The impact of the war in Ukraine on globalization processes and world financial markets: a wavelet entropy analysis*

Hanna B. Danylchuk[1], Liubov O. Kibalnyk[1], Oksana A. Kovtun[2], Oleg I. Pursky[3], Yevhenii M. Kyryliuk[1] and Olena O. Kravchenko[1]

[1]The Bohdan Khmelnytsky National University of Cherkasy, 81 Shevchenko Blvd., Cherkasy, 18031, Ukraine
[2]University of Educational Management, 52A Sichovykh Striltsiv Str., Kyiv, 04053, Ukraine
[3]State University of Trade and Economics, 9 Kyoto Str., 02156, Kyiv, Ukraine

Abstract

This paper is an applied research that aims to model and analyze how the war in Ukraine influenced the globalization processes and the world financial markets. This topic is relevant but underexplored in the literature. We used the wavelet entropy method to build models for the markets of natural gas, oil, gasoline, and currency pairs EUR/USD, GBP/USD. Wavelet entropy is a measure of complexity and uncertainty of unsteady signals or systems in both time and frequency domains. Our results show that the war in Ukraine was a source of crises in the studied markets and a factor that reshaped the world economic space.

Keywords

globalization processes, global financial markets, oil market, natural gas market, currency markets, crisis impact, wavelet entropy, war in Ukraine

1. Introduction

The turn of the 20th and 21st centuries has witnessed intensified scholarly interest in the challenges posed by globalization processes amid various crisis phenomena, fostering theoretical and methodological explorations in forecasting, analysis, and modeling. The trajectory of globalization theories, transitioning from Keynesian paradigms to neoliberal constructs throughout the 20th century, has underpinned the establishment of the post-industrial economy. The prevalence of contemporary crises—ranging from warfare and the COVID-19 pandemic to the quest for national self-determination, hunger, income disparities, and ecological, energy,

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abdanilchuk@gmail.com (H. B. Danylchuk); liubovkibalnyk@gmail.com (L. O. Kibalnyk); kovtun.oa71@gmail.com (O. A. Kovtun); Pursky_O@ukr.net (O. I. Pursky); en_kirilyk@ukr.net (Y. M. Kyryliuk); olena_kravchenko17@ukr.net (O. O. Kravchenko)
0000-0002-9909-2165 (H. B. Danylchuk); 0000-0001-7659-5627 (L. O. Kibalnyk); 0000-0002-0159-730X (O. A. Kovtun); 0000-0002-1230-0305 (O. I. Pursky); 0000-0001-7097-444X (Y. M. Kyryliuk); 0000-0002-8776-4462 (O. O. Kravchenko)

raw material, food, and demographic quandaries—attests to the state of crisis confronting the modern world.

These multifaceted predicaments have prompted conjectures that 21st-century economic growth will persist but chart novel directions, characterized by qualitative shifts in services, digitization, and transformations in scientific and technological progress. The currents of globalization are manifest in trends such as the division of world markets into core and peripheral domains, spawning divergent interests between hegemonic and peripheral nations. The consolidation of national economies and societies within robust regional frameworks, the ebb and flow of income polarization tied to increased productivity, swift capital mobility, financial elite-driven speculation, and the paradoxical dynamics between the virtual and real economic sectors typify globalization's canvas. Furthermore, the imperative to coalesce against terrorism and global crises compounds these intricate trends.

Maurice Allais, the renowned French economist and Nobel laureate, contemplated the comprehensive globalization of trade between nations with disparate wage levels. He envisioned an outcome marked by unemployment, declining economic growth, inequality, and poverty—a perspective that stirs questions concerning globalization's necessity and desirability [2].

This dichotomous nature of globalization, yielding both positive and adverse repercussions for the world economy, is exemplified in the erosion of sovereign, economic, political, and energy independence among nations. The ripples of financial crises travel swiftly across regions, exerting significant influence on dependent economies, amplified by political, food, and energy upheavals. The ongoing war in Ukraine, coupled with the concomitant blockade of its seaports, has underscored the vulnerability of grain-importing nations to potential food crises [3]. Concurrently, the surge in forced migration and escalating unemployment further underscores globalization's complex fallout.

Today, financial and investment spheres exemplify the zenith of globalization. Financial flows cascade through the global economy, primarily via financial markets—largely detached from tangible goods and services markets. This intricate interplay intermittently begets financial crises, eroding financial systems, and culminating in socio-economic, demographic, and financial instabilities. The ripples of regional financial crises [4], the resounding echo of the global COVID-19 crisis [5], and the recurring turmoil in markets like the USA and China illuminate this reality.

The military-industrial complex's upswing following the 9/11 attacks, propelled by NATO-led wars in Afghanistan and Iraq, demonstrates the interdependence between war, crises, and economic dynamics. The ongoing war in Ukraine, coupled with military assistance, has spurred heightened production within the military-industrial complexes of the US and specific European countries. The associated demand for financial investment reverberates in global and regional financial markets. Thus, the salience of this research topic is evident, demanding a comprehensive toolkit to decipher evolving trends within the globalized financial system, particularly financial markets.

In this context, the analysis and modeling of globalization processes during crisis phases, with ramifications for financial market states and trajectories, assumes paramount importance. A substantial body of work, from both domestic and international scholars, attends to this scientific challenge. For instance, the bankruptcy rates of Turkish banking institutions vis-à-vis the deep-rooted financial crisis were examined using diverse performance indicators via

stochastic methods, such as frontier analysis and data coverage analysis [6].

