# The Wavelet Coherence Approach in Oil Prices, Geopolitical Risk, Stock market, and Policy Uncertainty

**Yangguang Shi[1,a,#], Rongsheng Zhang[1,b,*,#], Xuedong Song[1,c,#]**

[1]School of Mathematics and Physics, Xi'an Jiaotong-Liverpool University, 111 Ren'ai Road, HET, SIP, Suzhou, Jiangsu, China

[a]Yangguang.Shi22@student.xjtlu.edu.cn, [b]Rongsheng.Zhang22@student.xjtlu.edu.cn, [c]Xuedong.Song22@student.xjtlu.edu.cn

[#]These authors contributed equally to this work

*Corresponding author

**Keywords:** Russo-Ukrainian War, global economy, oil prices, geopolitical risk, policy uncertainty

**Abstract:** In this paper, our study sheds light on the Russia-Ukraine conflict makes a difference to 5 variables, containing the S&P 500 index, the geopolitical risk index, Russia Trading System Index, the West Texas Intermediate index, and the economic policy uncertainty index. We use the line plot to demonstrate the change in the accurate index. The results show that the conflict makes a huge difference to the economy in a large degree. Furthermore, the connection between the S&P 500 index, the geopolitical risk index, Russia Trading System Index, the West Texas Intermediate index, and the economic policy uncertainty index respectively is investigated by the study before and after the Russo-Ukrainian War, from June 20, 2021, to June 4, 2023. To achieve the goals, we apply wavelet coherence to reveal the relationship between different two variables. We conclude a closed cycle that the local safety situation will influence the development of the economy, while the economic conditions play a role in the fluctuation of the geopolitical risk index.

## 1. Introduction

It was warned on October 3, 2022, that Russia's invasion of Ukraine had caused "immense human suffering" and was hurting international trade [1]. Acta Academiae Beregsasiensis. Economics claims that since the conflict began on February 24th, the outlook for the world economy has "darkened". Additionally, experts revised down from 4.7% to 3% their forecast for the increase of merchandise trade volumes in 2022, which includes both the import and export of commodities. In addition to having a significant negative impact on Russia and Ukraine's economies, the war has also increased market volatility throughout the world.

Recent research has reported on the impacts of the war between Russia and Ukraine. Take, for instance, how the war has affected stock markets [2]. They primarily concentrate on examining the damaging consequences of the war between Russia and Ukraine on the economy. On the British stock market, the conflict's features are specifically explored as those of World War II [3]. In the meanwhile, economic swings are significantly influenced by uncertainty. Stock markets have been directly impacted by economic policy uncertainty (EPU) [4].

We examine the war's effects on the GPR, S&P 500, WTI Oil price, RTSI, and EPU. These five indices, collected between June 2021 and May 2023, were examined. Additionally, we use wavelet coherency analysis to calculate the causation and dependency between each pair of pairings. In addition, for comparison's sake, we plot the times series trends of the GPR, S&P 500, WTI Oil price, RTSI, and EPU in the sample period. We want to distinguish between the aspects of the Russia-Ukraine crisis, which is now having major effects on the world economy, through these tests.

The rest of this essay is structured as follows. A review of the literature is described in Section 2. The approach and wavelet coherence analysis are presented in Section 3. Finally, Section 4 offers final observations.

## 2. Literature Review

We evaluate the relevant research, focusing on the Russo-Ukrainian War's financial and economic effects, from the three perspectives listed below: The Russo-Ukrainian War's financial effects, the conflict's effects on the economy's stability, and the wavelet coherence method are all mentioned. These studies focus on the first features. A worldwide multi-regional, multi-sector computable general equilibrium model, for instance, was used by [5] to study the effects of the energy disruption following the outbreak of the conflict. They discover that the battle causes the economies of these two nations to appear to contract, and the standard of living starts to drop. They also demonstrate how the growing costs of natural gas and refined oil have a substantial impact on the nations of the European Union. Additionally, [6] examined the influence of the Russo-Ukrainian War on the financial market using the ratio of import value between Russia and the rest of the globe. They also discover that the fighting had a considerable impact on the stock market, with steep declines in stock returns. According to [7], the war has a substantial influence on the world market, enhancing the risk of investment return and resulting in short-term losses for investors.

