COVID-19 pandemic, oil prices, stock market, geopolitical risk and policy uncertainty nexus in the US economy: fresh evidence from the wavelet-based approach

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Abstract

In this paper, we analyze the connectedness between the recent spread of COVID-19, oil price volatility shock, the stock market, geopolitical risk and economic policy uncertainty in the US within a time-frequency framework. The coherence wavelet method and the wavelet-based Granger causality tests applied to US recent daily data unveil the unprecedented impact of COVID-19 and oil price shocks on the geopolitical risk levels, economic policy uncertainty and stock market volatility over the low frequency bands. The effect of the COVID-19 on the geopolitical risk substantially higher than on the US economic uncertainty. The COVID-19 risk is perceived differently over the short and the long-run and may be firstly viewed as an economic crisis. Our study offers several urgent prominent implications and endorsements for policymakers and asset managers

Keywords: COVID-19, economic policy uncertainty, geopolitical risk, stock market, oil prices, wavelet, causality.

1. Introduction

The US economy is facing two serious shocks: the spread of the novel COVID-19 pandemic and the recent oil price slump. The combination of these two problems will likely initiate a long-term economic downturn and drive the US economy into the next recession. The COVID-19 pandemic outbreak continues its tremendous spread in the US causing unprecedented effects of the US stock markets volatility and the economic policy uncertainty where the recent stock volatility levels rival or exceed those observed during October, 1987, December, 2008 and during the 1929 crash. In a recent study, Baker et al. (2020) unveil that during the last 22 trading days (24 February to 24 March), 18 stock market jumps were recorded and 16 to 18 of them are perceived as a response to "bad news" attributed to either the new infectious disease or the US policy responses to the COVID-19 outbreak (Baker et al., 2020, p. 2). Similarly, during the same period the US economic policy uncertainty as gauged by news-based EPU index of Baker, Bloom and Davis (2016)[2], has shown a jump going from 100 to 400[3] by 24 of March, 2020.

In the financial press, the COVID-19 effects are often compared with the Global Financial Crisis (GFC) of 2008, which has been widely researched in interconnectedness, contagion and spillover effect literature (e.g. Kenourgios et al. 2011; Dimitru et al. 2013; Bekiros, 2014; Luchtenberg & Vu, 2015; Yarovaya et al., 2016, to name but a few). However, prior to the GFC, there were many structural problems in the US economy, while during the COVID-19 crisis the one distinctive crisis shock is evident, which is a spread of COVID-19. All other government actions and restrictions are an immediate response to the pandemic channel of the COVID-19 contagion. Thus, Harvey (2020) highlighted the differences between the GFC and COVID-19 crises and refers to the emerging pandemic crisis as the "*Great Compression*"[4]. Some journalists and experts also compare the

[2] http://www.policyuncertainty.com/us_daily.html

[3] The EPU index of Baker, Bloom et Davis was normalized to 100 from 1985 to 2010. Therefore, values exceeding 100 reflect higher than average uncertainty level.

[4] Campbell Harvey "The Economic and Financial Implications of COVID-19" (3rd April, 2020), the Mayo Center for Asset Management at the University of Virginia Darden School of Business and the Financial Management Association International virtual seminars series. https://www.darden.virginia.edu/mayo-center/events/virtual-speaker-series

COVID-19 crisis with global wars, responding to the dramatic news coming from China, South Korea, and recently from Italy and Spain, unveiling that this new infectious disease is different and much more dangerous from previous outbreaks. The lockdown measures that have been implemented by many countries affected businesses, job securities, and essential services, and some argued that the analysis of financial variables in response to COVID-19 is inconclusive, and focus should be made on the physical quantities referring to supply and demand imbalances in the labor market[5]. However, we argue that the COVID-19 crisis falls in the category of pandemics and generates a different type of contagion to both the GFC and wars. A more accurate comparison can be made with similar pandemics and epidemics events (Correia et al. 2020; Eichenbaum et al.,2020; and Ma et al., 2020), or natural disasters.

The COVID-19 pandemic is a source of systematic risk, therefore there is a need for further research on financial effects of coronavirus spread. In this paper, we specifically focus on the US financial markets for several reasons. First, the US markets were one of the main sources of a spillover effect to other markets and regions, as confirmed by Bekaert et al. (2011), Syriopoulos et al. (2015), among others. Second, the spread of COVID-19 in the US has followed the crisis in China, Korea, Iran, and Italy, therefore the US authorities already had more information about the risk related to the COVID-19 spread and could use the other countries' experience to mitigate the risk. By mid-January, only a few cases were disclosed in the United States, but their number started growing exponentially by the end of March. The situation is the US turned out to be quite similar to Lombardi in Italy or South Korea. According to the Worldometer Data Tracker (WDT), the number of the US confirmed cases exponentially rose to above 1.04 million, with 59,266 deaths by the 29th, April 2020. Third, the COVID-19 pandemic was not the only source of systematic risk to the US financial markets. Global financial markets also have been hit severely by oil price fall. Two months after the onset of the COVID-19 epidemic in Wuhan city, the oil price triggered a spectacular fall by around 30% (20% for the West Texas Intermediate (WTI) oil), which is the largest slump since the Gulf war, after the unexpected decision of Saudi authorities to offer price discounts of 6$ to 8$ to their main customers in Europe, Asia, and the US. These two serious shocks

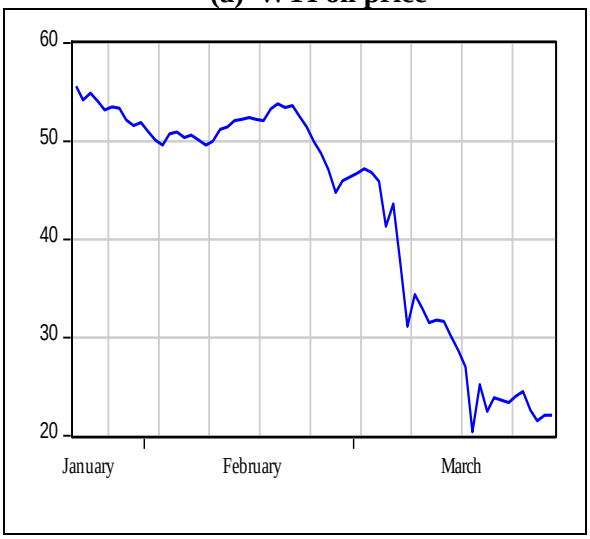
[5] For example, Branko Milanovic commentary at Foreign Affairs https://www.foreignaffairs.com/articles/2020-03-19/real-pandemic-danger-social-collapse

have triggered the worldwide stock markets to free fall as a result of the oil price war and fears over the dramatic news of infections and patient deaths cases coming especially from Italy, France and Spain. The study by Aloui et al. (2011) found that countries with higher sensitivity to commodity-price changes tend to co-move closely with the US in both bullish and bearish markets. Thus, by analysis of the impact of COVID-19 and oil shock on the US market, we can provide useful insights for the contagion and spillover effect studies in other countries and regions, contributing to this large and important research area.

