JOURNAL
OF EUROPEAN ECONOMY
Vol. 25. № 1 (96). January–March 2026
Publication of West Ukrainian National University

Primary Sector Economics

Iryna IVASHKIV,
Volodymyr SAIENKO,
Mariia LYZUN,
Ihor LISHCHYNSKYY

FORECASTING THE EXPORT OF GRAIN AND OILSEED CROPS THROUGH UKRAINIAN PORTS UNDER WAR CONDITIONS

Abstract

The article examines the transformation of logistics channels and the forecasting of exports of grain and oilseed crops through Ukraine's seaports under the conditions of the full-scale military invasion by the Russian Federation. The strategic importance of seaports as a key element of the logistics chain ensuring global food security is substantiated. It is established that the creation of the Ukrainian maritime corridor, despite continuous large-scale attacks on grain ter-

Ivashkiv Iryna, PhD (Economics), Senior Researcher, Precarpathian State Agricultural Experimental Station of the Institute of Agriculture of the Carpathian Region NAAS, Ivano-Frankivsk, Ukraine. ORCID: 0000-0002-8135-8260 Email: irynaivashkiv@ukr.net
Saienko Volodymyr, DSc (Organization and Management), Professor, Department of Innovation Management, Academy of Management and Administration in Opole, Opole, Poland. ORCID: 0000-0003-2736-0017 Email: v.saienko@poczta.wszia.opole.pl
Lyzun Mariia, DSc (Economics), Professor, Department of International Economics, West Ukrainian National University, Ternopil, Ukraine. ORCID: 0000-0003-3222-2962 Email: m.lyzun@wunu.edu.ua
Lishchynskyy Ihor, DSc (Economics), Professor, Department of International Economics, West Ukrainian National University, Ternopil, Ukraine. ORCID: 0000-0003-1602-1677 Email: lio@wunu.edu.ua

minals and port infrastructure, has made it possible to transport more than 138 million tons of cargo to various countries around the world.

The results of the study reveal the presence of a four-year cycle in the dynamics of grain transshipment in Ukrainian seaports and confirm a pronounced seasonal inertia of the process. Forecast calculations indicate a possible decline in transshipment volumes in 2025–2026, followed by a recovery in 2027–2028 to a level close to the indicators of 2024. The obtained results also demonstrate significant variability in development scenarios, which is associated with a high level of military, infrastructural, and market risks. The practical significance of the research lies in forming an analytical basis for strategic planning of port infrastructure development and improving the mechanisms of export logistics of Ukrainian agricultural products under conditions of wartime and post-war economic transformation.

Key Words:

agriculture, export logistics channels, export, food security, «Grain Corridor», international trade, oilseed and grain crops, seaports, transshipment, Ukrainian Maritime Corridor.

JEL: Q17, Q18, L92, F42, F20.

3 tables, 3 figures, 34 references.

Problem Statement

The full-scale military invasion of the russian federation into the territory of Ukraine caused a number of problems with the logistics channels used for exporting grain and oilseed crops from Ukraine to different countries of the world. A special place among the logistics channels for exporting grain and oilseeds is occupied by the export of agricultural products through seaports, which have always been and remain the main logistics channel for agricultural exports in Ukraine. Significant difficulties in the transshipment of grain and oilseed products arose with the beginning of the full-scale invasion of russian troops into Ukraine in 2022. During this period, the operation of seaports was almost completely blocked until the opening of the “Grain Corridor” in August 2022, initiated by the United Nations and Türkiye. Despite the relatively short period of operation of the Grain Corridor – from 1 August 2022 to 22 July 2023 – a significant volume of grain cargo was transported through Ukrainian seaports, namely 32.8 million tonnes of grain and oilseed products. Importantly, during the existence of the Grain Corridor, 1,002 foreign vessels were able to enter Ukrainian seaports and deliver agricultural products to 52 countries worldwide, including countries in Africa and Asia, contributing to global food security. Owing to the Grain Corridor, 54% of Ukraine’s total grain exports, 27% of vegetable oils, and 38% of meal were transported, which contributed to foreign currency revenues for the Ukrainian economy (Centre for Transport Strategies, 2023).

