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GEOPOLITICAL AND GEO-ECONOMIC INTEGRATION AND INTERNATIONAL ADJUSTMENT OF ECONOMIC CYCLES: AN EXTENDED CONCEPTUAL SVECM MODEL FOR UKRAINE AND THE EUROPEAN UNION

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The relevance of this study stems from increasing international interdependence, the transmission of geopolitical and financial shocks, and the need to analyze the multi-level macroeconomic synchronization between Ukraine and the European Union against the backdrop of the ongoing war, an energy crisis and the structural transformation of the global economy. The aim of this article is to develop an extended conceptual spectral SVECM model. The main hypotheses of the study concern the existence of long-term cointegration between Ukraine and the EU, the strengthening of international synchronization under the influence of geo-economic integration, the multidimensional nature of international adjustment, and frequency-dependent causality. The research questions relate to the analysis of the mechanisms of international adjustment, spectral synchronization, phase adaptation and the oscillatory dynamics of international economic cycles. The research methodology is based on a combination of structural vector error correction models (SVECM), spectral analysis, Fourier approaches, Breitung–Candelon causality, Johansen cointegration analysis, and Fourier-KPSS and Fourier-ADL tests. The model utilizes indicators of trade, financial, institutional, energy and geopolitical integration, combined into a geo-economic integration index. The results of the study show that international integration is a multi-scale process, and that cointegration can be interpreted as a mechanism for international macroeconomic adjustment and phase synchronization of linked macroeconomic oscillators. The scientific novelty of the article lies in the development of a conceptual spectral SVECM model explaining structural cointegration, spectral synchronization, oscillatory correction and frequency-dependent integration. The practical value of this research lies in the model's potential for forecasting international economic cycles, analyzing the stability of macroeconomic trends, and developing economic policy instruments for Ukraine and the EU.

Keywords: *geo-economic integration; SVECM; spectral synchronization; Breitung–Candelon causality; business cycles; asymmetric causality.*

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Оруджев Е. Г., Алізаде А. Р. Геополітична та геоекономічна інтеграція та міжнародна корекція економічних циклів: розширена концептуальна SVECM-модель для України та Європейського Союзу

Актуальність дослідження зумовлена посиленням міжнародної взаємозалежності, поширенням геополітичних і фінансових шоків, а також необхідністю аналізу багатомасштабної макроекономічної синхронізації України та Європейського Союзу в умовах війни, енергетичної кризи та структурної трансформації світової економіки. Метою статті є розробка розширеної концептуальної спектральної SVECM-моделі. Основні гіпотези дослідження полягають у існуванні довгострокової коінтеграції між Україною та ЄС, посиленні міжнародної синхронізації під впливом геоекономічної інтеграції, багатовимірності міжнародної корекції та частотно-залежної причинності. Дослідницькі питання пов'язані з аналізом механізмів міжнародної корекції, спектральної синхронізації, фазової адаптації та осциляційної динаміки міжнародних економічних циклів. Методологія дослідження базується на поєднанні структурних моделей векторної корекції помилок (SVECM), спектрального аналізу, підходів Фур'є, причинності Брейтунга-Канделлона, коінтеграційного аналізу Йохансена, тестів Фур'є-KPSS та Фур'є-ADL. У моделі використовуються показники торговельної, фінансової, інституційної, енергетичної та геополітичної інтеграції, що об'єднані в геоекономічний індекс інтеграції. Результати дослідження показують, що міжнародна інтеграція є багатомасштабним процесом, а коінтеграція може трактуватися як механізм міжнародної макроекономічної адаптації та фазової синхронізації пов'язаних макроекономічних осциляторів. Наукова новизна статті полягає у формуванні концептуальної спектральної SVECM-моделі, що пояснює структурну коінтеграцію, спектральну синхронізацію, осциляційну корекцію, частотно-залежну інтеграцію. Практична цінність дослідження полягає у можливості застосування моделі для прогнозування міжнародних економічних циклів, аналізу стійкості макроекономічної динаміки та розробки інструментів державної економічної політики України та ЄС.