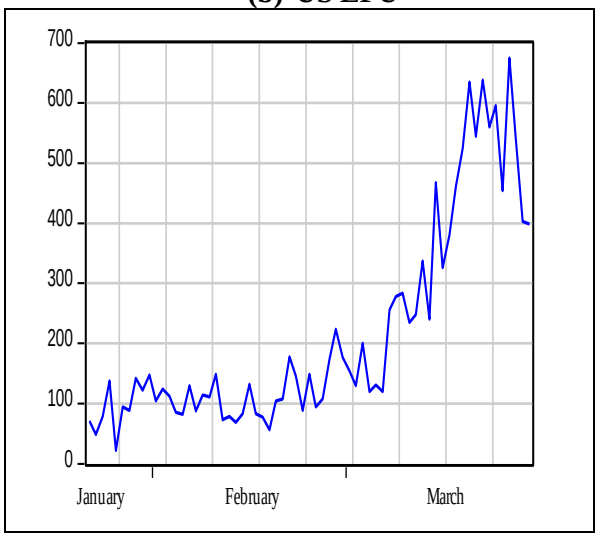
Apart from theoretical contributions, this paper will be interesting for a broad range of market participants. The investors' perception of coronavirus risk will shape the US economic anxiety, the economic policy uncertainty and the stock market behavior. In Fig. 1, we report the time paths of the WTI benchmark crude oil price, US economic policy uncertainty as measured by EPU index of Baker and Bloom (2016), the US-geopolitical risk as gauged by geopolitical risk (GPR) index designed by Caldara and Iacoviello (2018) and the US COVID-19 counts as reported by the US Center for Disease Control and Prevention (CDC).

Fig. 1 - Time series trend of US-COVID-19 counts, US-EPU index, US-GPR index, WTI price and Dow-Jones index

(a) WTI oil price

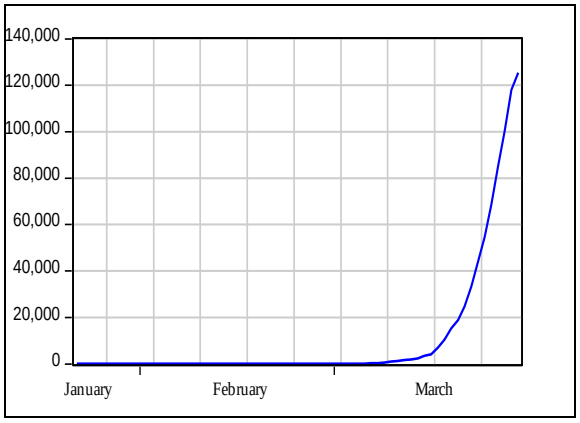


(b) US EPU

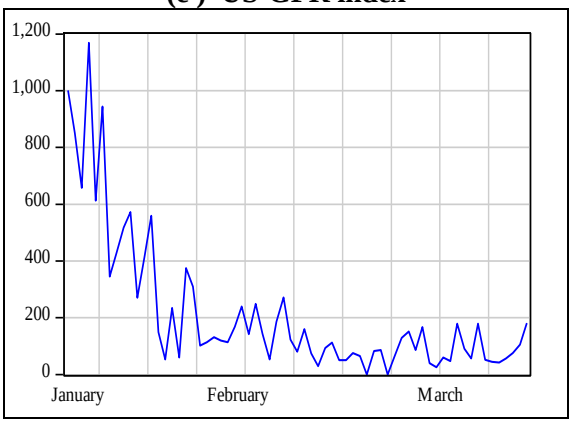


(c) US COVID-19 counts

(d) Dow-Jones Index



(e) US-GPR index



We can observe the free fall of oil prices, as well as the exponential increase of the infected cases in the US, have substantially raised the economic uncertainty and geopolitical risk levels in the US, while the Dow Jones index drops by 2,000 points in its worst day since December, 2008.

Undoubtedly, news regarding oil prices and the COVID-19 outbreak seem to be the irresistible drivers of the US stock market. The major concern is that oil markets may recover through OPEC+ alliance negotiations lead by oil mega-producers or any other arrangements, while uncertainty regarding the COVID-19 outbreak and its short- and long-term blows remain the main concern of the US policymakers. According to Fig.1(e) the geopolitical risk index has shown a free fall starting from the onset of the COVID-19 in China. The index went from 1.001 points on January, 21st to around 105 points on the March, 27th, 2020 pointing out an unprecedented upsurge of the geopolitical risk in the US. The COVID-19 seems to be the major global geopolitical shock.

These concerns are motivating our study. It is a first endeavor to analyze the connectedness and the lead-lag interplay between the COVID-19, oil price, EPU and stock market in the US within a time-frequency-based approach. To achieve this task, we resort to the wavelet methods. Specifically, we implement the continuous wavelet transform (CWT) and wavelet coherence (WC) as well as the wavelet-based causality tests to recent US data. At least three foremost aspects arouse the use of the wavelets. First, the wavelet method allows us to analyze the association between the selected variables within the time-scales and frequency bands (i.e. Investment horizons). Here, we hypothesize that due to differences in risk profiles, heterogeneous expectations and various perceptions of risk, US investors may react differently in terms of their investment decisions over investment horizons. For instance, "bad" news inherent to the US climbing COVID-19 infected cases, deaths, governments' distancing guidelines as well as oil price movement shocks may be perceived differently by market traders. Bad news may induce short-term traders to sell, while long-run traders may perceive the same news as a buying opportunity with the perception that such news would have a transitory bearing on the market (Chakrabarty et al., 2015).

For example, the anticipation of the fiscal policy response by the US government to support the economy in the times of COVID-19 might be interpreted by the investors as a positive signal, encouraging investment in SP500 stocks since the government will help the businesses to continue their operations. With the actual announcements of fiscal response to the COVID-19 crisis, US$ 2.3 trillion (around 11% of GDP) Coronavirus Aid, Relief and Economy Security Act ("CARES Act") in the US[6], would be interpreted as positive news by the investors even in the middle of the COVID-19 pandemic. Thus, investors will create a watch-list of top stocks to prepare for the future market uptrend. Based on that, we hypothesize that the association between the novel COVID-19 pandemic news, oil price volatility, US stock market and EPU will vary across time-scales and frequency bands. A key feature of wavelets pertains to their capacity to uncover latent processes with changing cycle patterns, trends, lead-lag interactions and non-stationary that characterize these time series.