The European sovereign debt crisis prompted statistical examinations of financial relationships to model bond market yield movements [7]. This elucidated long-term and short-term contagion effects, particularly pronounced in peripheral countries after the crisis's acute phase. Many investigations have delved into modeling the yield, volatility, and risk profiles of diverse financial instruments within financial markets, employing an array of methodologies.

Cross-quantile analyses explored the intricate relationships between developed and emerging market stock returns, unveiling nuanced time-varying characteristics [8]. The dynamics of illiquidity within developed stock markets during and post the global financial crisis were modeled using a multiplicative error model, revealing pronounced interdependencies in volatility and illiquidity, especially during crises [9]. GARCH models unraveled the far-reaching impact of COVID-19 on the precious metals market, exposing its long memory effect [10].

The high-dimensional conditional Value-at-Risk (CoVaR), which is based on the LASSO-VAR model, is used to study the systemic risks of financial contagion in crisis situations using the example of oil markets and G20 stock markets [11]. The authors proved that in the event of a crisis in the oil markets, the stock markets of those countries that are connected with oil production will experience the greatest shocks.

Changes in the environment and depletion of natural resources have led to investment in renewable energy sources, and therefore to the need to analyze herd (collective) behavior in this market [12]. In the article, the authors presented the results of testing the collective behavior of the renewable energy market using an empirical model during the periods of the global financial crisis and the coronavirus crisis. The authors proved the herd behavior of market participants during periods of crises in the oil markets. As a result, there is an invigoration of collective behavior in the stock markets as well. Attention is also paid to the study of contagion and the emergence of risks from fossil fuel energy markets to renewable energy stock markets.

The burgeoning interest in monitoring, modeling, and forecasting financial markets during crisis episodes has propelled the adoption of nonlinear dynamics tools. Fractal and entropy analyses uncovered trends in the cryptocurrency market [13] during the COVID-19 pandemic, serving as effective crisis identifiers [14]. Quantum models, exemplified by the heterogeneous economic model, offered insights into the flow and aftermath of various crises, thereby enriching comparisons.

The articles [15, 16] are devoted to the identification of special conditions in the cryptocurrency market. The authors classified and adapted quantitative indicators to this market, analyzed their behavior in the conditions of critical events and well-known cryptocurrency market crashes.

Danylchuk et al. [17] use entropy methods to determine the investment attractiveness of countries. For this purpose, regional stock markets are studied, as they are a reflection of the economies of countries.

Quantum modeling, namely the heterogeneous economic model, has been applied to stock markets [18]. With the help of "measurement of the temperature of the series" crisis periods in the markets were detected. This model made it possible to adequately compare the features of the flow and consequences of various crises.

Modeling the impact of geopolitical risks on the state and dynamics of financial markets under conditions of crises of various natures is a little-researched field. This issue becomes

especially relevant in the context of the creation of political and economic alliances and recent political crises. Choi [19] presents the results of using the method of multiple and partial wavelet-coherent analysis regarding the influence of geopolitical problems on stock markets in the countries of Northeast Asia.

Abdel-Latif and El-Gamal [20] investigate the global dynamic interrelationship between the prices of petroleum products, oil, financial liquidity, geopolitical risk and economic indicators of the economies of countries dependent on oil exports. For this purpose, the authors use the global vector autoregression (GVAR) model.

The full-fledged war in Ukraine has spurred inquiries into its financial market implications. Empirical evidence substantiates the war's deleterious impact on global stock market profitability, significantly affecting markets in geographically proximate countries, as well as those denouncing the war. Boungou and Yatié [21] provide empirical evidence of the negative impact of the war in Ukraine on the profitability of the global stock market. The largest decrease in the indicator was demonstrated by the markets of those countries geographically bordering Ukraine and Russia, as well as countries that condemned the war.

The war's influence on financial markets, particularly concerning countries reliant on Russian goods, is also studied [22]. Results indicate increased instability across markets, proportionate to a country's dependence on Russian goods.

The extent of globalization's influence on financial markets during crises remains a subject necessitating thorough investigation. While globalized markets appear more vulnerable, the reactions of US and Asian markets vary [23].

The study of modern crises—political, social, military, and pandemic—has engendered shifts in globalization patterns within financial markets, warranting a rigorous exploration. Classical analytical methods, however, often fall short in fully assessing and predicting these intricate dynamics. Consequently, the exigency of a comprehensive, interdisciplinary approach is evident in addressing this complex scientific endeavor.

2. Research methods

In this study, the wavelet entropy method is used to model and analyze the impact of the war in Ukraine on globalization processes using the example of the gas, oil, petroleum products, and currency markets. The method of wavelet transformations is proposed for the analysis of periods in time series with the aim of detecting the evolution of parameters [24]. Wavelet analysis based on wavelet entropy allows obtaining information about dynamic complexity [25].

We can describe wavelet entropy based on the work of Zunino et al. [26]. When studying the time series, which consists of sample values x_i, $i = 1, ..., M$, when using a set of scales $1, ..., N$, we will get a wavelet transformation (expansion)

$$X(t) = \sum_{j=1}^{N} \sum_{k} C_j \psi_{j,k}(t) = \sum_{j=1}^{N} r_j(t), \tag{1}$$

$r_j(t)$ contains information about the series X in scale 2^{j-1} and 2^j.

