

# EPU Index, Crude Oil Prices, and S&P 500: Wavelet Correlation

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**Abstract:** Between January 2020 and June 2022, we collect 1830 data in total, processing them with R and doing wavelet analysis. Additionally, using a time-frequency framework, we examine the linkages between the COVID-19 epidemic, the Russian-Ukrainian war, the price of crude oil, the S&P 500, and the uncertainty of economic policy. The COVID-19 epidemic and the Russian-Ukrainian conflict have exceptional effects on the three indexes, with the war's effects on the price of crude oil and US stocks being greater than their effects on US economic instability.

## 1. Introduction

Since 2020, the COVID-19 epidemic's expansion and the sharp decline in oil prices have each had a significant impact on the U.S. economy. When these two problems come together, the U.S. economy may experience a protracted recession. The COVID-19 pandemic's emergence and spread caused a 30% decline in U.S. oil prices, the largest drop since the Gulf War in 1991 [1]. And this result has persisted up to this point and probably will for a very long time to come. A new warning about the effects of climate change in the IPCC [2] report raises the widely debated question of whether the geopolitical crisis brought on by Russia's invasion of Ukraine will accelerate or hinder the transition to a low-carbon economy. In the meantime, the recent outbreak of war between Russia and Ukraine has had an impact on the global situation. The consequences of human choices, governmental actions, business policies, and the ongoing COVID-19 epidemic hamper attempts by academics to quantify changes in the post-World War II global economy.

The COVID-19 pandemic epidemic and the Russian-Ukrainian conflict's effects on the American market can be examined to gain important insights for studying other nations and areas dealing with the spread of the illness and the onset of war, as well as the accompanying spillover effects. The behavior of a wide range of market participants will be discussed in this paper, and how investors perceive the COVID-19 pandemic outbreak and the Russian-Ukrainian war will reveal how the U.S. economy views them, which will have an impact on changes to the U.S. stock market and the implementation of U.S. policies.

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## 2. Literature review

Chinese health officials announced the first patient death in Wuhan City on December 31, 2020, while the CDC confirmed the first US coronavirus infection on January 21, 2022. Since COVID-19 was declared a global pandemic two years ago, some states have repealed or loosened their limitations as of March 2022. Additionally, estimations indicate that Russia planned an invasion of Ukraine in 2021 or 2022 and organized a sizable military buildup along its borders. Ukraine was

attacked by Russia on February 24, 2022. In order to better illustrate the differences between before and after the COVID-19 epidemic and the Russian-Ukrainian war, we chose daily data from 2/1/2020 to 2/6/2022. The two incidents led to significant changes in the price of crude oil, the uncertainties surrounding economic policy, and the U.S. stock market [3]. S&P 500, WTI, and EPU are discussed by Yao et al. [4] from the viewpoint of a nonlinear system. They discovered a strong positive correlation between the stock market and the price of crude oil, and that the oil price or stock series would be a more significant factor in predictions than the EPU index. The dynamic relationship between economics, employment, investment, and output can be better studied using EPU. The volatility of the S&P 500 index is a net recipient of spillovers from significant EPU indexes [5]. As a result, there is a high link between the S&P 500, WTI, and EPU, which can represent national economic and political changes from all angles.

The wavelet correlation test method, which is frequently employed to analyze linkages and front-lag interactions [6, 7], is applied in this work. Wavelet analysis has the benefit of not requiring any stationarity assumptions and having a better grasp of how the index interacts. The timing of the COVID-19 pandemic, the price of crude oil, geopolitical risk, economic ambiguity, and the US stock market were all examined by Sharif et al. [8]. The COVID-19 outbreak has a greater influence on the US economy and global risk than it does on the US stock market, according to their wavelet-based analysis. The relationship between the S&P 500, EPU, and WTI during the COVID-19 epidemic has been the subject of numerous studies, but there has been little consideration of the relationship prior to and during the Russian-Ukrainian War.