[6]For all policy responses to COVID-19 see International Monetary Fund page: https://www.imf.org/en/Topics/imf-and-covid19/Policy-Responses-to-COVID-19#U

Second, wavelet methods are relevant when the interactive lead-lag relationship between the used time series are nonlinear. In a recent study using Google research data, Fetzer et al. (2020) unveiled a rapid increase of economic anxiety during and after the initial global spread of the Coronavirus. They report substantial nonlinearity in the COVID-19 spread and an overestimation of the mortality and its contagiousness effects. Here, we hypothesize the nonlinear effect which may be also attributed to the investors' heterogeneous expectations across short and long-run investment horizons. Third, the timeliness of data is a critical practical issue. We acknowledge that this paper is one of the first studies on COVID-19, and only a short period of data can be collected. To estimate the current and the future time-frequency causalities between COVID-19, EPU, stock returns and oil researchers would need long period data to get high statistical inference from the used tests, which makes the majority of traditional econometrics techniques not appropriate for the current study. Therefore, in this paper, we use the wavelet method since it is not affected by the size of the data sample.

Many scholars responded to the urgent need of research on the impact of COVID-19 pandemic on the global economy and international financial markets. Eichenbaum et al. (2020) utilized the canonical epidemiology model to study the interaction between economic decisions and pandemic, highlighting the existence of an inevitable trade-off between the severity of the short-run recession caused by the pandemic and the health consequences of the COVID-19 spread. Ma et al. (2020) compared global economic and financial effects of COVID-19 pandemic with past epidemic and pandemic events, such as SARS in 2017, H1N1 in 2009, and MERS in 2012, Ebola in 2014, and Zika in 2016, as identified by Jamison et al. (2017). Goodell (2020) discusses the economic and social impact of COVID-19 making parallels with previous crisis events. In corporate finance, Corbet et al. (2020a) analysed the impacts of being named "corona" on return and volatility behaviour of stocks during the COVID-19 pandemics. The results display that companies exhibit strong negative hourly returns and an exceptionally large increase in hourly volatility and trading volumes after the announcement of COVID-19 pandemic. Flights to safety behaviour on financial markets during the COVID-19 crisis have been analysed by Conlon and McGee (2020), as well as Corbet et al. (2020b) in relationship to gold and cryptocurrencies, providing consistent evidence that Bitcoin does not offer hedging nor safe haven properties during the COVID-19 pandemic. Furthermore, Yarovaya et al. (2020) analysed herding in

cryptocurrency markets during the COVID-19 pandemics, reporting that herding remains contingent on up or down markets days, but does not get stronger during the COVID-19.

The remainder of this paper is organised as follows. Section 2 discusses the prior research in this area used to build theoretical arguments of this paper. Section 3 explains the data and methodology employed in this study. Section 4 presents the empirical results, while Section 5 concludes.

3. Data and methodology

The data used in this study comprises of daily observations of COVID-19 (measured as a number of the infected cases of a novel COVID-19 in the US), oil prices (measured as WTI benchmark crude oil prices), US-EPU (news-based index), the US-geopolitical risk index (GPR) and US stock price index (SPI) as measured by the Dow Jones 30 index. The data of COVID-19 is collected from the website of the Centers for Disease Control and Prevention (CDC)[7]. Moreover, the data of oil and US stock market are gathered from DataStream, while the information of EPU is sourced from the website of Economic Policy Uncertainty. The US-GPR index is collected from Caldara and Iacoviello (2018) database. The time period of collected data is from January, 21st 2020 to March, 30, 2020, yielding 50 observations and all the series are converted into natural logarithmic series.

For the geopolitical risk, we refer to the updated global GPR index suggested by Caldara and Iacoviello (2018)[8]. The GPR index is an index based on news related to geopolitical events. It mirrors outcomes taken from automated text-search of the electronic archives which captures eleven national and international newspapers selected by above authors. The number of words related to geopolitical risk are counted each day in each newspaper to calculate daily GPR index[9]. Afterward, the entire index is normalized by equating the average value corresponding to the 2000-2009 decade to 100 (for details, see Caldara and Iacoviello (2018). At least three foremost aspects are motivating the use of the US-EPU and the US-GPR. First, using these indexes, we can assess the impact of the combined COVID-19 and oil prices on the US-economic policy uncertainty and the US-

[7] https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/cases-in-us.html

[8]Source: "Geopolitical Risk (GPR) Index" by Iacoviello (2019) at https://www2.bc.edu/matteo-iacoviello/gpr.htm.

[9] Various GPR indices are constructed by the authors by counting the words related to geopolitical tensions resulting from automated text searches in 11 leading national and international newspapers. The newspapers included in automated text search are Daily Telegraph, The Guardian, The Times, The Washington Post, The Chicago Tribune, The Wall Street Journal, The New York Times, The Financial Times, The Boston Globe, The Daily Telegraph and the Globe and Mail. Some of the key words used for construction of GPR index are

geopolitical risk within time-scales and frequency bands. Secondly, we deem that the GPR index is more relevant than the EPU index since the latter is more designed based on selected words related to US economic, uncertainty or others related to legislation or regulation. However, the GPR index includes words related to geopolitical tensions and other adverse geopolitical extreme events. Finally, using the two indexes, allows us to conduct comparative analysis in terms of responses to the oil and COVID-19 shocks. The time period of collected data is from 21 January 2020 to 29 March 2020 and all the series are converted into natural logarithmic series.

3.1 The continuous wavelet transforms (CWT)

The continuous wavelet transforms N_a (p, q) shows the projection of a wavelet ψ (.) in contrast to the time sequence a (t) $\in K^2(\underline{R})$, i.e.

$$N_a(p,q) = \int_{-\infty}^{\infty} a(t) \frac{1}{\sqrt{q}} \psi \left(\frac{\overline{t-p}}{M}\right) dt \quad (1)$$

An essential feature of this technique is its potential to decompose consequently and seamlessly recreate a time series a (t) $\in K^2(\underline{R})$:

$$a(t) = \frac{1}{C_\psi} \int_0^{\infty} \left[\int_{-\infty}^{\infty} N_a(\mathrm{p},\mathrm{q})\, \psi_{p,q}(t) du\right] \frac{dq}{M^2}, M > 0 \quad (2)$$

Moreover, this technique preserves the power of the observed time sequence,

$$\|a\|^2 = \frac{1}{C_\psi} \int_0^{\infty} \left[\int_{-\infty}^{\infty} |N_a(p,q)|^2 dp\right] \frac{dq}{M^2} \quad (3)$$

In the present paper, we count on the aforesaid flexible tactic in the form of the wavelet coherence, which enumerates the successiveness between two time series in a bivariate model.

"geopolitical", "uncertainty", "war risk", "Middle East tension" and similar words hinting toward some geopolitical tensions (For more details see Caldara and Iacoviello, 2018).