The Grain Corridor was officially launched on 1 August 2022, but eleven months later the russian federation began attacking foreign vessels. On 22 July 2023, the russian Federation officially announced its withdrawal from the Grain Corridor agreement. As an alternative, the Ukrainian Maritime Corridor was established on 10 August 2023, through which 138 million tonnes of grain cargo were exported over the following two years. It should be noted that as a result of intense russian missile and artillery attacks, 442 port infrastructure facilities were partially destroyed or damaged, 38 vessels were affected, and 138 people involved in port operations were killed or injured (Ministry for Communities and Territories Development of Ukraine, 2025).

At the same time, the creation of the Ukrainian Maritime Corridor contributed to the formation of export flows of grain and oilseed crops, enabling the transportation of export cargo totalling 140.3 million tonnes between August 2023 and December 2025 (Ukrainian Grain Association, 2025).

The aim of the study is to identify patterns in the dynamics of grain and oilseed exports through Ukrainian seaports under wartime conditions and to forecast the volumes of their transshipment using Fourier spectral analysis and ARIMA modeling in order to determine possible scenarios for the development of export logistics in the medium term.

Literature Review

An important task is to identify studies on forecasting the export of grain and oilseed products through Ukrainian ports under martial law conditions. Most of the previously functioning seaports in Ukraine have been occupied by the Russian aggressor and consequently blocked following the full-scale invasion of the Russian Federation into the territory of Ukraine. In this context, the issue of developing appropriate economic mechanisms to expand and increase grain exports by agricultural traders through the currently operating Ukrainian seaports becomes particularly relevant. This also involves optimizing their throughput capacity to meet market demand for the declared volumes of grain cargo.

In the pre-war period, Ukrainian scholars produced a substantial body of research addressing the export of grain and oilseed crops in Ukraine and their transshipment through seaports. A considerable number of scientific works have also been published by foreign researchers focusing on the main trends in grain cargo exports through seaports to various countries around the world.

For countries engaged in international trade, cargo exports are largely carried out by sea, which means that seaports constitute the key link in the logistics chain, ensuring the rapid and efficient delivery of grain and oilseed products over long distances (Stukalo et al., 2021). Well-established logistics transportation systems enhance the efficiency of international trade and provide competitive advantages for each country participating in this logistics process.

An important factor for any country engaged in the export and import of cargo is the adequacy of its core storage capacities, particularly grain terminals, through which grain cargo is received, stored, and processed.

Analysing the pre-war publications of Ukrainian scholars, it is worth highlighting the study by Kishchak & Porudieieva (2018), in which the authors argue that the competitiveness of Ukrainian ports should be based on optimizing the throughput capacity of seaports in Ukraine. The researchers also propose establishing transport and logistics centres within seaports, as well as improving the rational organization of labour, which in turn would contribute to increased labour productivity and enhanced competitiveness.

Rusnak et al. (2021) identify a number of key factors influencing the competitiveness of seaport development in Ukraine. The scholars propose competitive strategies for the effective functioning of seaports and advocate for their transition toward an innovation-intensive development path.

Particular attention should be paid to studies focusing on grain cargo exports through seaports. For instance, Goedhals-Gerber (2016) applies the Box–Jenkins methodology using the ARIMA autoregressive moving average model to forecast the throughput capacity of grain terminals at the Port of Cape Town for grain imports. The results of the study indicate that even with an increase in grain imports, the port throughput level would not exceed the current capacity of the grain terminal.

Jeong et al. (2024) conducted a study identifying 12 barriers that contribute to reducing idle time at grain terminals. Based on a survey conducted among grain terminal employees, it was found that the primary factor is the shipper's inventory requirements, the second factor is the capacity of storage facilities, and the third factor is the workload of port terminals.

Bernal et al. (2025), while assessing the competitive positions of grain terminals on the western coast of South Korea, applied the Herfindahl–Hirschman Index (HHI) and the BCG matrix to evaluate relative market share. Their findings indicate that not all grain terminals in the region are used efficiently. Consequently, the study is important for government decision-making, as it suggests that instead of constructing new grain terminals, existing facilities should be modernized and utilized more effectively.

