g} }{ \sum_{j=1}^{N} \psi_{ij,t}^g 2^{g} } \left( \sum_{i=1}^{N} \tilde{\phi}_{ij}^g (J) = 1 \text{ and } \sum_{i,j=1}^{N} \tilde{\phi}_{ij}^g (J) = N \right)
\]

The total connectedness index (TCI) may be constructed using the GFEVD and the total directional connectedness (TO others and FROM others) as follows:

\[
C_t^g (J) = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\phi}_{ij}^g (J) }{ N } \times 100
\]

\[
C_{i-j,d}^g (J) = \frac{\sum_{j=1}^{N} \tilde{\phi}_{ij}^g (J) }{ \sum_{j=1}^{N} \tilde{\phi}_{ij}^g (J) } \times 100
\]

\[
C_{i-j,d}^g (J) = \frac{\sum_{j=1}^{N} \tilde{\phi}_{ij}^g (J) }{ \sum_{i=1}^{N} \tilde{\phi}_{ij}^g (J) } \times 100
\]

Subtracting Eq. (8) by Eq. (7), the net total directional connectedness can be presented by:

\[
C_{i,j,d}^g (J) = C_{i-j,d}^g (J) - C_{i-j,d}^g (J) = \left( \frac{\sum_{j=1}^{N} \tilde{\phi}_{ij}^g (J) }{ \sum_{j=1}^{N} \tilde{\phi}_{ij}^g (J) } - \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\phi}_{ij}^g (J) }{ \sum_{i=1}^{N} \tilde{\phi}_{ij}^g (J) } \right) \times 100
\]
2.2 Data

This study employs monthly data of the U.S.CPU index, crude oil price, and REER log returns from January 2000 to March 2021. The novel U.S.CPU index is recently developed by Gavriilidis (2021), who follows Baker et al. (2016) using the newspaper-based method to measure uncertainty. The crude oil price is represented by the West Texas Intermediate (WTI) price. Moreover, we utilize the broad Real Effective Exchange Rate (REER) for G7 countries to represent the exchange rate dynamics in international financial markets. WTI price is retrieved from International Energy Agency (IEA) and REER can be obtained from Bank for International Settlements (BIS).

3 Empirical result

We apply the DCC-GARCH connectedness approach to uncover the time-varying spillovers. Table 1 summarizes the averaged dynamic connectedness results in the current study. We find that, on average, 56.33% of the shocks for each variable spill over to all others, while in turn, on average 43.67% of the shocks affect themselves. This outcome shows that the international financial market is highly correlated with crude oil prices and the U.S.CPU index. Besides that, the results also suggest that the main net transmitter of shock is the U.S.CPU index, which transmits 265.00% of the uncertainty on average, followed by WTI (114.11%), which indicates that U.S.CPU and WTI influence others more than being influenced by them. However, the REER of CA (−89.21%) and IT (−79.67%) have been the main receivers of other shocks. In a nutshell, therefore, these findings imply that U.S.CPU and WTI are driving G7 currencies in international financial markets, whereas CA and IT currencies are driven by the others.

Figure 1 illustrates the dynamic total volatility connectedness under consideration, which is larger than 45% and keeps a steady pattern, spanning approximately between 50 and 70%. This finding suggests that the U.S.CPU, WTI, and G7 currencies have an extraordinarily high fluctuation connectedness across the sample. Moreover, peaks of correlation happen during intervals such as the Kyoto Protocol entering into force (2005), the global financial crisis (2008–2009), the European sovereign debt crisis (2011–2013), the U.S. withdrawal Paris Agreement (2017), the US-China trade negotiations (2018), and the recent COVID-19 pandemics (2020–2021).