Oil-stock world interconnections have been proven by prior study [9, 10]. These studies demonstrate that there is no discernible relationship between changes in crude oil prices and stock returns in the financial markets, at least not at higher frequencies. There is a contradiction because some research suggests that the oil price and stock have beneficial relationships. The relationship between crude oil price and stock is discussed in our study in regard to the COVID-19 pandemic and the Russian-Ukrainian war. Recent research has shown a connection between EPU and the price of American stocks [11, 12]. They demonstrate how the effect of ambiguous economic policies on stock prices changes over time.

Researchers prefer to obtain data on the influence on the economy and financial markets when studying the relationship between stocks and other indices. Or numerous studies have examined the relationships between two of the three indices. The shift in index before and during the Russian-Ukrainian war and the interactions of three indexes—WTI, EPU, and S&P 500—have attracted little attention to this issue thus far. In order to evaluate the relationships between crude oil prices, EPU, and S&P 500, the paper used the wavelet correlation test approach, which advances existing research.

### 3. Data and methodology

The study, which used daily data gathered from January 2 to June 2 of 2022, included the S&P 500 Composite Index (S&P 500), Crude Oil WTI, and US-EPU Index from the Economic Policy Uncertainty website. 610 observations were generated, including the COVID-19 pandemic outbreak and the start of the Russian-Ukrainian war. Following that, all sequences were converted to natural logarithmic sequences.

#### 3.1 The continuous wavelet transforms (CWT)

If  $\Psi(t) \in L^2(R)$  satisfies the following three conditions:

$$\int \Psi(t) dt = 0 \tag{1}$$

$$\int |\Psi(t)| dt < +\infty \tag{2}$$

$$C_{\Psi} = \int_{-\infty}^{+\infty} \frac{|\Psi^2(w)|^2}{|w|} d\omega < +\infty \tag{3}$$

Equation 1 shows that  $A$  is an oscillating wave or a positive and negative alternating function, with a function value that is equal to a specific quantity of energy in both the positive and negative parts, and an average value of zero. Equation 2 shows that  $A$  is a "small wave," meaning that it has a limited volume or that as the independent variable is increased, the waveform's amplitude rapidly decays to zero. Equation 3 exists so that there is an inverse transform of the wavelet transform.

Then  $\Psi(t)$  is called a basic wavelet, and the wavelet change of the signal generally refers to decomposing the signal  $f(t)$  to be analyzed into "wavelet" clusters (formed by the basic wavelet  $\Psi(t)$  being expanded or stretched to different degrees and then translated to different positions):

$$\left\{ \Psi_{a,b}(t) = a^{-1/2} \Psi\left(\frac{t-b}{a}\right) \right\} \quad (4)$$

For any signal  $f(t) \in L^2(R)$ , its continuous wavelet transforms (CWT) are defined as:

$$WT_{\Psi} f(a,b) = \int_{-\infty}^{+\infty} f(t) \bar{\Psi}_{a,b}(t) dt = a^{-1/2} \int_{-\infty}^{+\infty} f(t) \bar{\Psi}\left(\frac{t-b}{a}\right) dt \quad (5)$$

Among them,  $a > 0$  is the scale parameter,  $b$  is the position parameter, and  $\bar{\Psi}(t)$  represents the complex conjugate of  $\Psi(t)$ .