Munim et al. (2023) applied four of the most commonly used time-series forecasting methods, including ARIMA, SARIMA, and HWES. The results showed that the SARIMA model produced the best results for the Port of Nagoya, while the HWES method performed better for the ports of Shanghai and Busan. The findings indicate that forecast data can serve as an approximate guideline for adjusting seaport management, particularly for making important decisions that assist port administrations in implementing effective management practices.

At the same time, it should be noted that significant attention from scholars has been directed toward studying the negative impacts and consequences experienced by European and African countries as a result of the full-scale war in Ukraine, particularly regarding food security issues in developing countries caused by the blockade of seaports by Russian military forces and continuous missile attacks.

The research by Rose et al. (2023) deserves attention, as it examines the consequences arising from disruptions in grain exports caused by the Russian military invasion of Ukraine. Based on modeling results, the researchers concluded that Ukraine will experience the greatest impact in the future, when its real GDP may decrease by approximately USD 859 million due to reduced exports.

Another important contribution comes from a group of scholars from the United Kingdom, France, and Spain (Jagtap et al., 2022), who studied the impact of the Russia–Ukraine war on global food supply chains. In their research, the PRISMA approach was applied to analyse food supply chains. The results indicate that African and Asian countries are the most affected, and the most viable solution is the search for alternative trade partners in the Middle East, Australia, and North and South America.

Investigating the export potential of agricultural crops during wartime, Ukrainian scholars Mulyk & Mulyk (2022) identified the main factors influencing export formation and outlined several difficulties and challenges facing agricultural exports under wartime conditions.

Feng et al. (2023) conducted research using a structural equilibrium model and concluded that the consequences of the full-scale war will have a significant global impact. According to their estimates, the war could lead to food shortages affecting 276 million people, as well as food price increases ranging from 10% to 30%, which would ultimately reduce global welfare levels. At the same time, the authors note that if major grain-producing countries increased their production, many of these problems could be mitigated.

Yanovska et al. (2025), studying the logistics of grain exports from Ukraine during the war, emphasize the problems caused by the blockade of seaports. Based on survey research, they concluded that the main challenges for grain exports during wartime were the lack of preparedness of alternative logistics export channels and significant problems in the development of railway infrastructure in Ukraine.

Karakas et al. (2024) examined the disruption of maritime supply chains during the full-scale Russia–Ukraine war. Within the framework of the UN Grain Initiative, the establishment of the Grain Corridor contributed to restoring grain shipments. Based on their calculations, the authors conclude that vessel size plays an important role in the transportation of bulk grain cargo.

The invasion of russian troops into Ukraine led to the blockade of seaports, which in turn contributed to the emergence of food supply problems in African countries, where grain and oilseed seeds, as well as processed agricultural products from Ukraine, were expected to be delivered. As demonstrated by Goyal & Steinbach (2023), even the establishment of the Black Sea Grain Initiative did not lead to a reduction in global grain futures prices; on the contrary, it contributed to their increase by 16%.

Caramuta et al. (2023) highlight the negative consequences for the global economy resulting from the russian invasion of Ukraine, which caused significant logistics disruptions, including the breakdown of traditional supply chains for raw semi-finished materials delivered to Italian enterprises.

Analyzing the negative impact of the war on the grain market, Devadoss & Ridley (2024) used a spatial equilibrium model to assess the consequences of the russia–Ukraine war for global wheat prices, production, and consumption. Their calculations show that due to the military aggression, wheat prices increase by about 2% in each country, while in Ukraine the price of wheat decreased by 27% compared to the global price.

Bodnar et al. (2024) emphasize that under wartime conditions there is a need to develop marketing strategies for grain and oilseed trade in Ukraine aimed at ensuring the efficiency of export logistics activities of domestic agricultural producers.

Cheremisina et al. (2025) focused their research on identifying the main problems of grain market exports and measuring price imbalances in the grain market. Their objective was to compare global grain prices with domestic prices. During the war, corn and wheat prices decreased by 22.7% and 28.2% respectively in Ukraine. The modeling results show that before the war, a USD 1 increase in the global wheat price led to a USD 0.71 increase in domestic prices in Ukraine. In contrast, after the war, a USD 1 increase in the global price would lead to only a USD 0.19 increase in domestic prices. Thus, significant disparities between global and domestic grain prices are observed during the wartime period compared to the pre-war period.