Regarding the economic uncertainty brought on by the conflict, [8] uses EPU, or economic policy uncertainty, to measure the index and applies a time series mixed-frequency forecasting model to examine the relationship between the economic situation and EPU. Through tracking changes in the dynamics of economic activity (GDP), they discover that the war causes the EPU index to rise, worsening the Russian economy.

Based on a wavelet coherence method, [9] uses this strategy to look at the correlation between crude oil prices and the Eurostoxx, RTSI, S&P 500, RUB/USD, and EUR/USD currency rates. Additionally, they discover a connection between RTSI and crude oil. Furthermore, [10] demonstrates how the Russo-Ukrainian War contributed to increasing the danger of Bitcoin's return and making investing more challenging. According to [11], the conflict slows the expansion of the economy and raises the danger of global financial growth.

The financial effects after the start of the Russo-Ukrainian War are the focus of this research assessment. The economic uncertainty brought on by the conflict is then described in this section. Finally, the remaining part displays the association between several war-representative indices.

## 3. Empirical methodology and data

### 3.1. The wavelet coherence (WC)

By considering the commonly used approach, i.e., wavelet coherence, independent of the time series, it is possible to study the connections between the S&P 500 index, geopolitical risk (GPR) index, RTSI index, economic policy uncertainty (EPU), and WTI oil prices via time scales. Practically, the cross wavelet transform (CWT) is explained. According to [12], the cross-wavelet transform can be explained by the two-time sequences a (t) and b (t) as follows:

$$N_{ab}(p,q) = N_a(p,q)N_b^*(p,q) \tag{1}$$

where p represents the location index and q represents the measure, respectively, and (*) illustrates the composite conjugate. These two continuous transformations of a (t) and b (t) are illustrated by Na (p, q) and Nb (p, q). The wavelet power of | Na (p, q) | may be determined by applying the cross wavelet transform. When contrasted with the time series under investigation, the cross-wavelet power spectra distinguish the region where a significant energy concentration (cumulus of the constrained variance) is seen. The co-movement patterns of the time series under observation might experience unexpected and significant fluctuations in some locations in the time-frequency domain, which can be identified using the wavelet coherence method (WCT). According to [13], the equation for the coefficient of adjusted wavelet coherence is as follows:

$$W^2(p,q) = \frac{\left|M(M^{-1}Nab(p,q)\right|^2}{M(M^{-1}|N_a(p,q)|^2)\, M(M^{-1}|N_b(p,q)|^2)} \tag{2}$$

The smoothing mechanism is called M. The wavelet squared coherence has a value between 0 and

1 ($0 \leq W^2(p,q) \leq 1$) .The squared wavelet coherence coefficient's range reveals the strength of the association. In fact, when this coefficient is near 0, it shows that there is no correlation (i.e., there is no co-movement), and when it is close to 1, it suggests that there is a larger correlation (i.e., there is more co-movement), which is what is known as the scale-specific squared correlation between series. The fictitious wavelet coherence allocation is examined using the Monte Carlo approach. This method avoids the problem of the squared coherence being unable to discern the positive and negative correlations between two series, allowing us to evaluate the lead/lag relationship between two series.

We calculated and compared each pair of variables' co-movement. The arrows on the graphs indicate the relative phasing of the two series, which represent the approximated wavelet coherence approach. The red/warm colored zone is the one with a significant correlation, while the blue/cold colored area shows regions with weak correlations. The black outline of the estimated plots denotes the 5% significance level. According to [13], and others, the direction of arrows indicates the direction of interdependence and causation links. The two variables are positively associated when the arrow points to the right, and negatively correlated when it points to the left. The first variable leads the second according to the up-right and down-left (↗↙) arrows, whereas the second variable leads the first according to the up-right and up-left (↘↖) ) arrows. The variables are suggested to be leading and trailing, respectively, by the up (↑) and down (↓) arrows.