3.2. The wavelet coherence (WC)

The connectedness between the COVID-19, Economic policy uncertainty (EPU), US stock market and crude oil prices can be analyzed through time scales by considering the widely implemented methodology irrespective of the time series, i.e., wavelet coherence. Practically speaking, the cross wavelet power and cross wavelet transform (CWT) defined first. Torrence and Compo (1988), stated that the cross wavelet transform can be clarified by two-time sequence a (t) and b (t) as:

$$N_{ab}(p,q) = N_a(p,q)\, N^*{}_b(p,q), \tag{4}$$

where, $N_a(p,q)$ and $N_b(p,q)$ depicts two continuous transforms of a (t) and b (t), separately, p shows the location index and q is the measure, whereas composite conjugate is shown by (*). The cross wavelet transform can be used to calculate wavelet power by $|N_a(p,q)|$. The cross wavelet power spectra separate the section in which strong energy concentration is revealed (cumulus of the restrained variance) in the domain related to time-frequency comparatively to the time series under consideration. The wavelet coherence technique (WCT) can ascertain the specific parts in the domain of time-frequency, where unexpected and major variations happen in the co-movement patterns of the time series under observation. The equation of the coefficient of adjusted wavelet coherence as identified by Torrence and Webster (1999) is as follows:

$$W^2(p,q) = \frac{|M(M^{-1}N_{ab}(p,q))|^2}{M(M^{-1}|N_a(p,q)|^2)M(M^{-1}|N_b(p,q)|^2)} \tag{5}$$

where M is the smoothing mechanism. This $0 \leq W^2(p,q) \leq 1$ shows the range of squared wavelet coherence coefficient. Closeness to zero is the indication of the absence of correlation, while closeness to unity is the indication of a high correlation. The method of Monte Carlo is utilized to examine the hypothetical allocation of wavelet coherence.

4. Empirical results and discussion

4.1. The continuous wavelet transforms and the wavelet coherence.

The continuous wavelet transforms (CWT) plots for each variable are conveyed in Fig. 2. The CWT describes the movements of each variable in the time-scales and frequency bands. For the US, stock market risk is clearly

apparent as a response to the announcement of the unexpected price discount by the Saudi Arabia and the subsequent meltdown in crude oil markets which become visible through a significant island of high volatility over the short-run (1-4 days' frequency bands). A relatively different pattern is observed for the EPU index. High EPU index volatility is noticed starting from the inception of the sample period which may be mainly explained by the bad news related to the novel infectious disease upsurge and tumultuous sanitary conditions in China. After that, the US EPU jumps to reach its zenith at the end of the sample period (around 400 by the end of March, 2020) reflecting an unprecedented level of EPU in the US. The CWT plot is in line with the time path of the EPU index reported in Fig.1. As for oil price time-path, two islands of high volatilities for the 1 to 8 and up to 16 days-frequency bands and initiating from February can be easily spotted in the CWT plot. The visual inspection of the US COVID-19 counts' CWT reveals small island of high volatility from the inception of the sample period which corresponds to the first COVID-19 patient deaths in the US. When inspecting to the US-GPR, we observe that the CWT plot is a mixture of the CWTs of oil prices and the US-COVID-19 counts, which indicates that the unprecedented increase of the geopolitical risk levels in the US is driven by the combined shocks of the novel infectious disease and the recent free fall of oil prices. Furthermore, we identify huge island of red color corresponding to a substantial volatility jumps by the end of February, 2020 when the US-GPR plunges from 559 points at the beginning of the month to go under 100 points and at the same date the oil prices dropped and the COVID-19 curve started its exponential trend, as it was demonstrated in Fig.1.

Fig. 2. CWT plots for the stock market, the economic policy uncertainty (EPU), the geopolitical risk (GPR), Oil and the COVID-19 counts in the US.

Fig. 2 (a) the US stock market

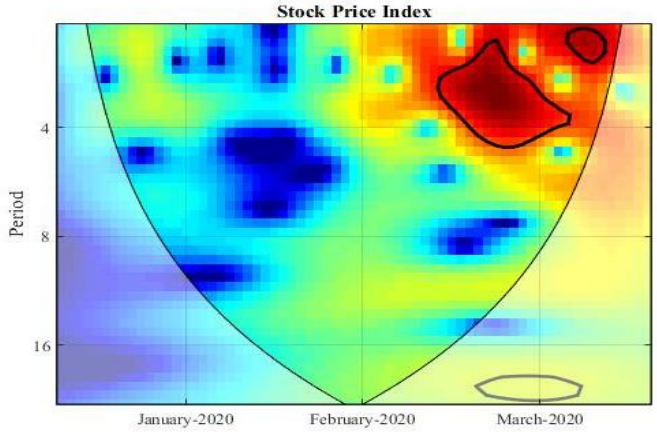


Fig. 2 (b) the US-EPU

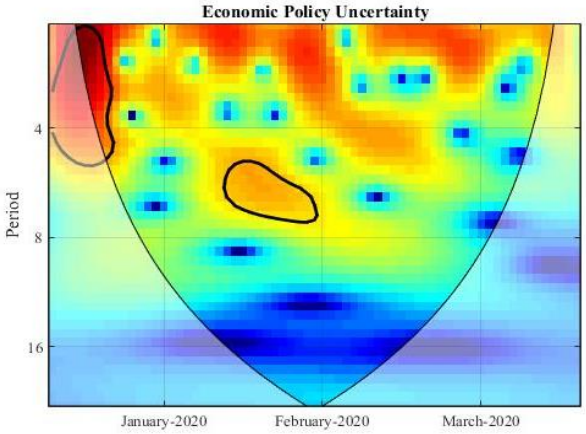


Fig. 2 (c) the US- COVID-19 counts

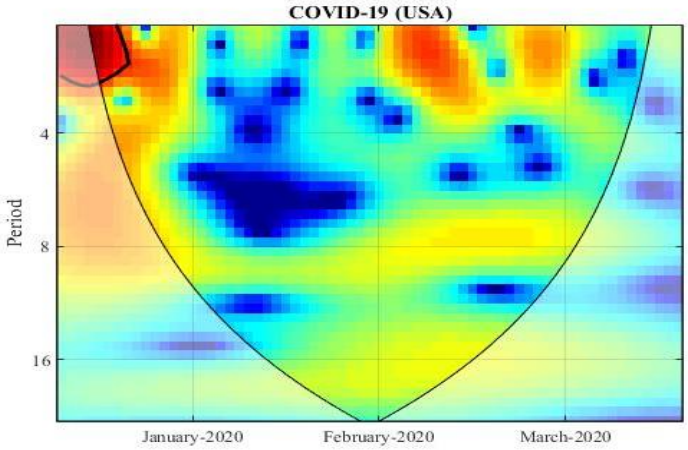


Fig. 2 (d) the Oil (WTI)