Bezpartochnyi & Britchenko (2022) argue that agricultural producers need diversification of logistics channels for grain and oilseed exports, as well as strategies to support export logistics under wartime risks, in order to ensure food security for third countries.

Kakabadze (2023), examining the role and importance of the Black Sea Grain Initiative, concludes that its creation and functioning helped address several humanitarian problems, particularly the provision of food to African countries. According to the researcher, the initiative became one of the successful measures that enabled the restoration of food supply chains to Africa.

As noted by Ay & Söylemez (2023), Türkiye played an important role in the creation of the Black Sea Grain Initiative, pursuing a "balanced" strategy while providing Ukraine with logistical, military, and diplomatic support. The authors argue that the initiative was also beneficial for Türkiye, as it strengthened its ties with Middle Eastern and African countries and ensured access to essential agricultural imports.

Ihle et al. (2022) argue that the Russian military invasion of Ukraine increased the synchronization of global food prices and heightened price uncertainty in commodity markets. The authors conclude that the war disrupted all links in agri-food supply chains, which on the one hand caused significant food price volatility and, on the other hand, limited consumers' access to alternative food products.

Martins (2024) highlights the positive aspects of the Black Sea Grain Initiative, noting that it contributed to the stabilization of the global grain market, as the departure of grain vessels significantly reduced prices. At the same time, the prolonged period of hostilities in Ukraine creates problems for farm enterprises involved in grain cultivation, as massive attacks by Russian forces destroy business assets and complicate grain transportation.

Mottaleb et al. (2022) demonstrate that if Ukraine's wheat exports decrease by 50%, global prices could increase by 15%, while consumption could decline by

8%. The authors recommend expanding wheat cultivation areas in African countries to strengthen regional food security.

In other scientific publications, researchers (Ivashkiv et al., 2021; Iegorov et al., 2021; Ivashkiv et al., 2019; Shelenko et al., 2023; Karbivska et al., 2024; Shpykuliak et al., 2025; Maksymova et al., 2024) analyse the development and activities of agricultural enterprises engaged in crop production, examining the existing problems and prospects for the development of the agricultural sector in Ukraine.

The analysis of scientific studies by Ukrainian and foreign economists on this topic made it possible to develop practical recommendations for forming mechanisms for adapting the agricultural sector across all links of the logistics chain under wartime conditions, with prospects for post-war recovery and reconstruction.

Methodology

In the course of the study, the method of spectral analysis based on Fourier series was applied to identify periodic patterns in the dynamics of economic indicators. This approach makes it possible to represent a complex time series as the sum of harmonic components with different frequencies and amplitudes, which allows the identification of hidden cycles, trends, and seasonal fluctuations.

For a continuous function *f(x)*, that is periodic with period 2*π*, the Fourier series expansion has the following form:

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left[a_n \cos(nx) + b_n \sin(nx) \right], \quad (1)$$

where the coefficients a_n and b_n are calculated according to the formulas:

$$a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x) \cos(nx) dx, \quad b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x) \sin(nx) dx, \quad (2)$$

The Discrete Fourier Transform (DFT) was used to analyse economic data presented as a discrete time series (e.g., quarterly or annual values of profit, yield, expenditure levels, etc.):

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-2\pi ikn/N}, \quad k = 0, 1, \ldots, N-1, \quad (3)$$

where:

x_n – input series value,

N – number of observations,

X_k – spectral component.

In practice, the calculations are performed using the Fast Fourier Transform (FFT) algorithm. The interpretation of the analysis results is carried out by constructing an amplitude spectrum, which reflects the contribution of each harmonic component to the overall structure of the time series. The identification of dominant frequencies makes it possible to draw conclusions regarding the presence of seasonal or cyclical processes. For the purpose of visualization and validation of the analysis results, time-series graphs, spectral diagrams, and signal reconstruction based on a limited number of principal harmonics were used.