Application of the theory of Fourier expansions allows us to determine the energy on each scale using

$$E_j = ||r_j||^2 = \sum_k |C_j(k)|^2. \tag{2}$$

The total energy of the series can be calculated by

$$E_{tot} = ||X||^2 = \sum_{j=1}^{N} \sum_k |C_j(k)|^2 = \sum_{j=1}^{N} E_j. \tag{3}$$

The next step is to determine the relative wavelet energy

$$p_j = \frac{E_j}{E_{tot}}, \tag{4}$$

which provides hidden characteristics of the series in time and frequency spaces.

Using the concept of Shannon entropy, we can determine the normalized total wavelet entropy

$$E_{WT} = \frac{-\sum_{j=1}^{N} p_j \ln p_j}{X_{max}}. \tag{5}$$

The improvement of the wavelet entropy calculation algorithm was the use of a window procedure [27]. The following formula is used to calculate the wavelet energy for a time window

$$E_j^{(i)} = \sum_{k=(i-1)L+1}^{i\cdot} |C_j(k)|^2, i = 1, ..., N_T. \tag{6}$$

The total energy in the window is calculated by

$$E_{tot}^{(i)} = \sum_{j=-N}^{-1} E_j^{(i)}. \tag{7}$$

The change in time of relative wavelet energy and normalized total wavelet entropy is obtained by

$$p_j^{(i)} = \frac{E_j^{(i)}}{E_{tot}^{(i)}}, E_{WT}^{(i)} \sum_{j=-N}^{-1} p_j^{(i)} \cdot \frac{\ln p_j^{(i)}}{X_{max}}. \tag{8}$$

3. Results and discussions

Oil is considered to be the benchmark of world economic activity. The price of crude oil reflects such market properties as stability/volatility and liquidity.

The article examines the oil, gas and gasoline market. The most popular grades of oil are Brent and West Texas Intermediate (WTI). For this purpose, daily values of Brent and WTI brand oil indices, natural gas and gasoline for the period from January 2015 to September 2022 were used. All calculations were performed in Matlab. Calculation parameters: window width

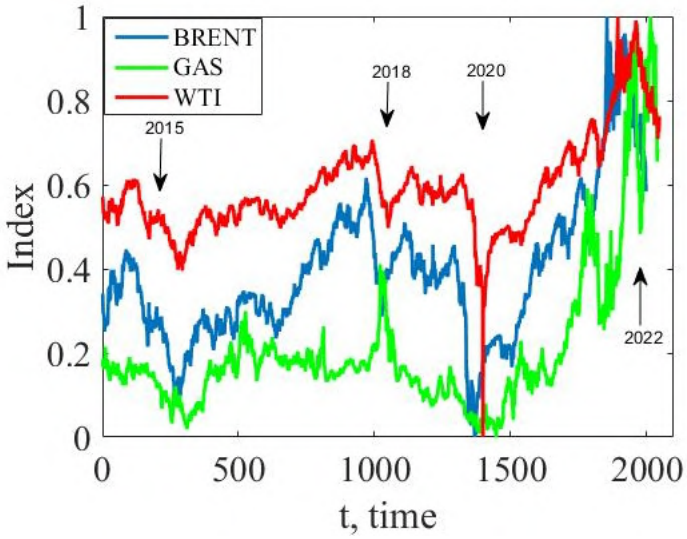

Figure 1: Comparative dynamics of oil (Brent and WTI) and gas indices.

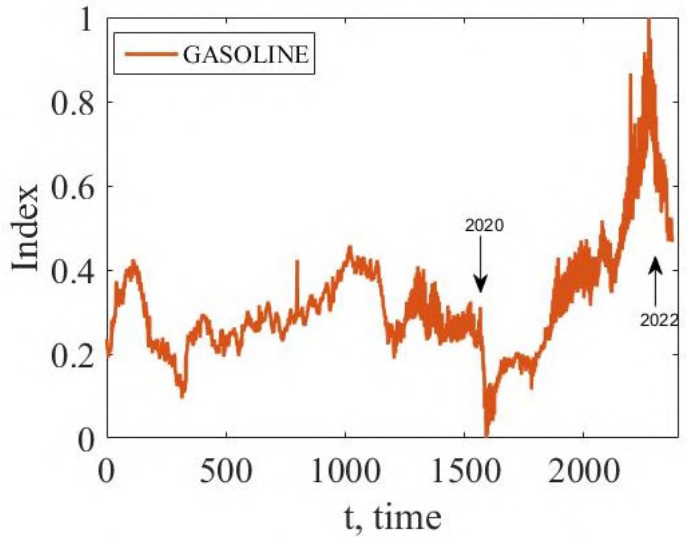

Figure 2: Dynamics of the gasoline index.

100 points, step – 10 points. Calculations were made according to the official website Yahoo Finance [28].

In figures 1, 2 shows the dynamics of indices. Arrows indicate the periods of 2020 (the beginning of the coronavirus pandemic) and 2022 (the beginning of the war in Ukraine).

From figures 1, 2 we can note 2020 a drop in oil and gasoline indices. And in 2022, all indices experienced a rapid decline. The situation regarding 2020 is quite obvious and understandable. The announcement of the pandemic halted and slowed down economic activity. Demand for oil

and gasoline fell.