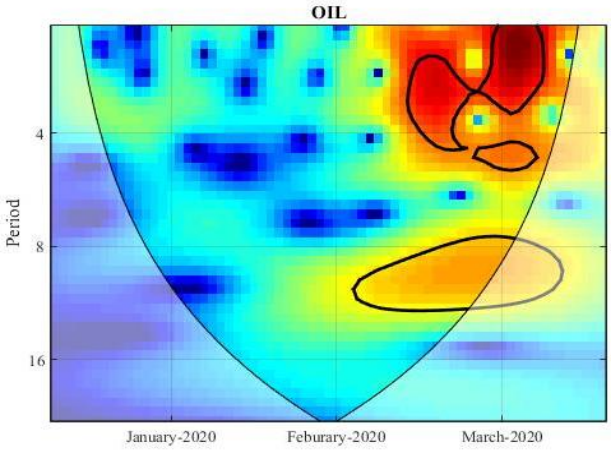
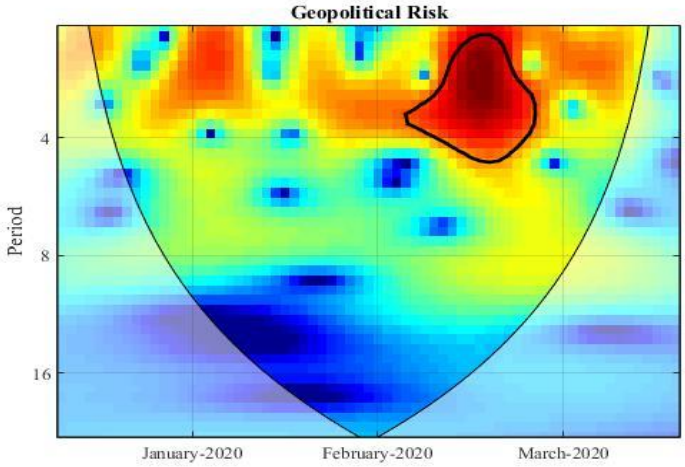


Fig. 2 (e) the US-GPR



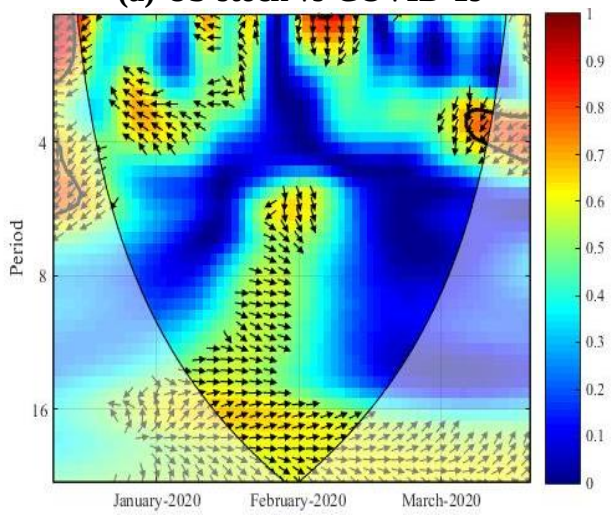
Notes: X-axis represents the time whereas, Y-axis shows the period (in days). The thick black contour represents the 5% significance level against the red noise.

These results show that the US markets initially reacted to oil shock, rather than COVID-19 news coming from Wuhan and other areas. However, the escalating COVID-19 crisis had an immediate and profound impact on the economic policy uncertainty, which confirms our initial hypothesis that for the US economy oil remains the main source of systematic risk, while a spread of COVID-19 increases the uncertainty due to the unpredictable severity of the response to the pandemic.

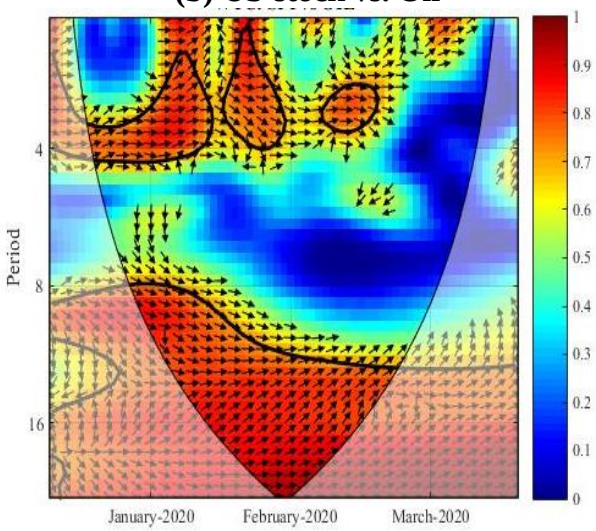
To further analyze the interactions between selected variables, Figure 3 repots the wavelet coherence plots for each couple of variables. Fig. 3a plots the wavelet coherence between the US stock index and the US COVID-19 infected cases. We detect the existence of small islands of strong dependence at the beginning, the mid and the end of the sample period over the 4-8 days' frequency bands. The US market seems to react to bad news coming from Wuhan city, December, 31st, the Chinese sanitary authorities announced the first patient death and a few days later, researchers identified the new unknown dangerous virus and the first death was recorded on January 11. At the same time, some infected cases were identified in South Korea, Japan and the US. Moreover, another high coherency area is identified on mid-February corresponding to some COVID-19 pandemic bad news such as the reported first patient death in the US on February, 28th, the number of global cases raised to 87,000 and the high-level warning announced by the US authorities. The last substantial coherence is identified at the end of the sample period and may be mainly due to the combined effect of the sharp drop of oil prices and COVID-19 fears. Furthermore, arrows are mostly turned down and left which means that there is an anti-cyclic effect between COVID-19 and US stock index where COVID-19 is leading. We identify a quite similar configuration in terms of islands of strong coherencies in Fig. 3d showing the coherence between the reported COVID-19 cases and the US EPU. However, we perceive that the COVID-19 outbreak has a greater effect on the US economic uncertainty. The red islands identified at the beginning and the end of the sample period correspond to lower frequencies (8 to 16 days-frequency bands) which means that it is expected to have a long-term negative effect on the US economic uncertainty. The uncertainty is primarily related to the long-term path of the US economy and how the Federal Reserve will react to the notable rise of uncertainty and bad news of the COVID-19. This is in addition to an adverse impact on the potential US output and unemployment rate that are quite independent from the monetary policy.

Figure 3. Wavelet coherence plots, pairwise estimates.