Ключові слова: *геоекономічна інтеграція; SVECM; спектральна синхронізація; причинність Брейтунга-Канделона; бізнес-цикли; асиметрична причинність.*

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Introduction. The modern international economy is characterized by increasing interdependence of national macroeconomic systems, the intensification of the transmission of international shocks, and the gradual formation of transnational economic regimes. In the context of geopolitical instability, the energy crisis, sanction-related fragmentations, and the structural transformation of the global economy, traditional models of international integration prove insufficient to describe the processes of international macroeconomic synchronization. This problem becomes especially relevant for Ukraine, since integration with the EU is not only a political and institutional process but also a profound transformation of macroeconomic dynamics. As a result, Ukraine's economy is gradually entering a single geo-economic space with the EU, which leads to increased synchronization of economic cycles, the transmission of European macroeconomic shocks, the formation of international correction mechanisms, and the growth of spectral coherent economic fluctuations. The available literature pays significant attention to trade integration, financial interdependence, and standard cointegration. However, spectral integration mechanisms, frequency-dependent causality, international phase synchronization, and nonlinear dynamics of international correction are far less studied.

This article aims to form an expanded conceptual model of international geo-economic synchronization between Ukraine and the EU based on the spectral dynamics of SVECM. Within the framework of the proposed conceptual model, the following research hypotheses can be formulated:

1. The existence of long-term cointegration between Ukraine and the EU.
2. Geopolitical integration strengthens international synchronization.
3. International correction is multidimensional.
4. International causality is causal-frequency based.
5. Ukraine and the EU form a system of interconnected macroeconomic oscillators.

Analysis of recent studies and publications. Contemporary research on international integration and the synchronization of economic cycles can be divided into several main directions.

The first group of studies is based on the application of VAR/VECM and cointegration analysis. In the works [1–3] and other researchers, Johansen cointegration, impulse response functions, and variance decomposition are used to analyze international trade-economic relations. These studies show the presence of long-term equilibria between countries and the potential existence of several cointegration relationships.

The second group is related to the analysis of macroeconomic synchronization and convergence. In particular, in the study [4], Ukraine's integration into the EU is considered through the lens of harmonizing inflation, interest rates, and other macroeconomic parameters. However, synchronization is mainly interpreted as static convergence without the use of dynamic correction models.

The third direction encompasses modern research in the wavelet and frequency domains. The further articles [5; 6] demonstrate that the synchronization of economic cycles is a multi-scale and frequency-dependent process. These studies significantly deepen the understanding of international macroeconomic dynamics, but they show a number of limitations: the absence of SVECM structural models, the lack of interpretation of cointegration as a mechanism of international adaptation, the absence of frequency causality, and a geo-economic integration index.

Unlike existing approaches, this article combines SVECM, spectral synchronization, Breitung-Candelon frequency causality [7], and oscillatory properties of economic cycles, forming a conceptual extended nonlinear model of cycle alignment.

Moreover, the proposed approach significantly expands the results of study [8], in which the cyclicality of the Ukrainian economy is analyzed mainly in the context of politico-legal transformation, wavelet analysis, and spectral decomposition. Unlike the above mentioned work, in the present study the synchronization of economic cycles is considered as an integrated cyclical system. This allows moving from the analysis of the internal cyclicality of the Ukrainian economy to the study of multi-scale international macroeconomic synchronization.

The article [9] along with the present work share a common research basis, as both analyze the cyclical dynamics of the Ukrainian economy and apply a modern approach. However, there are fundamental differences between them in terms of the level of theoretical exposition, the scale of the model, the economic-mathematical apparatus, and the interpretation of cyclical processes. In this article, cointegration is practically not a central element of the model. Another study [10] is significantly closer to this work in terms of methodological depth than the previous article on the Ukrainian Financial Cycle Index. Still, even in this case, there are fundamental differences between this work and the current article – primarily in the theoretical architecture of the model, the level of dynamic analysis, and the understanding of the nature of economic cycles.