The fall in 2022 is due to various factors, but in our opinion, the war in Ukraine should be considered the main one. Although the events unfold on the territory of Ukraine, the consequences are felt by almost all countries. European Union countries, Great Britain, the USA, Turkey, etc. support Ukraine not only with military aid, but also with the introduction of political and economic sanctions. Russia was a strong player in the oil and gas markets. The introduction of sanctions, the refusal of Russian gas forces the market and all market participants to quickly reorient themselves and reformat connections (e.g. increasing oil production in Norway, expected deliveries from Nigeria and Venezuela).

The use of wavelet entropy is due to the illustrative nature of this indicator and its predictive properties. The formation of three increasing entropy wavelet waves is a proven indicator-precursor of crisis phenomena of various natures [29]. As soon as the third wave exceeded the maximum of the second wave, it can be argued that the market is waiting for a crisis ahead. The maximum of the third wave is a crisis itself. Therefore, the use of such an indicator allows for predicting a crisis and having time to take measures that can mitigate the consequences of the crisis. In addition, the wavelet transform provides a time-frequency representation of the signal, which allows you to obtain additional information that is not reflected in the time representation of the signal.

In figures 3–10 shows the results of wavelet entropy calculation for the gas, oil, and gasoline markets.

Analysis of the energy surface of the wavelet coefficients (figure 3) allows us to draw conclusions about the crisis situation in the gas market. On a small scale, there is a manifestation of disturbance. In wavelet analysis, small scales correspond to high frequencies.

Figure 4 shows the dynamics of wavelet entropy. We observe the formation of three waves in a neighborhood of 1750-2000 points, which is an indicator of the crisis. This crisis is the

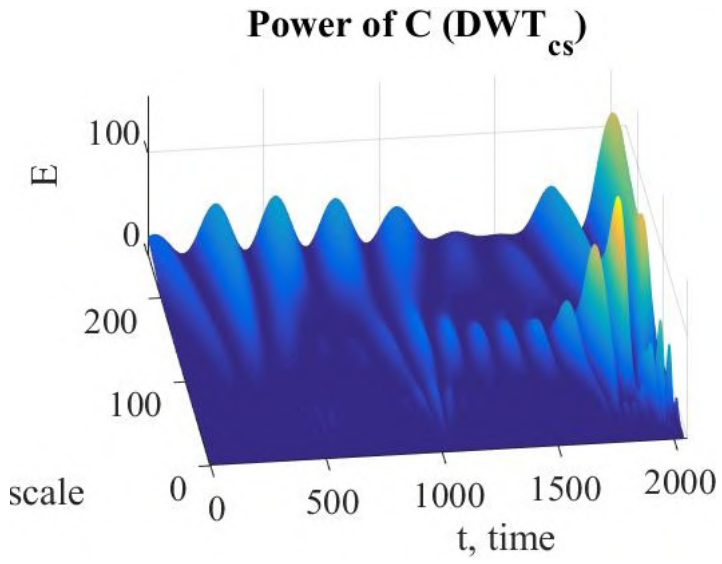

Figure 3: Wavelet coefficient energy for gas index.

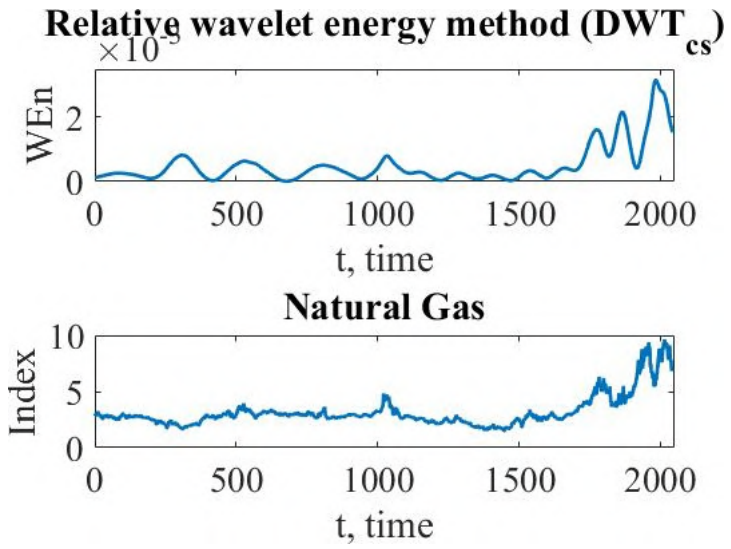

Figure 4: Wavelet entropy and dynamics of the gas index.