### 3.2. Data and line chart

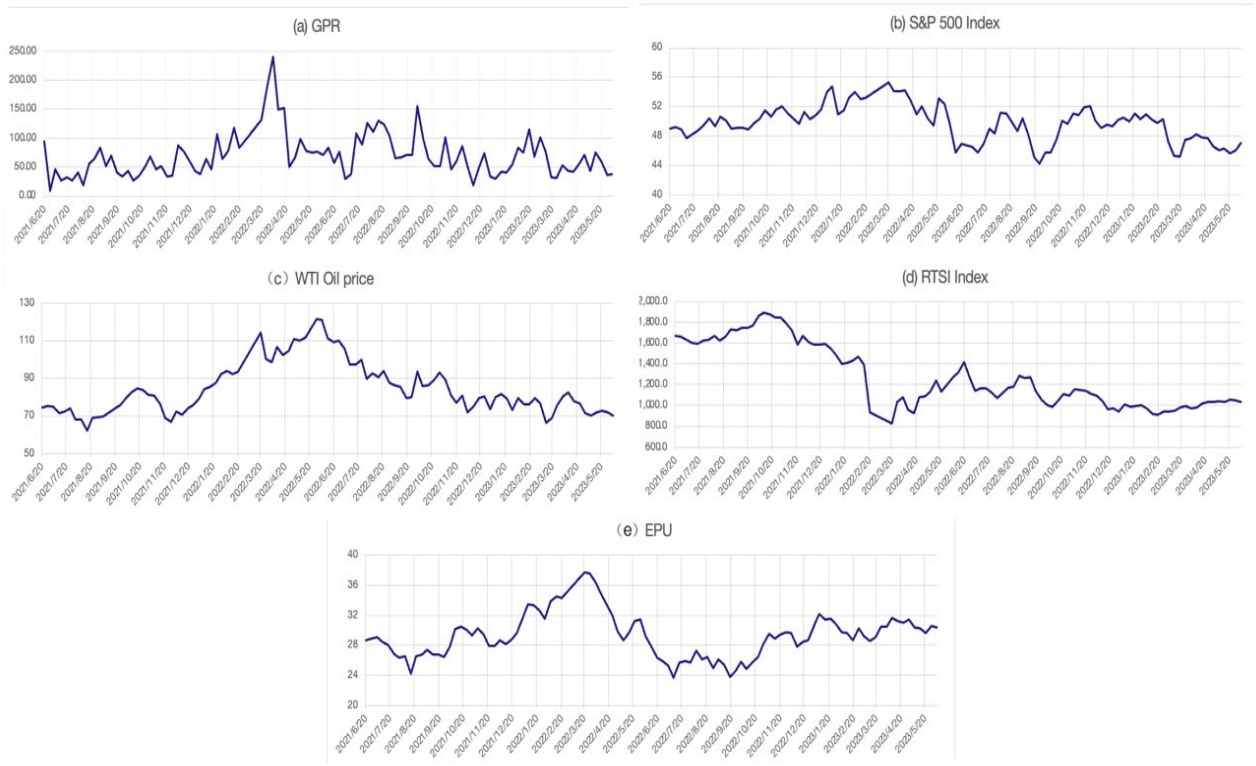


Figure 1. Time series trend of GPR, S&P 500, WTI Oil price, RTSI and EPU.

In Fig. 1a, we report the time paths of GPR. We can find that values fluctuated around 50 before the war and a sharp rise in value happened within a short period time because of the outbreak of war. The highest value reached 250. It shows that the world is at great geopolitical risk. The average value increased, and the instantaneous values are influenced by events during the war. As for Fig. 1b, we can find the stock market has seen several significant swings after the war began. According to Fig. 1c, the WTI Oil price has shown a sustained increase due to the outbreak of war. Undoubtedly, volatility in global financial markets and disruption of world trade exchanges seem to be the irresistible drivers of oil prices. The major concern is that oil markets may be shocked through OPEC+ alliance negotiations led by oil mega-producers or any other arrangements. One of the parties to the war, Russia, is not a member but is closely linked to APEC due to its large oil production and reserves.

The Russian stock market was hit hard by the war and has not recovered since we can find from the result of Fig. 1d. In Fig. 1e the index continued to move higher before the outbreak of war and levelled off as the war progressed. It also stays at a high level during the war.