Yet another article [11] appears to be the closest to this approach among all previously considered studies, as it directly links political proximity, international integration, and business cycle synchronization. Despite the thematic closeness, there are fundamental differences between this work and the present article in theoretical depth, the mathematization of the economy, and analytical dynamic analysis. The main hypothesis of the aforementioned article is that political proximity strengthens the synchronization of business cycles, and here geo-economic integration is considered as a dynamic synchronization system [12]. This article develops the Fourier-VECM, previously applied in the same article for the analysis of nonlinear banking dynamics, and transfers it to the level of international macroeconomic integration. The most important methodological extension here is that while sinusoidal and cosinusoidal components are used there to analyze smooth structural changes and nonlinear income cycles, in the considered work they are structural international oscillators. Furthermore, in the aforementioned article, the cointegration rank equals one, whereas here the presence of two cointegration vectors is allowed, which makes it possible to have multiple equilibrium states, two system adjustment mechanisms, as well as simultaneous institutional and financial integration between the EU and Ukraine. This approach in the discussed work is extended to a spectral SVECM model of international geo-economic integration, within which Ukraine and the EU are considered as coupled oscillators with multiscale phase synchronization and frequency-dependent geo-economic integration aspects. Resonant amplification of oscillation through harmonic components has been unidimensionally analyzed in work [13] using real data, and this idea is conceptually extended here to a multidimensional frequency-dependent correction mechanism.

Main factors of cointegration analysis. A key element of the proposed model is a system of macroeconomic variables reflecting the main mechanisms of international integration between Ukraine and the EU: Ukraine's real GDP (CDP_U), reflecting the domestic economic cycle and the degree of adaptation of Ukraine's economy to the European area), the EU's real GDP (CDP_E), an indicator of the European economic cycle) (one can also use the GDP growth rates of Ukraine and the EU); trade integration ($TradeEU_t$), which includes exports, imports, and the EU's share in Ukraine's foreign trade (shows how economically connected Ukraine and the EU are through trade), which can be determined using the formula of Trade $TradeEU = \dfrac{X_t + M_t}{GDP_{E_t} + CDP_{U_t}},\ t = 1,2,...,T,$

where X_t and M_t are exports and imports between the EU and Ukraine); financial integration ($Finance_t$), which includes foreign direct investment from the EU, cross-border banking flows, and European lending (this variable measures the volume of portfolio investments, financial flows, for which the formula $\left(Finance_t = \dfrac{Portfolio_t}{GDP_{E_t} + GDP_{U_t}},\ t = 1,2...,T\right)$ can be used; Ukraine's credit cycle ($Credit_{U_t}$), which reflects domestic financial dynamics and credit expansion cycles; inflation $Infolation_{U_t}$, which characterizes macroeconomic stability and the degree of monetary synchronization; interest rates $(Interest_t)$ for analyzing international monetary transmission; exchange rate ($Exchange_t$), reflecting external stability and financial volatility; energy factor $(Energy_t)$, which includes energy prices. Another important factor is the geo-economic integration index:

$$G_t = w_1 T_t + w_2 F_t + w_3 I_t + w_4 E_t + w_5 P_t, \qquad (1)$$

where T_t is trade integration, F_t is financial integration, and I_t is institutional harmonization.

For the quantitative assessment of the institutional factor, we can use the implementation index of the Association Agreement (AA_t) and the quality of governance index (GOV_t), the first of which includes indicators of trade, regulatory, energy, and institutional harmonization, and the second – components of the rule of law, government effectiveness, corruption control, and regulatory quality, sources of which can be reports of the EU, the European Commission, Ukraine Reform Index, and indicators of the transitional economy from the European Bank for Reconstruction and Development.

Where E_t is energy integration, P_t is political-geopolitical integration. A possible structure of this component can be expressed as

$$P_t = military\ support\ index\ -\ geopolitical\ risk\ index.$$

P_t = military support index – geopolitical risk index.

The structure of the first component on the right-hand side of the difference includes the volumes of military assistance, arms supplies, defense cooperation programs, technological support, grants, the sources of which can be NATO reports [14], the Ukraine Support Tracker of the Kiel Institute for the World Economy [15], European Union aid reports, and the Ukraine Recovery and Reconstruction Program [16].

The weighting coefficients in (1) can be estimated by the principal component (PCA) method of time series [17], generated using a VAR model to synthesize multidimensional information into a single indicator reflecting the economic cycle. PCA in SVECM allows the identification of hidden regimes, dominant cycles, and common trends, which is especially useful for spectral SVECM. High interdependence of variables may lead to the problem of multicollinearity. The use of PCA allows reducing the correlation of all explanatory variables and increasing the robustness of spectral SVECM estimates. This index can be normalized by bringing all components to the [0,1] scale using the formula $G_t = \dfrac{G_t - G_{\min}}{G_{t_{\max}} - G_{t_{\min}}},\ t = 1,2,...,T$, with the final index being $0 \le G_t \le 1.$

Among all the factors described above, macroeconomic factors of Ukraine can be considered exogenous. Geo-economic indices are partially endogenous since they affect the economy but at the same time change under the influence of integration. The EU indicators are exogenous. Geopolitical shocks are better treated as exogenous: GR_t (geopolitical risk), WAR_t

(wartime shock), SAN_t (sanctions). Exogenous variables participate in the correction mechanism and adapt to changes in geo-economic integration. Exogenous variables are interpreted as external influence mechanisms that determine frequency-dependent shock transmission and spectral structure, as well as the dominant oscillator, while the economy of Ukraine is characterized as an adaptive oscillatory subsystem.