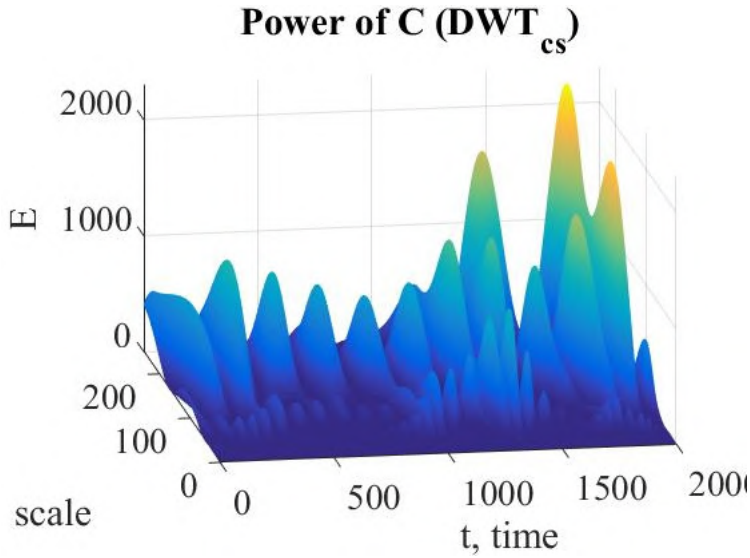

Figure 5: Wavelet coefficient energy for oil Brent index.

market's reaction to Russia's refusal to supply natural gas to Europe and the introduction of sanctions.

In figures 5, 6 shows the results of calculations for Brent oil, and figures 7, 8 – for WTI oil.

The energy of the wavelet coefficients shows a different situation for these two oil brands. This can be explained by the fact that Brent oil is traded on the markets of Europe and Asia, while WTI oil is traded on the US markets. But for the current time, the situation for these two brands of oil is similar. We see the formation of stable three waves, which indicates a

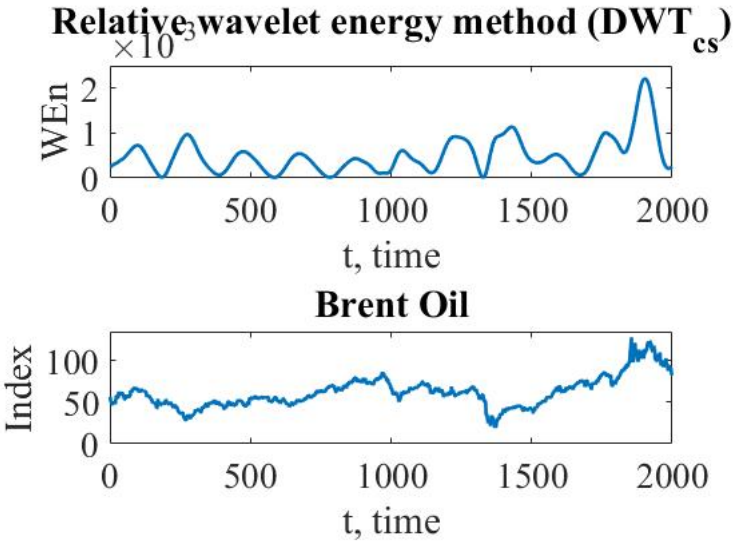

Figure 6: Wavelet entropy and dynamics of the oil Brent index.

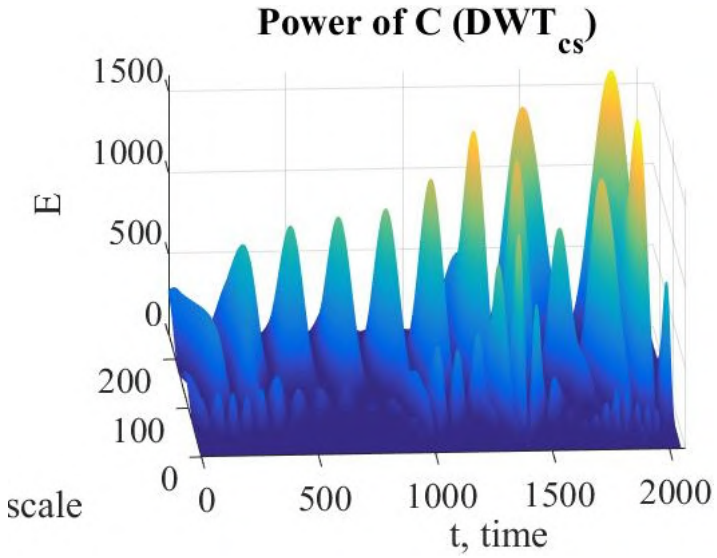

Figure 7: Wavelet coefficient energy for oil WTI index.

crisis. What is happening in the oil market? It can be seen that the price of Brent and WTI oil benchmarks continue to fall. In our opinion, this is related to the war in Ukraine and the risk of recession. The European Union in the eighth package of anti-Russian sanctions "included a ceiling" on oil prices. In addition, the EU plans to ban sea imports of crude and refined oil from Russia. In response to the EU sanctions, Russia decided to reduce oil production by 3 million barrels per day, arguing that this is a lever to increase oil prices on the market. For

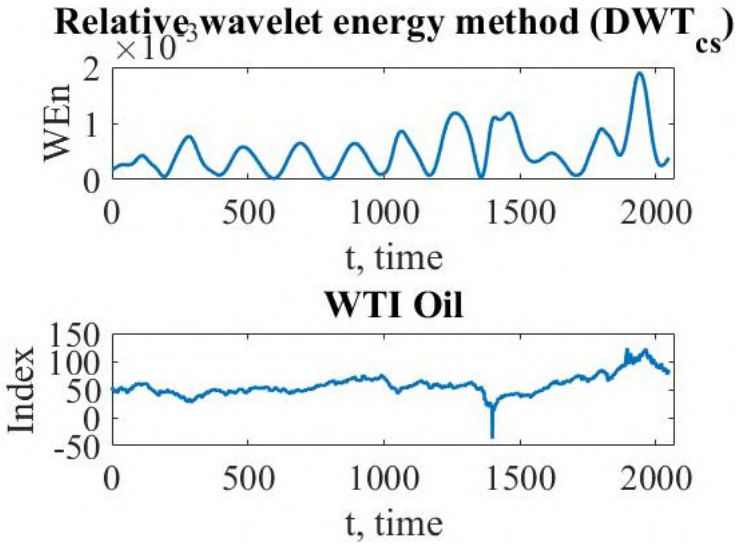

Figure 8: Wavelet entropy and dynamics of the oil WTI index.