## 4. Empirical results and discussion

Fig. 2 displays the wavelet coherence plots for each pair of variables to examine the interactions between those variables. The wavelet coherence between GPR and S&P 500 infected instances is presented in Fig. 2a. At the beginning over the 18–24 frequency bands and end over the 6–12 frequency bands, we can find a significant portion with a high degree of dependency. The arrow's primary direction is upward, indicating that the economy carries most of the risk. In terms of the relationship between the S&P 500 and oil (Fig. 2b), we can see a large red island with a high degree of dependency. Long before the start of the conflict and during the early stages of the war, two factors had a high correlation. The frequency bands for 4 to 8 weeks also show the red islands. They appear to be impacted by the shifting state of conflict. Additionally, most of the arrows are pointing right, indicating that there is an anticyclical relationship between OIL and S&P 500, with OIL leading. Fig. 2c displays the S&P 500-EPU connectivity over timeframes and frequencies. The strong coherency islands that have been seen during all wartime times are those with a greater frequency, indicating that they have profound long-term repercussions. At the start of the conflict, the arrows are pointing right and downward, indicating that S&P 500 swings affect EPU. The wavelet coherence plot between the S&P 500 and RTSI is displayed in Fig. 2d. Strong coherency islands that were discovered around the middle and end of the time correspond to higher frequencies, indicating that they had major short-term effects following the start of the conflict. At the start of the conflict, the arrows are pointed down and to the left, indicating that the S&P 500 is what influences RTSI swings.

Fig. 2e reports the wavelet coherence between the EPU and GPR. Additionally, it reveals some regions where association is strong. Because the arrow's orientation goes to the left, we notice a short-term negative coherence near the conclusion of the plot. While the direction of the arrow over the short term usually goes to the up-left, leading to the EPU, there is an island over the mid-term frequency bands where the direction of the arrow tends to the up-right, in contradiction to the direction mentioned above. Fig. 2f shows the relationship between OIL and RTSI. The visual inspection of the wavelet shows a huge red island of high dependence over 4-8 weeks' frequency bands. Two variables were strongly correlated at the beginning and the middle of the war. They seem to be affected by the fluctuating levels of war. Furthermore, arrows are mostly turned left up which means that there is an anticyclic effect between OIL and RTSI where RTSI is leading. In Fig. 2g, we find the existence of the small islands which represent the high degrees of the co-movement over the short-term frequency bands. Over the 0-4 scale bands, there exists a strong dependence between EPU and RTSI at the beginning of the Russo-Ukrainian War. The plot also displays a large part of the area which shows the high degree of dependence between two indexes over the 24-35 frequency bands from the beginning of the war to the middle period. The direction of the arrows is down-right, which means that the uncertainty and Russia's economy are negatively correlated, while up-right which means that the uncertainty and Russia's economy are positively correlated.

The wavelet plot between the OIL price and geopolitical risk is presented in Fig. 2h. In the long-term frequency band, a red island existed before the war and the arrows over it are turned down. We can speculate Oil prices and GPR are long-term correlated and oil price changes lag behind GPR. Another red island in the short-term frequency band appeared during the war. Arrows over it turn up and right which means geopolitical risks exacerbated by changes in oil prices. The connectedness between EPU and OIL in Fig. 2i shows a huge red island of high dependence throughout the whole war. The arrows are turned right up at the beginning of the war which means that OIL leads EPU. And the arrows are turned right down in the middle and end of the war which means that EPU.