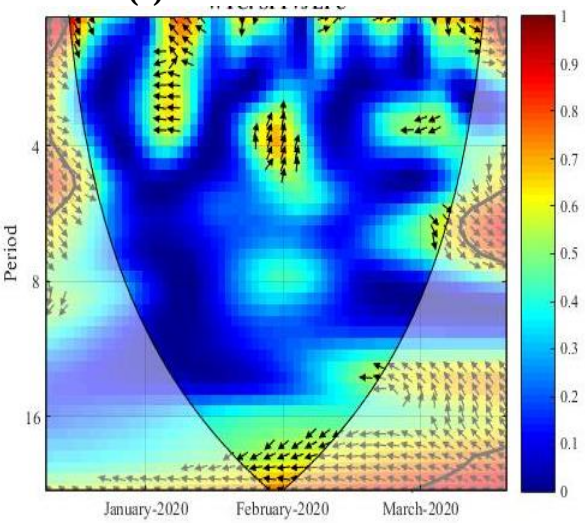
(a) US-stock vs-COVID-19



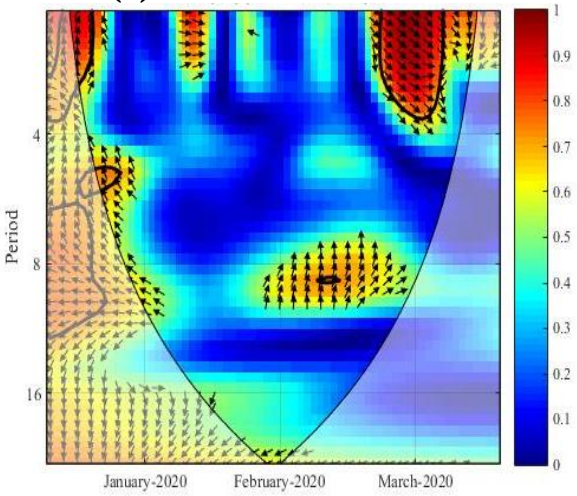
(b) US-stock vs. Oil



(c) US-stock vs. US-EPU

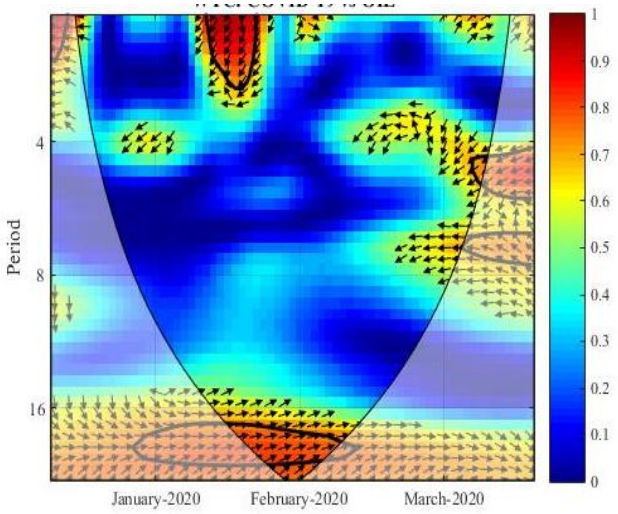


(d) COVID-19 vs. US-EPU

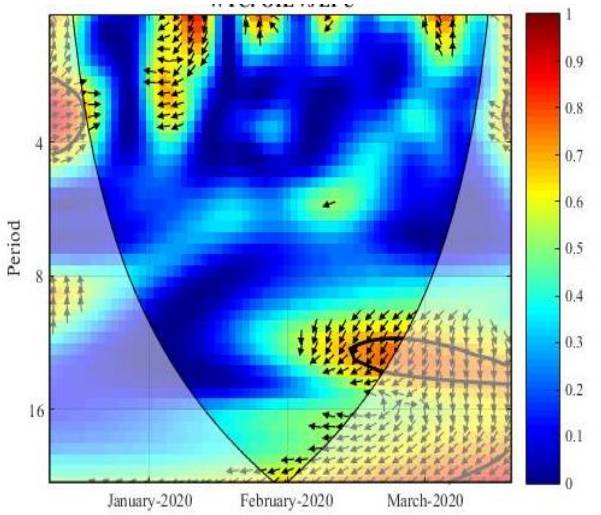


(e) COVID-19 vs. Oil

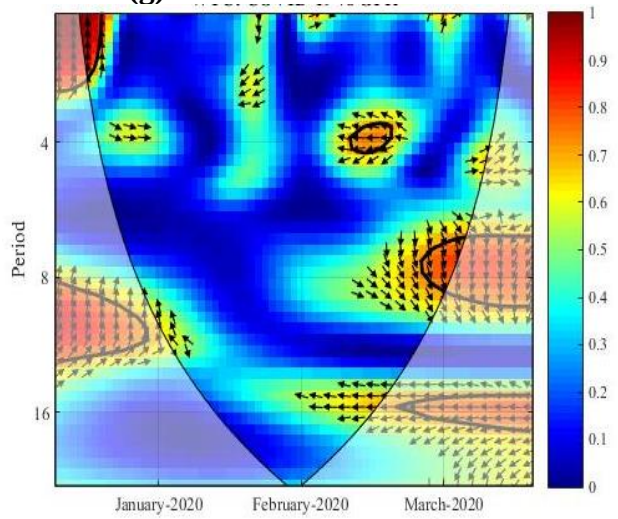
(f) Oil vs. EPU



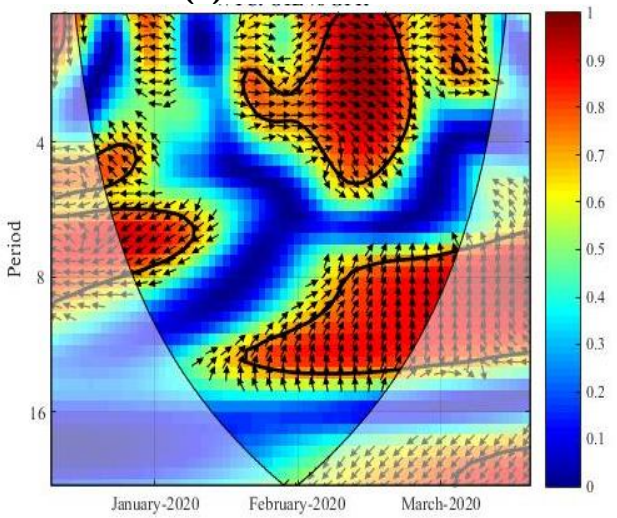
(g) COVID-19 vs. US-GPR



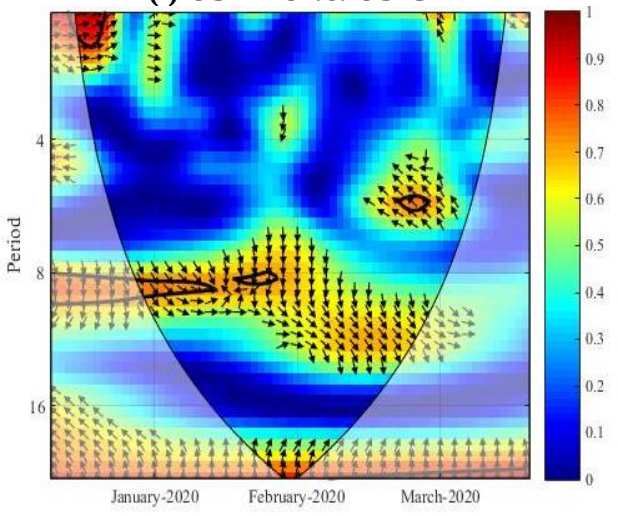
(h) Oil vs. US-GPR

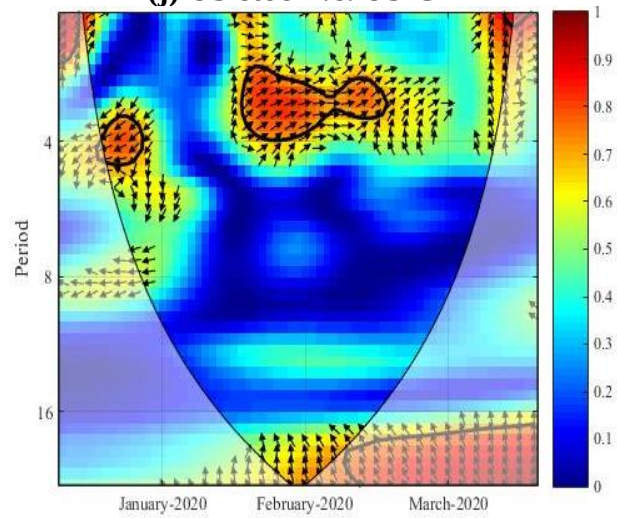


(i) US-EPU vs. US-GPR



(j) US-stock vs. US-GPR





Notes: X-axis represents the time whereas, Y-axis shows the period (in days). The thick black contour represents the 5% significance level against the red noise.