Russia, the imposition of sanctions is a blow, as this is a budget-forming article (about 40% of budget revenues are in the form of taxes on hydrocarbon exports, and direct and indirect revenues related to this export make up to 60%). That is, the consequence of the introduction of sanctions will be a reduction in revenues from oil and gas. That is, it is precisely in this sector that Russia's "Achilles' heel" is, but the refusal of Saudi Arabia and other large Middle Eastern players to replace the Russian share of the oil market leads to fluctuations in its price, which in some way neutralizes the measures of the EU and the US countries regarding the oil embargo against Russia. They are trying to regulate the oil market. Thus, OPEC+'s decision is to reduce oil production by 2 million barrels per day, which should lead to an increase in oil prices. However, such a decision by OPEC+ has a reverse side. In particular, the United States began selling oil from reserves.

So, according to the results of the calculations, it can be stated that the oil and gas market is in a state of crisis, which was formed as a result of the war in Ukraine and the efforts of the main players to carry out its transformation, blocking Russia and reducing its influence on the world market. One such move by the global anti-Putin coalition (producing countries account for 60% of global GDP) is the declared creation of a buyers' cartel that has set a "price ceiling" for Russian oil and oil products. Even if India and China do not join the "price ceiling", the path of Russian oil to the world market will be difficult in December 2022, as the EU, Switzerland and Great Britain will not only ban their factories and traders from buying it, but will also introduce sanctions on insurance, financing and ship freight, which will lead to the need for Russia not only to look for new sales markets, but also to build alternative supply chains to the world market from scratch.

In figures 9, 10 shows calculations for the gasoline market. Gasoline is a derivative of oil. Therefore, the behavior of the gasoline market should be similar to the behavior of the oil market. If oil becomes cheaper, then the price of gasoline should also fall.

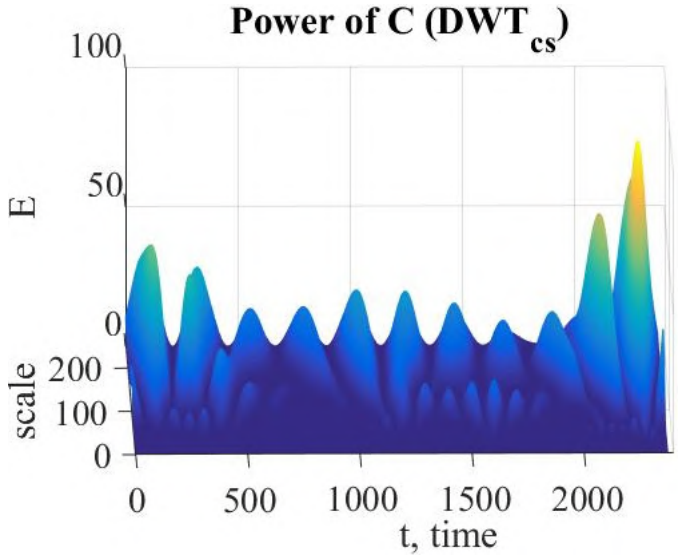

Figure 9: Wavelet coefficient energy for gasoline index.

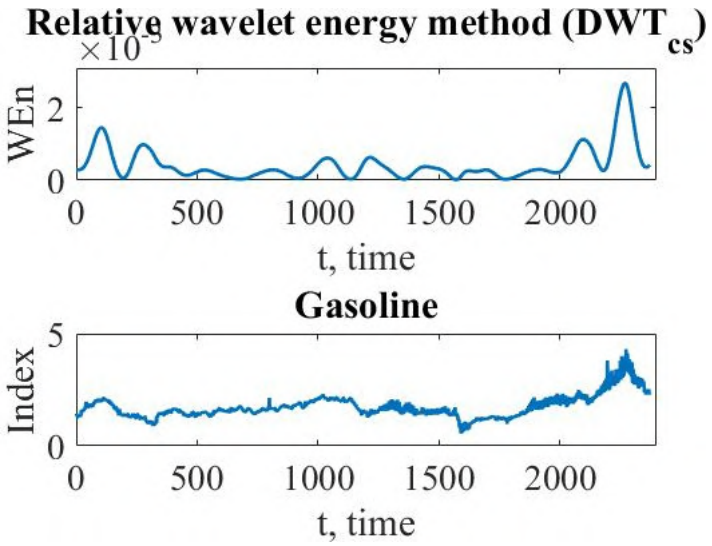

Figure 10: Wavelet entropy and dynamics of the gasoline index.