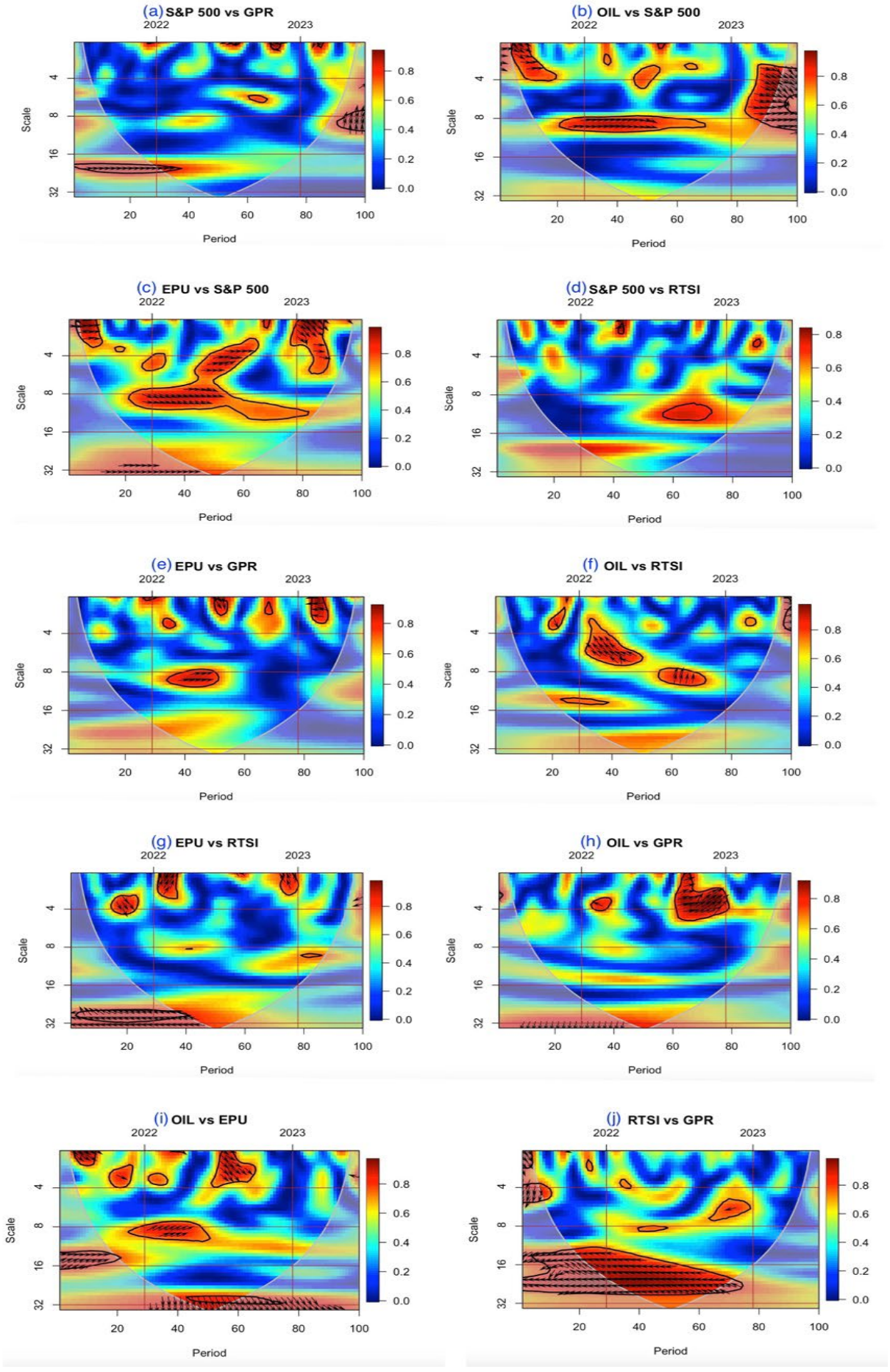


Figure 2. Wavelet coherence plots.

The wavelet plot between the OIL price and geopolitical risk is presented in Fig. 2h. In the long-term frequency band, a red island is existed before the war and the arrows over it are turned down. We can speculate Oil prices and GPR are long-term correlated and oil price changes lag behind GPR. Another red island in the short-term frequency band appeared during the war. Arrows over it turn up and right which means geopolitical risks exacerbated by changes in oil prices. The connectedness between EPU and OIL in Fig. 2i shows a huge red island of high dependence throughout the whole war. The arrows are turned right up at the beginning of the war which means that OIL leads EPU. And the arrows are turned right down in the middle and end of the war which means that EPU leads OIL. The picture in the end (Fig. 2j) shows the wavelet coherence between RTSI and GPR. We identify the huge red island of high dependence over the 16-week frequency band. Two variables were strongly correlated long before the outbreak of war and early in the war. The red islands also appear over 4-8 weeks' frequency bands. They seem to be affected by the fluctuating levels of war. Furthermore, arrows are mostly turned down and left which means that there is an anticyclic effect between RTSI and GPR where RTSI is leading.