Research Methodology. The proposed methodology includes several consecutive stages.

1. Stationarity check. A rigorous empirical analysis is conducted using the Hodrick-Prescott and Christiano-Fitzgerald filters to determine the phases of growth and decline of the economies of Ukraine and the EU [18; 19] and to analyze the degree of integration of time series using the ADF test, Phillips Perron test, KPSS test [20], Fourier-KPSS test, Bai Perron test [21]. The main aim is to determine the presence of unit roots and to check the integration of series I(1), the Fourier ADL cointegration analysis conducted in [22], as well as the analysis of causal relationships in [23].
2. Selection of the optimal lag structure. The Akaike, Schwarz, and Hannan-Quinn information criteria are used to adjust the choice of lags necessary for an adequate assessment of cointegration and dynamic causality.
3. Johansen cointegration analysis [24]. Johansen test check for the matrix

$$\Pi = \alpha\beta',$$

where β are cointegration vectors, and α – are adjustment speeds.

If the rank $(\Pi) = r = 0,$ then long-term integration is absent; if $r = 1$, there exists a single mechanism of international equilibrium. If $r = 2$, a multidimensional structure of international synchronization arises. In the case of $r = 2$ the first cointegration vector may reflect trade-production integration and long-term GDP synchronization. The second cointegration vector may be associated with financial cycles, credit dynamics, and geopolitical factors. Considering that the EU and Ukraine are unequal in size, have different adaptation speeds, and $|\alpha_U| \geq |\alpha_E|$, an asymmetric dynamic and rapid adjustment of Ukraine to the EU is created.

4. Construction of the basic SVECM. This study develops the classical SVECM methodology presented in [25] and extends it to a spectral SVECM model of international macroeconomic integration, oriented toward the frequency-dependent adaptation mechanism. To build the model, it is first necessary to conduct the Fourier–Shin cointegration test [26] and the cointegration test with Fourier elements for SVECM [27–28]. The structural model is written as follows:

$$A\Delta Y_t = \alpha(\beta' Y_{t-1} + \gamma G_t) + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + B\varepsilon_t, \quad t = 1,2,...,T. \tag{2}$$

Where Y_t is column vector of the variables (GDP_{U_t}, GDP_{E_t}, $TradeEU_t$, $Finance_t$. $Credit_{U_t}$, $Infolation_{U_t}$, $Interest_t$, $Exchange_t$, $Energy_{G_t}$),

$\beta' Y_{t-1}$ – matrix of long-term international equilibrium,

α – matrix of international correction speed, which shows which variable adjusts after the equilibrium is disturbed,

γ – column matrix whose elements are coefficients, when GR_t, for the matrix Y,

Γ_i – matrix of short-term dynamics,

G_t – geopolitical integration index,

A – unidentified matrix of structural relationships between system variables,

B – unidentified matrix of structural shocks,

ε_t – structural shocks.

For our analysis, the matrix β characterizes the structure of long-term international equilibria, the matrix α reflects the speed of the adaptation process and the intensity of geo-economic interdependence, and the matrix Γ_i shows short-term cyclical changes. The matrix A is economically interpreted as variables that affect each other within a period, that is, not through lags, but through instantaneous transmission, and allows the identification of the direct transmission of structural shocks within the international system. SVECM separates shocks, for example, $U_t = B\varepsilon_t$ representing the observed residuals. For the identification of the spectral model, SVECM can use economically interpretable restrictions based on the assumption of different speeds of transmission of trade, financial, and monetary shocks between the EU and Ukraine. For example, to identify structural shocks, short-term and long-term as well as sign restrictions can be used, allowing the separation of integration shocks from short-term financial and geopolitical fluctuations. In the model (2), when $\gamma > 0$, the correction accelerates, the cycle synchronization increases, and when $\gamma < 0$, the divergence of cycles strengthens decreases.