The wavelet coherence between the US stock market and oil price reported in Fig.3b reveals huge islands of red color, which indicates strong dependency over the 4 to 8-days frequency bands for the whole sample period. Unsurprisingly, the arrows are predominantly turned up and to the right indicating that oil prices are leading the US market. As for the connectedness between the US stock index and EPU, (Fig. 3c), the WC plot reveals the existence of strong coherency islands at the onset of the novel coronavirus and by the end of March 2020 corresponding to a dramatic increase of the infected counts in the US and the free fall of oil prices. The arrows are mostly turned up and to the left, implying the US stock market is leading the US-EPU and the sharp decrease in the US market has strikingly raised the economic policy uncertainty in the US. Fig. 3e shows the wavelet plot between oil and the US COVID-19 counts. We identify an island of high dependence over the 16-days frequency band over the entire sample period and the arrows are mostly pointed up to the left. Other coherencies over 4-8 days' frequency bands can be observed with arrows turned up and to right suggesting a cyclic relationship between COVID-19 and oil where oil prices are as following. These results show that the COVID-19 pandemic seems to have severe implications on oil price volatility through the demand side because of travel restrictions and low expected output growth in China and European countries. However, it seems early to conceptualize the effect of the new infectious disease outbreak on the long-term future oil prices, it is incontestable that the oil markets are facing a complicated circumstance due to the rare combination of rising supply and falling demand. This may explain the time-frequency varying pattern of the COVID-19-oil interrelationship over the last three months.

The oil-EPU connectedness over time-scales and frequencies is shown in Fig 3f., it is evident that the US economic policy uncertainty is strongly affected by the recent oil price. Indeed, a strong island of red color is identified starting from the beginning of March 2020 over the 16-days investment horizon corresponding to the unexpected price discount announced by Saudi Arabia. In addition, the arrows are mostly turned down to the left implying that there is an anti-cyclic relationship between US economic uncertainty and oil prices where economic uncertainty leading to lower oil prices. Fig. 3g shows the wavelet coherence plot between the US-

COVID-19 and the GPR. The visual inspection of the wavelet shows the existence of huge zones of high coherence located at the beginning of the sample period over two frequency bands (4-days and from 8 to16-days), matching with the onset of the new infectious disease and the arrival of bad news from China. Another two islands of red color are identified at the end of February over the 6-8-days and up to 16-days frequency bands. Indeed, at the last day of February, only 15 infected cases were announced by the US Center of Disease Control and Prevention (CDC) but two weeks later, the country's testing capacity increased and more than 17,000 positive cases are identified during the first two weeks of march. When referring to the arrows, we perceive that most of them are turned right and down which implies that the causality is going from the Coronavirus pandemic to the US-GPR during the month of March. The tremendous spread of the COVID-19 has significantly affected the US-GPR levels. As for the dependence between the oil and US-GPR (Fig, 3h), the wavelet plot is extremely edifying. We identify strong areas of strong dependence at the inception and at the end of the sample period. At the beginning of the sample period areas are covering the 4-8 days' frequency while those located at the end of the period are over the 8-16 days. For the entire period, arrows are predominantly turned up and to the left revealing the oil as leader and the GPR as follower. The recent oil price war is the main driver of the US geopolitical risk and seems to harm chances of international cooperation to overcome the COVID-19 pandemic.

The wavelet plot between the US-EPU and geopolitical risk are presented in Fig. 3i. The dependence structure is principally observed over the long-run (up to 16-days investment horizons) and the arrows are mainly turned up and the right showing pointing out the GPR as leading variable. The unprecedented volatility jumps in the US-geopolitical risk due to the simultaneous effect of the COVID-19 and oil price volatility is raising the uncertainties of the US economic policies. The wavelet coherencies between the US stock market as measured by the Dow Jones price index and local GPR index are conveyed in Fig. 3j. This figure clearly shows the existence of small hot red zones over the 0-4 days- frequency band (i.e. short investment horizons) strong dependence between the two variables. For these small zones, arrows are mostly turned up and to the right indicating that the GPR is leading the US stock market. Over the short-run, US investors are reallocating their portfolios' assets based on their risk assessment and their short-run individual perceptions of the bad news

inherent to the Coronavirus outbreak, as the main geopolitical shock in the US. Furthermore, another huge hot red area is identified over the 16-days frequency band and starts from the end of February. The arrows are mostly pointed up and to the left suggesting the stock market index as a leading variable and the GPR as a follower. To sum up, the stock-GPR relationship and causalities vary through time-scales and frequencies banks.

4.2 Robustness test, the wavelet-based Granger Causality

To check the robustness of the CWT and WC analysis outcomes, we implement the wavelet-based Granger Causality tests. The causality tests are implemented for six frequency domains (D1 to D6), and the results are conveyed in Table 1. From these results, we notice that unsurprisingly oil price volatility is causing the US stock index for all the selected frequencies. This result is in line with previous studies showing the substantial sensitivity of the US market to oil volatility shocks (see, among recent studies, Torun et al., 2020 and Wu et al., 2020). The effect of the EPU on the US stock market is evidenced over very short-run investment horizons (D1 to D2). Furthermore, the wavelet-based causality is running from the COVID-19 pandemic to the US stock market and the EPU for only the D1 and D2 frequency domains. It is worthily noting that the COVID-19 is not causing the US-GPR risk levels over all the selected frequency bands, while it affects the US-EPU over only the D1 and D2 time-horizons. This result may be due to the US investors who perceive the COVID-19 outbreak firstly as an economic crisis rather that reverse geopolitical event. No significant effect of the COVID-19 is detected on the oil price volatility over the remaining frequency domains since the two exogenous shocks are independent.

As for the EPU, causality is strongly influencing the oil price for all the selected frequencies, while its effect on the US market is observed over the short-term investment horizons (D1 to D2). The EPU is substantively causing the GPR levels in the US, which means that uncertainty related to US economic conditions are mainly causing the increase of the GPR levels. When looking to the oil effect, we found a significant effect on the US market and reveals a bidirectional causal linkage over all the selected frequency bands. For the EPU, the oil impact is shown over only short-run investment horizons (D1 to D2). Finally, the wavelet causality tests show that the GPR is causing the US stock market, the oil prices as well as the economic policy uncertainty

across all the selected frequency bands (D1-D6). The bi-directional causalities between these variables are identified over the short-term investment horizons (D1-D2).