Next, we further investigate the time-varying behavior of correlations under climate policy uncertainty. Figure 2 displays the dynamic net pairwise volatility connectedness among variables. The blue area indicates a net spillover from the former variable to the latter, the red area indicates a net spillover from the latter variable to the former, and the

---

2 The Augmented Dickey-Fuller (ADF) test results show that the series are stationary.
3 The data can be downloaded from http://policyuncertainty.com/climate_uncertainty.html.
4 Based on the Akaike information criterion (AIC), the lag order is set to 2.
Table 1 Full-sample spillover indices

|          | U.S.CPU | WTI   | CA     | FR     | DE     | IT     | JP     | GB     | U.S    | From Others |
|----------|---------|-------|--------|--------|--------|--------|--------|--------|--------|-------------|
| U.S.CPU  | 100.00  | 0.00  | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00        |
| WTI      | 8.84    | 90.27 | 0.47   | 0.01   | 0.00   | 0.00   | 0.17   | 0.01   | 0.23   | 9.73        |
| CA       | 17.68   | 59.52 | 17.34  | 0.05   | 0.09   | 0.02   | 0.39   | 0.01   | 4.90   | 82.66       |
| FR       | 8.86    | 1.81  | 0.11   | 36.63  | 41.26  | 1.69   | 0.02   | 0.22   | 9.40   | 63.37       |
| DE       | 36.60   | 0.36  | 0.09   | 18.84  | 37.34  | 1.06   | 0.00   | 0.16   | 5.55   | 62.66       |
| IT       | 66.69   | 1.66  | 0.26   | 7.51   | 10.10  | 7.29   | 0.25   | 1.09   | 5.17   | 92.71       |
| JP       | 30.49   | 36.76 | 0.63   | 0.02   | 0.00   | 0.04   | 31.52  | 0.53   | 0.01   | 68.48       |
| GB       | 23.76   | 12.32 | 0.04   | 0.52   | 0.82   | 0.53   | 1.58   | 60.35  | 0.07   | 39.65       |
| U.S      | 72.08   | 11.41 | 1.39   | 1.18   | 1.52   | 0.15   | 0.00   | 0.00   | 0.00   | 12.27       |
| To others| 265.00  | 123.84| 2.99   | 28.12  | 53.78  | 3.50   | 2.41   | 2.03   | 25.32  | 507.00      |
| Net      | 265.00  | 114.11| -79.67 | -35.25 | -8.88  | -89.21 | -66.07 | -37.62 | -62.40 | TCI         |
| NPDC     | 0.00    | 1.00  | 3.00   | 6.00   | 5.00   | 8.00   | 4.00   | 7.00   | 2.00   | 56.33       |

NPDC represents the net pairwise directional connectedness
green area indicates that the spillover effect is interactive. First, we find that U.S.CPU has a positive spillover effect on most variables, which suggests that U.S.CPU is a critical risk transmitter to WTI and G7 currencies. Our findings are supported by Degiannakis et al. (2018) and Zhang and Yan (2020), suggesting that high levels of U.S. government policy uncertainty affect investors’ investment decisions and companies’ production plans, which in turn affects demand for crude oil production and oil price volatility. The outcome also reveals that U.S. and IT currencies are the major receivers of the shock of U.S. climate policy. Moreover, despite being affected by U.S.CPU, WTI has a spillover influence on G7 currencies, with a larger impact on CA and JP currencies. In addition, there is a strong spillover effect of WTI against most currencies during the sample periods of the second half of 2008 and the first half of 2020, which may be connected to the global financial crisis (Diaz et al. 2016) and the COVID-19 pandemic factors (Shah et al. 2021). Our outcomes suggest that U.S.CPU can not only directly affect G7 currencies but also indirectly exert influence on exchange rates through the pass-through effect of changes in crude oil prices.

In addition to this, the dynamic net directional linkage also illustrates how the G7 currencies are connected. Specifically, the U.S. currency has been a positive net transmitter, while both the GB and IT currencies show major net receivers. This finding suggests that the U.S. currency has a positive spillover effect on other currencies, while the GB and IT currencies are generally influenced by other currencies (Wang and He 2021). Furthermore, the pairwise volatility connectedness analysis also shows that G7 currencies are more correlated in times of crisis, such as the global financial crisis and the European sovereign debt crisis. This outcome is supported by (Dimitriou et al. 2017; Shah et al. 2021), suggesting that financial risk spillovers are stronger during economic downturns.
Fig. 2 Dynamic net pairwise connectedness. Note: Blue areas represent the net spillover of the former to the latter, red areas indicate the net spillover of the latter to the former, and green areas suggest the interaction of spillovers.
4 Conclusion