5. Structural impulse responses and variance decomposition. At this stage, the response function is used to analyze the transmission of point European shocks in one of the structural equations of Ukraine's economy and the duration of the adaptation process. Variance decomposition allows determining the contribution of European factors and geopolitical integration to Ukraine's macroeconomic fluctuations. Here, these functions play not just a technical role, as is usually the case in VAR/VECM, but become a tool for analyzing spectral adaptation over different time horizons, phase synchronization, and geo-economic shock transmission. The impulse response acquires an oscillatory character, meaning that after a shock, the elements of the system oscillate, change phases, and spectral coherence. When using sinusoidal and cosinusoidal components, the impulse responses acquire an oscillatory character and provide

such dynamics of attenuation or amplification of macroeconomic fluctuations. The decomposition of variance in the spectral SVECM will show which integration mechanisms become dominant at different frequencies, thereby reflecting the degree of Ukraine's dependence on the EU, allowing the separation of short-term financial-geopolitical shocks and long-term mechanisms of structural integration between them.

6. Breitung-Candelon frequency causality. Causality at different frequencies of economic cycles is analyzed. In this case, low frequencies may reflect institutional integration, structural convergence, and stable cointegration. High frequencies may characterize financial volatility, crisis impulses, and geopolitical shocks.

Unlike standard Granger causality, which in the time domain does not take into account possible changes in causality dynamics because it is based on the strict assumption of VAR system linearity, the Breitung-Candelon approach allows not only to determine the presence of causal relationships but also to identify the spectral frequencies at which structural adaptation and shock transmission are most statistically significant according to certain critical F-statistic values.

For identical frequencies, such causality will be understood as a phase synchronization causal mechanism, with its economic interpretation being that the EU sets the overall cycle, and Ukraine adjusts with a phase lag. Strengthening geopolitical integration contributes to a reduction in the phase lag of economic cycles between them. And for different frequencies, different integration mechanisms, different adaptation speeds, partial synchronizations, and spectral heterogeneity will arise.

7. Spectral analysis. An analysis of spectral cointegration is conducted, and a Fourier SVECM model is built with a spectral interpretation of the adjustment mechanism. This allows researching multiscale synchronization, phase alignment of cycles, and the situation with temporal variability. Within the framework of the spectral SVECM model, international adjustment is considered as a frequency-dependent process, the adaptation rate of which changes depending on the time scale of economic fluctuations. International adjustment will mean phase tuning, frequency alignment. By adding sinusoidal and cosinusoidal components with the same (or different) frequencies to the SVECM, the system will begin to describe cyclical adaptation, creating oscillatory adjustment. In the case of identical frequencies, the system will have a common cycle with different phases and amplitudes and different transmission mechanisms. At this, the SVECM can be as follows:

$$A\Delta Y_t=\alpha(\beta' Y_{t-1}+\gamma G_t)+\sum_{i=1}^{p-1}\Gamma_i\Delta Y_{t-i}+$$
$$+\sum_{i=1}^{q}\delta_{1ki}\sin(w_i t)+\delta_{2ki}\cos(w_i t)+B\varepsilon_t, \qquad (3)$$
$$t=1,2,...,T.$$

Where δ_{1ki}, δ_{2ki} – is the intensity of cyclic influence, w_i, $i=\overline{1,q}$ are frequencies, *k* is the number of the elements of the matrix *Y*.

Sine and cosine of one frequency are equivalent to $c_i\sin(w_i t+\varphi_i)$, where $c_i=\sqrt{\delta_{1ki}^2+\delta_{2ki}^2}$ – is amplitude, and $\varphi_i=\dfrac{\delta_{1ki}^2}{\delta_{2ki}^2}$, $i=\overline{1,q}$ is the phase shift. This may mean that Ukraine and the EU can have the same frequency of cycles, but different phases of movement; for example, the EU is already entering a growth phase, while Ukraine lags behind, adapting later not monotonously, but in an oscillating manner. Here the EU acts as the leading oscillator, and Ukraine as the adapting oscillator.