### 3.2 The wavelet coherence (WC)

The coherence coefficient is defined as a function of power-spectrum density (PSD) and cross-spectrum density (CSD) for two complex random signals  $x$  and  $y$ , and the formula is as follows:

$$Coh^2_{xy} = \frac{|P_{xy}(f)|^2}{P_{xx}(f) \cdot P_{yy}(f)} \quad (6)$$

Among them,  $Coh_{xy}$  represents the coherence coefficient of the signal  $x$  and the signal  $y$  at the frequency  $f$ , and  $Coh_{xy}$  satisfies  $0 \leq Coh_{xy} \leq 1$  (when  $Coh_{xy} = 0$ ,  $x$  and  $y$  are incoherent; when  $Coh_{xy} = 1$ ,  $x$  and  $y$  are completely coherent).  $P_{xx}(f)$ ,  $P_{yy}(f)$  and  $P_{xy}(f)$  respectively satisfy the following formulas:

$$P_{xy}(f) = M(M^{-1}N_{ab}(x,y)) \quad (7)$$

$$P_{xx}(f) = M(M^{-1}N_a(x,y)) \quad (8)$$

$$P_{yy}(f) = M(M^{-1}N_b(x,y)) \quad (9)$$

$P_{xx}(f)$  and  $P_{yy}(f)$  represent the PSD (real function of frequency  $f$ ) of signal  $x$  and signal  $y$ , respectively, and  $P_{xy}(f)$  represents the CSD (complex function of frequency  $f$ ) between signal  $x$  and signal  $y$ .  $M$  is the smoothing mechanism, and  $a(t)$  and  $b(t)$  are two time series,  $N_{ab}(x,y)$  is the cross wavelet transform, which is defined as follows:

$$N_{ab}(x,y) = N_a(x,y)N_b^*(x,y) \quad (10)$$

Where  $N_a(x,y)$  and  $N_b(x,y)$  represent two continuous transforms of  $a(t)$  and  $b(t)$ , respectively, while  $p$ ,  $q$ , and  $(*)$  respectively show the location index and measure.

## 4. Empirical results and discussion

### 4.1 The continuous wavelet transforms

The three variables of the S&P 500, WTI, and EPU are plotted using the continuous wavelet transform (CWT) in Figure 1. The CWT of the S&P 500 index (Figure 1) shows a significant island of high volatility over the medium and long range (32-64 days' frequency bands), which happened

in early 2020. An important aspect that contributed to the collapse of the US stock market after the turbulence escalated was the COVID-19 pandemic's global spread since the announcement of the first group of pneumonia cases in Wuhan. On March 11, US President Donald Trump imposed a temporary 30-day travel ban on all goods and individuals from Europe in response to the COVID-19 infection. The prohibition did, however, exacerbate market panic, which sparked the bigger stock market disaster of 2020. With the exception of a notable island of high volatility, concerns about COVID-19 infections, the lack of prospects for federal stimulus, and the unpredictable nature of the U.S. election have caused the S&P 500 to experience a sustained period of high volatility since the sample period (128-256 days' frequency bands). The stock market starts to fluctuate again around 2022, and at this time it was claimed that Russia had begun making preparations to invade Ukraine. On February 24, 2022, Russia officially declared war. Due to the economic sanctions the US put on Russia as a result of the conflict, WTI oil prices skyrocketed. On March 2, they traded above \$110 for the first time since 2014 [13]. Investors have withdrawn a substantial sum of money from the U.S. stock market and moved to lower-risk assets in an effort to reduce the negative impacts of the spike in oil prices on the U.S. stock market and protect their own interests. As a result, during the war, there was some turbulence on the American stock market.

The beginning of 2020 saw the commencement of long-term increased fluctuations, according to the CWT of WTI (Figure 1) (128-256 days' frequency bands). This was a result of growing concerns about Saudi Arabia and Russia starting a price war on the oil market, as well as decreased demand as the COVID-19 pandemic devastated economic activity. The market has shifted from supply to demand concerns towards the end of the year as a result of OPEC's (Organisation of the Petroleum Exporting Countries) reluctance to respond to a recovery in demand under the new normal. Global oil prices plunged on March 23 as a result of the Suez Canal blockage, and the WTI index has since witnessed extreme volatility (days' frequency bands). The energy issue is still a problem in 2022, but the volatility of the WTI index has grown, which is consistent with the impending confrontation between Russia and Ukraine that U.S. President Bai predicted in January and the actual commencement of the conflict on February 24.