This study employs the DCC-GARCH connectedness approach to detect the spillover effects of the U.S. CPU shock on crude oil prices and exchange rates. The outcomes indicate substantial dynamic connectedness between the concerned variables. Specifically, the new CPU index acts as the main net transmitter, affecting crude oil prices and G7 currencies. The findings suggest that international financial market participants should implement a diversified portfolio strategy based on currency heterogeneity to guard against CPU-related risks. In a period of relative volatility in climate policymaking, participants should adopt a more cautious strategy in foreign exchange markets and avoid vulnerable currencies. Furthermore, given that CPU shocks can lead to abnormal exchange rate fluctuations, governments should take a more determined climate policy stance to stabilize public expectations and reduce policy uncertainty.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

References

Baker, S.R., Bloom, N.A., Davis, S.J.: Measuring economic policy uncertainty. Quart. J. Econ. 131, 1593–1636 (2016)
Barnett, M., Brock, W., Hansen, L.P.: Pricing uncertainty induced by climate change. The Rev. Financial Stud. 33, 1024–1066 (2020)
Barnett, M., Brock, W.A., Hansen, L.P., 2021. Climate change uncertainty spillover in the macroeconomy. In: Eichenbaum, M., Hurst, E. (Eds.), Macroeconomics Annual. University of Chicago Press, Chicago.
Chenet, H., Ryan-Collins, J., van Lerven, F.: Finance, climate-change and radical uncertainty: towards a precautionary approach to financial policy. Ecol. Econ. 183, 106957 (2021)
Degiannakis, S., Filis, G., Panagiotakopoulou, S.: Oil price shocks and uncertainty: how stable is their relationship over time? Econ. Model. 72, 42–53 (2018)
Diaz, E.M., Molero, J.C., Gracia, F.: Oil price volatility and stock returns in the G7 economies. Energy Econ. 54, 417–430 (2016)
Dimitriou, D., Kenourgios, D., Simos, T.: Financial crises, exchange rate linkages and uncovered interest parity: Evidence from G7 markets. Econ. Model. 66, 112–120 (2017)
Fried, S, Novan, K., Peterman, W., 2021. The Macro Effects of Climate Policy Uncertainty. Federal Reserve Bank of San Francisco Working Paper 2021–06. Available at https://doi.org/10.24148/wp2021-06
Gabauer, D.: Volatility impulse response analysis for DCC-GARCH models: the role of volatility transmission mechanisms. J. Forecast. 39, 788–796 (2020)
Gavriilidis, K., (2021) Measuring climate policy uncertainty. Available at SSRN: https://ssrn.com/abstract=3847388.
Handley, K., Limao, N.: Trade and investment under policy uncertainty: theory and firm evidence. Am. Econ. J. Econ. Pol. 7, 189–222 (2015)
Hansen, L.P.: Central banking challenges posed by uncertain climate change and natural disasters. J. Monet. Econ. 125, 1–15 (2022)
Kido, Y.: On the link between the US economic policy uncertainty and exchange rates. Econ. Lett. 144, 49–52 (2016)
Li, X.L., Li, X., Si, D.K.: Investigating asymmetric determinants of the CNY-CNH exchange rate spreads: the role of economic policy uncertainty. Econ. Lett. 186, 108827 (2020)
Monasterolo, I., Roventini, A., Foxon, T.: Uncertainty of climate policies and implications for economics and finance: an evolutionary economics approach. Ecol. Econ. 163, 177–182 (2019)
Nilavongse, R., Rubaszek, M., Uddin, G.S.: Economic policy uncertainty shocks, economic activity, and exchange rate adjustments. Econ. Lett. 186, 108765 (2020)
Shah, A.A., Paul, M., Bhanja, N., Dar, A.B.: Dynamics of connectedness across crude oil, precious metals and exchange rate: Evidence from time and frequency domains. Resour. Policy 73, 102154 (2021)
Wan, Y., He, S.: Dynamic connectedness of currencies in G7 countries: a Bayesian time-varying approach. Financ. Res. Lett. 41, 101896 (2021)
Zhang, Y., Yan, X.: The impact of US economic policy uncertainty on WTI crude oil returns in different time and frequency domains. Int. Rev. Econ. Financ. 69, 750–768 (2020)

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.