As for the SVECM models with different frequencies:

$$A\Delta Y_t=\alpha(\beta' Y_{t-1}+\gamma G_t)+\sum_{i=1}^{p-1}\Gamma_i\Delta Y_{t-i}+$$
$$+\sum_{i=1}^{q}\delta_{1ki}\sin(w_{1i} t)+\delta_{2ki}\cos(w_{2i} t)+...+B\varepsilon_t, \qquad (4)$$
$$t=1,2,...,T.$$

where $w_{1i}\neq w_{2i}$, the component $\sin(w_{1i}t), i=\overline{1,q}$ is one type of cycle, and $\cos(w_{2i}t), i=\overline{1,q}$ is another type, which indicates different types of fluctuations, different speeds of movement, different moments of integration.

In the formulas (3)-(4), dummy variables can be introduced to reflect dates of structural breaks, geopolitical shocks, institutional changes, energy crises, military events, as well as various changes in the integration regime of Ukraine and the EU. The most important dates would be: 2014 – annexation of Crimea and the beginning of the ongoing war, 2016 – the free trade area between Ukraine and the EU came into force (institutional shift), 2020 – the COVID pandemic, 2021–2022 – the energy crisis, 2022 – full-scale war and Ukraine becoming a candidate for the EU. It is even possible to use spectral dummy variables with the Fourier components of $D_{2022\sin(wt)}$, $D_{2022\cos(wt)}$ as a factor in changing the spectral structure.

In the models (3)-(4), the case of a linear trend entering the long-term equilibrium is possible. In this case, the equilibrium on the right-hand side will shift over time. After a shock, the system will return not to a constant, but to a moving function with a linear component and two others – as sinus and cosine. After a shock, the system does not return to the past but oscillatory adapts to the current oscillatory function with a transition to a linear trend. The impulse response function will oscillate, but the amplitude will decrease over time, and the system will gradually stabilize.

Necessary identification restrictions for the structural matrices *A* and *B* in the formula (4) are the conditions:

$$\det(A)\neq 0,\ \det(B)\neq 0$$

that is, they must be non-singular. Otherwise, shocks cannot be separated, the system becomes singular, and structural interpretations are lost. A restriction on the main matrix $\Pi = \alpha\beta'$ is also required. The restriction on the real eigenvalues will be $|\lambda_i| < 1.$ If they are complex ones, such as $\lambda = a + bi$, then cyclic oscillations arise. It is necessary that $\sqrt{a^2 + b^2} < 1.$ From the economic point of view, this inequality means a damped oscillatory correction. If an eigenvalue of λ is multiple, the polynomial with respect to *t* of the factor of $\sin wt$ begins to accelerate the dynamics. When eigenvalues of λ are inside the unit circle, the system is stable, and the term of $t\lambda^t$ ultimately decays, since λ^t decreases faster than *t* increases. If $\lambda = 1$, this is the most dangerous case. If the value $\lambda = 1$ (unit root) is significantly higher than the number of different cointegration vectors, the system moves from the I(1) category to I(2) or higher, random shocks begin to accumulate not just into a «rambling», but into a quadratic trend, the error correlation of (α) stops coping with the imbalance, and the system begins to deviate from equilibrium at an accelerated pace. Multiplicity often reflects the synchrony of expectations or the identity of regulatory mechanisms.

For the identical frequencies $w_1 = w_2$ in the formula (4), the spectral matrix $S(w)$, whose elements are the Fourier transform of lagged covariances, must be positive definite. This condition ensures the spectral invertibility of the system and guarantees the correctness of the frequency decomposition of the dynamics. If $w_1 \neq w_2$, then it is important to avoid spectral singularity, which can lead to unstable synchronization. In both frequency restrictions, to ensure the stability of the dynamics, it is necessary to avoid resonant amplification of oscillations ($|\lambda| \to 1,\ |\delta_{1ki}|,\ |\delta_{1ki}|$) (too large, growth of the elements of the matrix $S(w)$, in which shocks begin to reinforce existing cyclical fluctuations of the system due to the coincidence or closeness of the dominant frequencies of economic dynamics (for example, $w_{EU} \approx w_{UA}$). In this case, the spectral SVECM coefficients start to amplify rather than suppress the oscillatory dynamics, and the correction mechanism destabilizes the joint dynamics.

For the models (3)-(4), the impulse response becomes oscillatory: after shocks, the system elements oscillate, change phases and spectral coherence, meaning that after European shocks, the Ukrainian variables may initially intensify the downturn, then move towards recovery, after which they oscillate again. In a standard SVECM with identification restrictions, as shown in work [29], this function can monotonically decay. For the models (3)-(4), phase lag will occur at the same frequencies $w_{EU} = w_{UA}$, while for different frequencies the response will be non-uniform, depending on the specific frequencies.