Comparing figure 9 from figure 5 and figure 7, we see that the energy surface for the gasoline market differs from the energy surfaces for oil. As you can see, the gasoline market is not stable. But starting from around the point of 1800, which corresponds to the year 2022 (figure 10), we observe the appearance of a triad of growing waves. And from this period, the behavior of the gasoline market becomes similar to the oil and gas market. And we state the crisis state of the market. What is the impact of the war in Ukraine? The world market of oil, oil products, and gas is being reformatted, and connections are changing. Ukrainian markets are also undergoing

transformation, reorienting themselves towards the EU. It is obvious that the change of players in the market (both strong and not so) leads to instability, problematic issues of redistribution of resources.

The foreign exchange market is an important component of the financial market. Modeling and analysis of the currency market will allow an understanding of the economic and organizational relations between the participants.

In figure 11 shows the comparative dynamics of currency pairs EUR/USD and GBP/USD. These currency pairs are the most traded, which influenced the selection for the study.

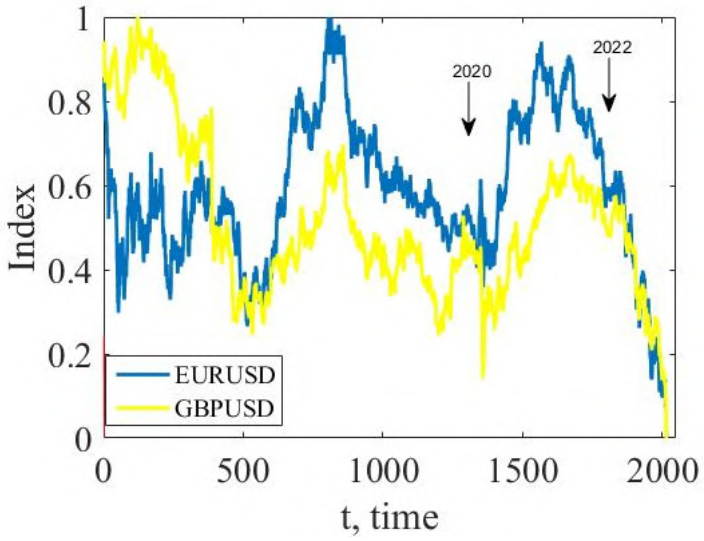

Figure 11: Comparative dynamics of indices of currency pairs EUR/USD and GBP/USD.

Figure 11 shows the sharp decline of currency pair indices in 2020. As for 2022, there is a drop in indices, but it is not of a rapid nature.

Applying the wavelet entropy method to the currency market allows you to get an answer to the question of the existence of a crisis in it. For both currency pairs, the formation of three waves, which is an indicator-precursor of the crisis phenomenon, was observed during 2015-2017 (within points 50-520, see figures 13, 15). The same situation is observed for the currency pair GBP/USD during the pandemic period (figure 15). The current situation for both currency pairs is marked by a gradual drop in the index values. The reasons for the subsidence may be the war in Ukraine, sanctions against Russia, the dependence of European states on Russian gas supplies, the political crisis in the EU regarding the support of sanctions and aid to Ukraine. The euro is the base currency, but it is also a tool for speculation.

Therefore, the simulation results indicate the absence of a crisis state at the time of the study. This market needs further monitoring, as the next wave is still in the process of formation.

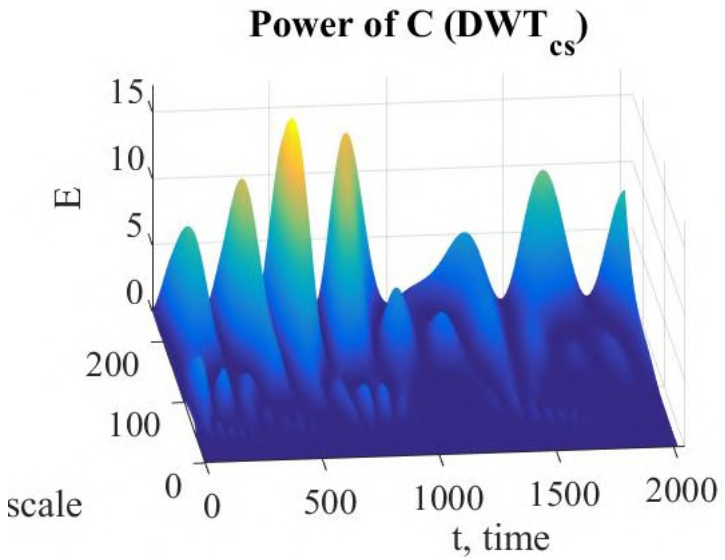

Figure 12: Wavelet coefficient energy for the currency pair EUR/USD.

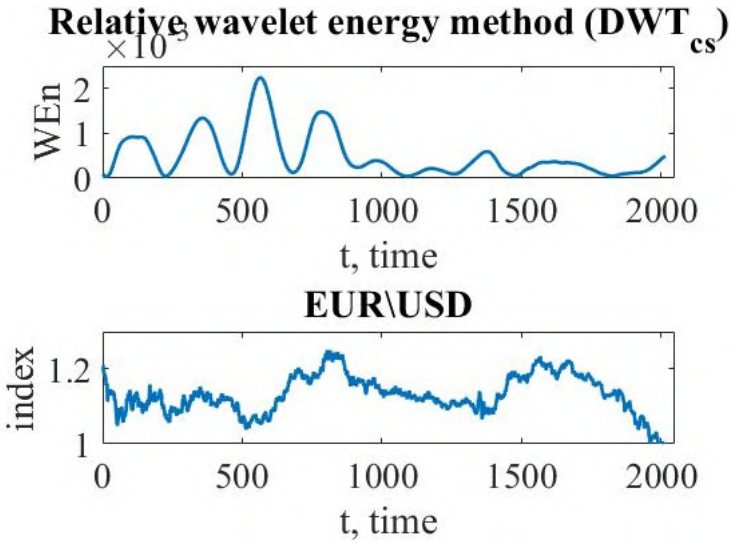

Figure 13: Wavelet entropy and dynamics of the currency pair EUR/USD.