Table 1. Results of wavelet-based Granger causality

Frequency Domains	Dependent Variables	Independent Variables				
		US-Stock	**COVID-19**	**EPU**	**OIL**	**GPR**
D1	US-stock	-	0.753	17.382***	27.492***	26.483***
	COVID-19	6.583*	-	19.583***	1.584	2.525
	EPU	54.934***	1.493	-	22.491***	13.883***
	OIL	29.554***	2.832	12.484**	-	3.021
	GPR	16482***	0.583	17.095***	19.593***	-
D2	US-stock	-	0.482	18.694***	25.483***	25.955***
	COVID-19	14.694**	-	35.437***	0.593	0.835
	EPU	5.246*	0.117	-	18.658***	15.229***
	OIL	38.593***	1.442	19.464***	-	2.925
	GPR	9.531**	2.583	26.652***	32.049***	-
D3	US-stock	-	0.382	1.049	24.599***	3.524
	COVID-19	0.005	-	1.854	0.559	0.746
	EPU	2.001	1.521	-	18.482***	12.486***
	OIL	19.943***	0.547	2.005***	-	2.571
	GPR	8.686**	1.689	14.635***	27.531***	-
D4	US-stock	-	0.284	1.448	16.485***	2.069
	COVID-19	0.048	-	1.553	0.491	0.562
	EPU	0.795	1.592	-	16.385***	17.694***
	OIL	22.486***	2.211	1.115	-	0.667
	GPR	10.052**	2.684	3.091	20.158***	-
D5	US-stock	-	2.195	4.593*	18.707***	8.246**
	COVID-19	2.372	-	0.559	1.533	0.359
	EPU	5.492*	0.481	-	25.203***	3.037
	OIL	57.492***	1.887	0.485	-	0.583
	GPR	19.692***	7.593**	2.948	16.327***	-
D6	US-stock	-	2.003	1.471	94.473***	10.537**
	COVID-19	0.002	-	1.574	0.348	0.236
	EPU	3.028	1.029	-	18.472***	2.437
	OIL	83.472***	0.551	0.083	-	0.436
	GPR	20.537***	11.695**	0.368	14.215***	-
Original	US-stock	-	2.258	0.0837	17.676***	23.643***
	COVID-19	26.328***	-	19.493***	1.049	1.059
	EPU	0.234	2.018	-	19.482***	7.592**
	OIL	10.483**	1.382	0.449	-	2.221
	GPR	8.448**	1.058	7.483**	21.936***	-

Notes: Asymptotic Chi-square values are reported. ***, ** & * significant value at 1% significant value, 5%, significant value and 10% significant value. SPI refers to Dow-Jones stock market index while EPU designates the US economic policy uncertainty index and GPR denotes Geopolitical risk .

5. Conclusion, some policy implications and future research

The economic and social costs of the COVID-19 pandemics concern the society, policy makers, and all financial markets participants and individual investors. In this study, we analyze the time-frequency connectedness between the recent COVID-19 outbreak, crude oil price volatility shock, the economic policy uncertainty, the geopolitical risk and the stock market in the US using the continuous wavelet transform, the wavelet coherence and the wavelet-based Granger causality tests. The wavelet-based approach allows us to analyze the interactive lead-lag interactions in the time frequency domain and to overcome some practical challenges inherent to the short sample period as well as other stylized facts including stationarity and non-linearity. Using recent daily data for the US, our wavelet analysis unveils an unprecedented sensitivity of the US stock market, the US economic policy uncertainty and the US geopolitical risk to the combined shocks of the COVID-19 and oil volatility shocks. The associations between the variables vary across time-scales and investment horizons, where both cyclical and anti-cyclical patterns of connectedness have been identified.

This paper is one of the pioneer studies on the financial effects of the COVID-19 pandemic, and the importance of research in this area is highlighted by Goodell (2020). Thus, our results provide several important pieces of evidence. First, the COVID-19 outbreak has a greater effect on the US geopolitical risk and on the US economic uncertainty. These results confirm that the COVID-19 pandemic itself and related regulatory response to this crisis are sources of geopolitical risk, and we recommend including the geopolitical risk index in the future analyses of financial effects of COVID-19 outbreak. Strong connectedness at low frequencies display that COVID-19 is expected to have a long-term negative effect on the geopolitical risk levels and economic uncertainty. The uncertainty is primarily related to the long-term path of the US economy and how the Federal Reserve will react to the pandemic. Second, the oil slump had the strongest impact on the US stock markets in comparison to both COVID-19, EPU and GPR. We found that oil prices were leading the US market at both low and high frequencies throughout the observation period. Third, the results show that the COVID-19 pandemic

also affect the oil prices, which can be explained by imposed travel restrictions. The robustness test estimated the wavelet-based causality in six frequency bands, suggest the short-term causality of COVID-19 pandemic and both the US stock and the EPU, for COVID-19 - oil causality is significant at all frequencies analyzed.

Our findings offer fresh and prominent policy and practical implications. It is becoming clear that the COVID-19 pandemic is causing outcome disruption, an exceptional increase in the US economic policy uncertainty and unprecedented response of the stock market. While the oil volatility shocks may be sensed as a transitory risk that could be depressed through the OPEC+ deals, the COVID-19 crisis can further affect oil price due to the travel restrictions around the world during the pandemic. This result is important not only for oil exploration and production companies, but for companies in transportation and hospitality industries, as well as investors who have allocations in the stocks sensitive to the oil price and commodity derivatives. The US investors' perceived risk inherent to the tumultuous spread of the COVID-19 as a systematic risk shaking the US stock market raising the economic policy uncertainty indexes to enormous levels. This result is consistent with a recent survey study outcome of the World Economic Forum (March, 2020)[10]. Therefore, the US government must avoid creating additional uncertainty by designing a coherent COVID-19 economic strategy that fosters opening the markets. From an asset management perspective, our results show the strong short-term impact of COVID-19 on the US stock markets, however, we cannot exclude the possibility that investors might still expect that with the further government interventions, the US stock markets will be able to recover in the long-term. In the meantime, while the COVID-19 pandemic is still ongoing, asset managers and individual investors should know how to handle stock market volatility and systematic risk associated with COVID-19 spread. The used risk management framework should be reassessed to address the new and enhanced risks caused by the upsurge of the COVID-19 pandemic.

We would like to acknowledge, that our findings should be taken with caution given the small size of the sample and the statistical inference from the used tests, but they pave the way for many research questions regarding the short and long-run effects of the COVID-19 pandemic on the US output, financial stability, monetary policy and other macroeconomic factors using large data sample or even real-time data.

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