The statistical stability of the model is also checked using the analysis of the eigenvalues of the main system matrix, tests of parametric stability, and spectral stability of international dynamics. To verify the correctness of the model, conditions of eigenvalue stability, CUSUM and CUSUM SQ tests for parameter stability, recursive model estimation, cointegration space stability, and spectral coherence stability can be used. In the end, it is necessary to check both the statistical and spectral stability of the model.

Ultimately, it is necessary to verify both the statistical and spectral stability of the model. The verification of the statistical correctness of the predicted spectral SVECM model requires an extended set of diagnostic procedures, which include not only standard and Fourier-extended component tests of stationarity and cointegration, based on spectral components and the stability of the SVECM, but also the analysis of spectral stability of international macroeconomic dynamics. In particular, the stability of cointegration relationships, the stability of the adjustment matrix, the presence of structural shifts, spectral coherence, phase synchronization, the stability of oscillatory dynamics, and frequency-dependent Breitung-Candelon causality are examined. Special attention is paid to the statistical significance of the sinusoidal and cosinusoidal components, reflecting the multi-scale cyclical structure of international integration between Ukraine and the European Union.

In the developed spectral SVECM model, forecasting becomes significantly deeper than in conventional VAR/VECM. The model begins to forecast not only the level of variables but also the spectral structure of international economic cycles, phase dynamics, synchronization, frequency-dependent correction, and international structural shifts of macroeconomic regimes. At this, low frequencies (long-term integration), medium frequencies (economic cycles, trade dynamics, investment cycles), and high frequencies (financial shocks, currency volatility, geopolitical crises) are forecasted separately. It is also possible to forecast potential synchronization of Ukraine or an increase in divergence.

For identical frequencies, the amplitudes of cycles, phase, periodicity, and oscillatory regimes are forecasted using sine and cosine components, which will show how quickly Ukraine is catching up with the EU, as well as the speed of phase synchronization. In the case of different frequencies, it is possible to forecast the frequencies of strengthening or weakening integration.

Main theoretical results. The developed conceptual model allows us to formulate the following main conclusions:

1. International integration is a multi-scale process.
2. Cointegration is interpreted as a mechanism of international adaptation.
3. Ukraine and the EU form a system of interconnected macroeconomic oscillators.

Practical value of the research. The practical value of this conceptual spectral SVECM model lies in forming an extended analytical instrumentarium for studying geo-economic integration, macroeconomic synchronization, and forecasting the dynamics of relations between Ukraine and the EU. The model can be used to solve a wide range of applied tasks in the field of macroeconomic analysis, state economic policy of the National Bank of Ukraine, the Ministry of Economy, the Ministry of Environment and Agriculture of Ukraine, the Ministry of Finance of Ukraine, as well as analytical and international organizations dealing with issues of macroeconomic integration and financial stability.

Conclusion. The article develops an extended conceptual model of the international geopolitical and geo-economic integration of Ukraine and the EU, which combines SVECM, spectral SVECM, Breitung-Candelon frequency causality, spectral synchronization interpreted as a process of synchronization of related oscillators, allowing a transition from simple correlation to spectral causality, from statistical convergence to dynamic adaptation, from standard cointegration to geo-economic synchronization.

Further empirical analysis. The developed conception forms a methodological basis for further empirical analysis of international macroeconomic synchronization between Ukraine and the European Union and does not include a full methodological assessment of the model parameters. In particular, the following require further analysis: the assessment of the SVECM spectrum on real macroeconomic data, quantitative identification of cointegration relationships, estimation of spectral correction parameters, and empirical testing of phase synchronization between Ukraine and the EU. These analyses under conditions of wartime, geopolitical instability, structural breaks, and the transformation of international economic regimes represent prospects for further empirical research.

The Ukrainian economy after 2022 is characterized by significant structural breaks, wartime shocks, and changes in international trade and financial regimes. To account for such changes, besides the Bai-Perron test and spectral SVECM methods, the model can also be re-evaluated over different time intervals to analyze the change in parameters. It is planned to present them in the next separate article under the conditions of the war between Russia and Ukraine, geopolitical instability, structural breaks, and the transformation of international economic regimes.

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