4. Conclusion

In summation, the utilization of the wavelet entropy method for modeling and analyzing the oil, gas, oil products, and foreign exchange markets unveils the war in Ukraine as a potent force driving extant or emerging crisis phenomena within these domains. The wavelet entropy models distinctly underscore a crisis presence in the oil, gas, and gasoline markets. Concurrently, the primary currency pairs within the foreign exchange market exhibit a gradual yet protracted

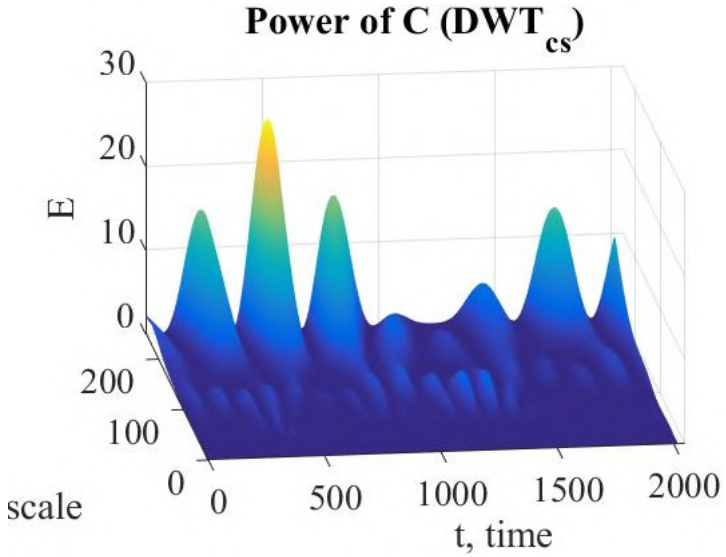

Figure 14: Wavelet coefficient energy for the currency pair GBP/USD.

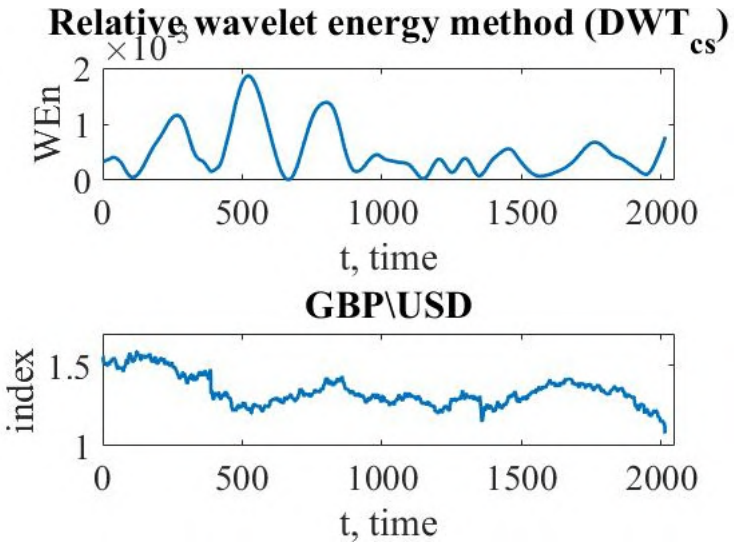

Figure 15: Wavelet entropy and dynamics of the currency pair GBP/USD.

decline. Notably, the intricacies of the currency market necessitate continuous vigilance, and the employment of the wavelet entropy method for its modeling holds promise in preemptively flagging crisis states.

These findings harmonize with existing conclusions, such as the heterogeneous impact of the oil market on diverse financial assets, peaking during the Ukraine conflict, and the greater susceptibility of globalized markets to its ramifications. The realm of globalization within the world economic landscape, while conferring advantages, is fraught with inherent perils. Today,

these threats reverberate within the energy sectors, spanning oil, gas, and related commodities. The war ignited by Russia in Ukraine—a manifestation of its aspirations for supremacy, territorial aggrandizement, and fear of relinquishing its standing—compels the global community to reevaluate the architecture, interconnections, and dynamics of globalization within the world economic tapestry.

In essence, the research underscores that crises—whether triggered by political strife, military engagements, or global pandemics—resonate across financial markets and globalization's intricate fabric, demanding a holistic comprehension fostered by interdisciplinary methodologies. The wavelet entropy method, by detecting the foreboding ripples of crisis at early junctures, emerges as an indispensable tool for anticipating and navigating the complex intersections of financial markets, globalization processes, and geopolitical convulsions. The war in Ukraine, emblematic of contemporary geopolitical tensions, serves as a poignant illustration of the profound reverberations that crises can engender, catalyzing a transformative reevaluation of economic interconnectedness and collective security in a rapidly evolving world.

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