To model the dynamics of the time series, the ARIMA (*Autoregressive Integrated Moving Average*) approach was applied, which allows for accounting for the internal temporal dependence of the indicator, as well as trend and seasonal components. The methodology includes a preliminary analysis of the time series in order to identify trend and seasonality, testing for stationarity, and, if necessary, eliminating non-stationarity through differencing. Subsequently, the optimal model structure was identified based on autocorrelation analysis and information criteria. After estimating the parameters, the adequacy of the model was verified through residual analysis. At the final stage, a forecast was generated and confidence intervals were determined. Such an approach ensures statistically grounded modeling of seasonal dynamics and short-term forecasting of the studied indicator.

Research Results

To assess the efficiency of Ukraine's agricultural export sector, we conducted a forecast of the time series of grain transshipment in Ukrainian ports based on the extrapolation of data for 2005–2024 for the subsequent four-year period (2025–2028). This time series also includes the period of the beginning of the Russian military aggression, namely 2022–2024.

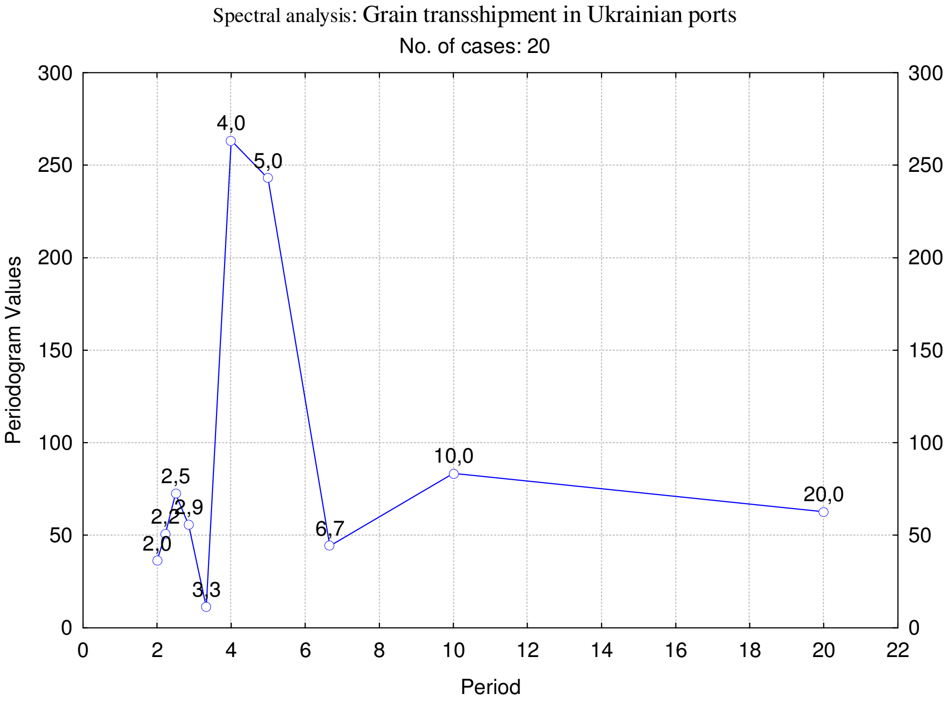
The information base of the study consists of statistical data from the Ukrainian Grain Association, obtained from the Ministry of Agrarian Policy and Food of Ukraine. It should be noted that exports, after a significant decline in 2022, increased substantially in 2023–2024, which made it possible to reach a record level in 2024 for the entire observation period. Undoubtedly, these trends influenced the structure of the time series and, accordingly, the forecast results.

Vol. 25. № 1 (96). January–March 2026.
ISSN 2519-4070

At the first stage of the analysis, our objective was to identify clearly expressed frequencies (cycles) within this time series. This can be achieved using the Fourier analysis method. The results of the spectral analysis of the dynamics of grain transportation (including oilseed crops) in Ukrainian ports for the period 2005–2024 are presented in Figure 1.