## 5. Conclusion

Our research thus gains the following results, which form a closed cycle, through using wavelet coherence. First, the conflict between Russia and Ukraine exacerbates local instability, leading to the GPR index increasing. In addition, this fact contributes to increasing uncertainty, making the world stock market fluctuate further. Second, the fluctuation in the world stock market (S&P 500) makes a difference in oil prices directly and indirectly by influencing Russia's trade. Finally, any changes in the aspects described above will worsen the international surroundings and increase the geopolitical risk index, making people's lives at risk.

First and foremost, our study sheds light on Russia-Ukraine conflict makes a difference to 5 variables, containing the S&P 500 index, the geopolitical risk index, Russia Trading System Index, the West Texas Intermediate index, and the economic policy uncertainty index. We use the line plot to demonstrate the change in the accurate index. The results show that the conflict makes a huge difference to the economy in a large degree. Furthermore, the connection between the S&P 500 index, the geopolitical risk index, Russia Trading System Index, the West Texas Intermediate index, and the economic policy uncertainty index respectively is investigated by the study before and after the Russo-Ukrainian War, from June 20, 2021, to June 4, 2023. To achieve the goals, we apply wavelet coherence to reveal the relationship between different two variables. We conclude a closed cycle that the local safety situation will influence the development of the economy, while the economic conditions play a role in the fluctuation of the geopolitical risk index.

## References

[1] Сінгх, М. К., Саркозі, Х., Сінгх, С. К., & Земан, З. (2022). Impact of Ukraine-Russia war on global trade and development: an empirical study. Acta Academiae Beregsasiensis. Economics, 1(1) , 80-92.

[2] Boungou, W., & Yatié, A. (2022). The impact of the Ukraine–Russia war on world stock market returns. Economics Letters, 215, 110516.

[3] Hudson, R., & Urquhart, A. (2015). War and stock markets: The effect of World War Two on the British stock market. International Review of Financial Analysis, 40, 166-177.

[4] Hudecová, K., & Rajčániová, M. (2023). The impact of geopolitical risk on agricultural commodity prices. Agricultural Economics/Zemedelska Ekonomika, 69(4).

[5] Cui, L., Yue, S., Nghiem, X. H., & Duan, M. (2023). Exploring the risk and economic vulnerability of global energy supply chain interruption in the context of Russo-Ukrainian war. Resources Policy, 81, 103373.

[6] Lo, G. D., Marcelin, I., Bassène, T., & Sène, B. (2022). The Russo-Ukrainian war and financial

markets: the role of dependence on Russian commodities. Finance Research Letters, 50, 103194.

[7] Karabag, S. F., & Imre, Ö. (2022). The Global, Regional, National, Sectoral, Economic, and Commercial Impact of the Russo-Ukrainian War and the Emerging Second Cold War. Journal of Applied Economics and Business Research, 12(1), 58-70.

[8] Diakonova, M., Ghirelli, C., Molina, L., & Pérez, J. J. (2023). The economic impact of conflict-related and policy uncertainty shocks: The case of Russia. International Economics, 174, 69-90.

[9] Basdekis, C., Christopoulos, A., Katsampoxakis, I., & Nastas, V. (2022). The impact of the Ukrainian war on stock and energy markets: A wavelet coherence analysis. Energies, 15(21), 8174.

[10] Xu, L., & Kinkyo, T. (2023). Hedging effectiveness of bitcoin and gold: Evidence from G7 stock markets. Journal of International Financial Markets, Institutions and Money, 85, 101764.

[11] Santorsola, M., Caferra, R., & Morone, A. (2022). The financial repercussions of military escalation. Physica A: Statistical Mechanics and its Applications, 603, 127791.

[12] Torrence, C., & Compo, G. P. (1998). A practical guide to wavelet analysis. Bulletin of the American Meteorological society, 79(1), 61-78.

[13] Torrence, C., & Webster, P. J. (1998). The annual cycle of persistence in the El Niño/ Southern Oscillation. Quarterly Journal of the Royal Meteorological Society, 124(550), 1985–2004. https://doi.org/10.1002/qj.49712455010 Wiley.