The CWT plot (Figure 1) of the temporal path of the EPU index makes it easy to spot small islands (26-36 days' frequency bands) that have seen significant volatility in the EPU index from the beginning of the sample period. This is because since the COVID-19 pandemic began, the daily reported new infections and rising fatality rates have increased dread and alarm in society. On March 11th America's \$1.9 trillion economic stimulus bill signed by Joe Biden took effect with a substantial island of high volatility during the short-term (8-30 days' frequency bands) in March 2021. The Kojima (45-48 days' frequency bands), which has medium and long-term high volatility in the EPU index in 2022, will be significantly impacted by the Russian-Ukrainian war.

The results show that the COVID-19 pandemic outbreak in the US market in 2020 resulted in significant volatility in the US stock market, WTI oil prices, and economic policy uncertainties. They would, however, endure violent turmoil once more when the COVID-19 pandemic was contained and began to stabilize in 2021 and the Russian-Ukrainian war broke out in 2022.

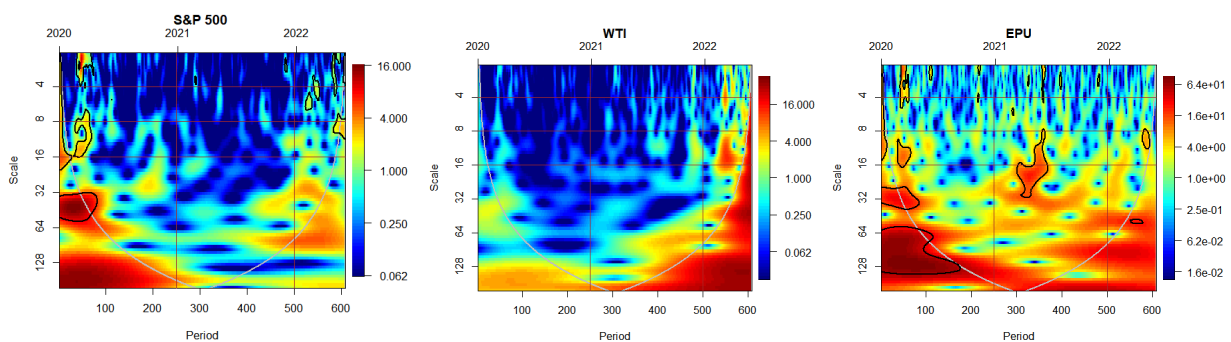


Figure 1 CWT plots for the stock market(S&P 500), Oil (WTI) and the economic policy uncertainty (EPU) in the US.

## 4.2 The wavelet coherence

Figure 2 displays the wavelet coherence plot between the S&P 500 and the EPU. The presence of small, highly dependent islands in the frequency range of 4–128 days in 2020. Additionally, the majority of the arrows are pointing up and to the right, indicating that the correlation between the S&P 500 and the EPU is relevant and significant. At the time, EPU was leading the American stock market. The COVID-19 outbreak that occurred in China and the subsequent news that reached the United States generated panic in the American population and a decline in the US stock market. Beginning in 2021, the islands' territory shrinks and they only exist in the 0–4 day frequency bands. It's because most Americans have loosened up on taking measures against pandemics and aren't paying as much attention to the COVID-19 pandemic. The island grew larger than 2021 between the beginning and the middle of 2022. Since Russia invaded Ukraine on February 24, 2022, there are several islands over the 4-8 and 64-128 days frequency bands in 2022. European sanctions against Russia have increased the price of the most basic foods, such as wheat and oil, and this has had a significant influence on economies all around the world.

The wavelet coherence plot between the S&P 500 and WTI is shown in Fig. 2. Beginning in 2020, a lengthy island exists over the frequency bands of 4–128 days, with up-right and down-right arrows. This indicates a cyclical relationship between the S&P 500 and the WTI index. There will be a few little islands in the 8–16 day frequency bands in 2021 and 2022. The right arrows indicate that there is less correlation between WTI and the S&P 500. This might be the result of investors pulling much of their money out of the stock market and moving to other fixed assets with better value preservation after the Russian-Ukrainian War broke out and the oil price soared substantially.

Figure 2 displays the wavelet coherence plot between WTI and EPU. In 2020, there are four to thirty-two day frequency bands on the small islands. The majority of the arrows point upward, indicating a positive correlation between the two variables and a considerable impact of the recent oil price on the unpredictable nature of US economic policy. EPU leading the crude oil price in 2020 Due to Saudi Arabia and Russia initiating a pricing war on March 8, 2020, oil prices decreased by 65 percent quarterly. At the start of 2021 and in the middle of 2021, there is a little island across the 4–8 day and 8–16 day frequency bands, respectively. The islands are indicated by the correct arrows. It demonstrates that their connection has not changed. World petroleum demand increased more quickly than world petroleum supply in 2021 as a result of rising COVID-19 vaccination rates, reduced pandemic-related restrictions, and an improving economy. Over the frequency bands of 0–4 days, there is a little island at the beginning of 2022. The start of the Russian-Ukrainian conflict caused sharp price swings in oil, which significantly exacerbated and reduced the uncertainties surrounding economic policy.

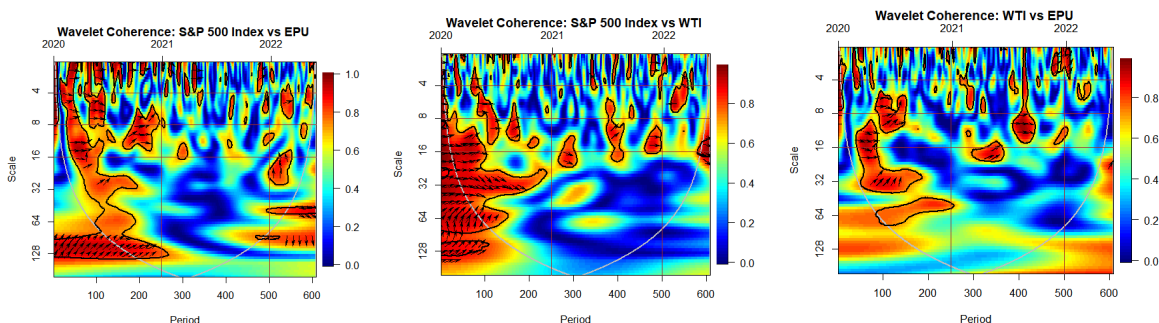


Figure 2 Wavelet coherence plots, pairwise estimates

## 5. Conclusion

The COVID-19 pandemic and the Russian-Ukrainian war have an impact on society, policymaking, and finances. In this study, we use continuous wavelet transforms and wavelet coherence to evaluate the relationships and front-lag interactions between the COVID-19 epidemic, the Russian-Ukrainian war, oil prices, EPU, and the U.S. stock market. Our wavelet analysis of the

S&P 500, WTI, and EPU data demonstrates a historically high sensitivity of the US stock market, the unpredictability of US economic policy, the beginning of the Russian-Ukrainian war, and the COVID-19 pandemic all had a substantial impact on oil prices and stock markets.

At some moment in time, there is a correlation between these three variables. During the COVID-19 epidemic and prior to the Russian-Ukrainian war, there were significant connections between the S&P 500, WTI, EPU, and S&P 500. During the COVID-19 epidemic, the correlation between WTI and EPU was not as great as that between WTI and the S&P 500. Additionally, our research explored the relationship between the COVID-19 epidemic, the Russian-Ukrainian War, oil prices, EPU, and the American stock market. It also filled a research gap on the Russian-Ukrainian War. In the future, we'll examine how the S&P 500, WTI, EPU, and other indices behaved before and during the Russian-Ukrainian crisis.

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