Figure 1

Dynamics of grain and oilseed transshipment through ports, 2005–2024

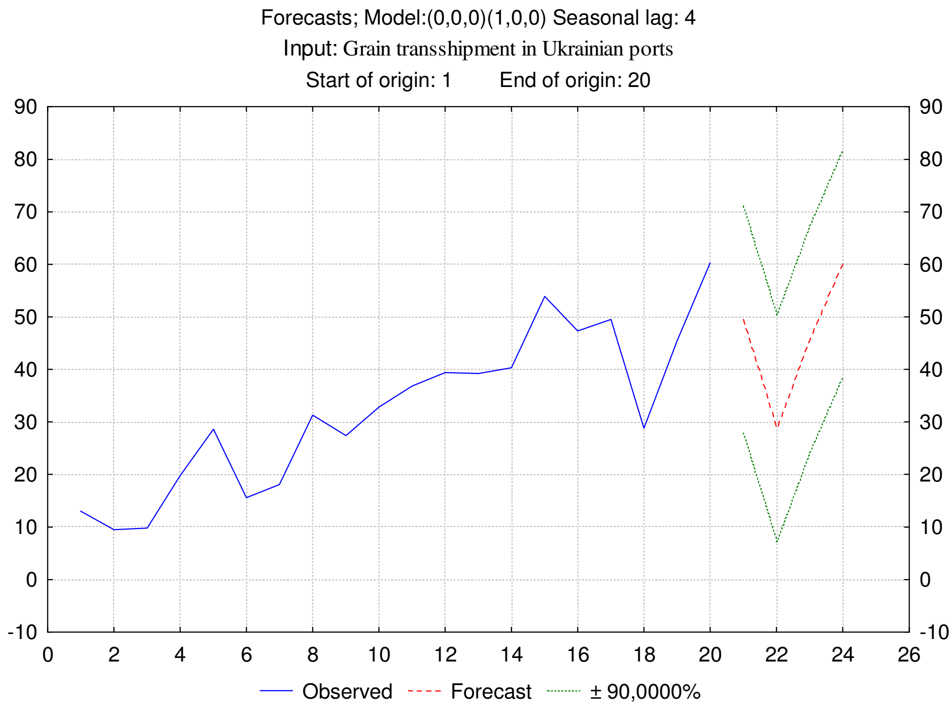


Source: compiled by the authors based on statistical data from the Ukrainian Grain Association (2025).

As shown in Figure 2, the most prominent frequency in the time series is four years. This indicates a hidden cycle with a duration of approximately four years. Consequently, given this specific feature of the time series, it was decided to perform forecasting for this exact period – namely 4 years, covering 2025–2028. For this purpose, the Autoregressive Moving Average function was used.

Figure 2

Dynamics of forecasted export data for seeds, grain, and oilseed products in Ukrainian ports for the period 2005–2028.



Source: compiled by the authors based on statistical data from the Ukrainian Grain Association (2025).

At the same time, the software product we used (Statistica 12.0) allows us to carry out the most probable forecast, as well as two additional forecasts that cover positive and negative trends with a 90% probability.

The results obtained are presented in Table 1. They indicate that the nature of the previous data provides grounds to predict that in 2025, according to the most probable scenario, the volume of grain transshipment will be 49.5 million tons, which is significantly less than in 2024 (60.3 million tons). However, they may decrease even further in 2026 to 28.8 million tons. From our point of view, this is a low level of grain transshipment, but it is entirely possible, as this exact volume of grain transshipment occurred in 2022.

Table 1

Forecasted grain transshipment data in Ukraine for 2025–2028

	Forecast; Model: (0,0,0)(1,0,0) Seasonal lag: 4 (Forecast) Input: Grain transshipment in Ukrainian ports Start of origin: 1 End of origin: 20			
CaseNo.	**Forecast**	Lower 90.0000%	Upper 90.0000%	Std.Err.
21	49.49841	27.87962	71.11720	12.50268
22	28.79908	7.18028	50.41787	12.50268
23	45.49854	23.87974	67.11733	12.50268
24	60.29806	38.67927	81.91686	12.50268

Source: compiled by the authors.

In this case, this scenario unfolded due to the intensification of enemy attacks on port infrastructure. In 2027, the volume of grain transshipment is projected at 45.5 million tons. At the same time, in 2028, it is expected to reach 60.3 million tons, returning to the 2024 level. Under the optimistic scenario, the transshipment volume would amount to 81.9 million tons, while under the pessimistic scenario, it would be 38.7 million tons.

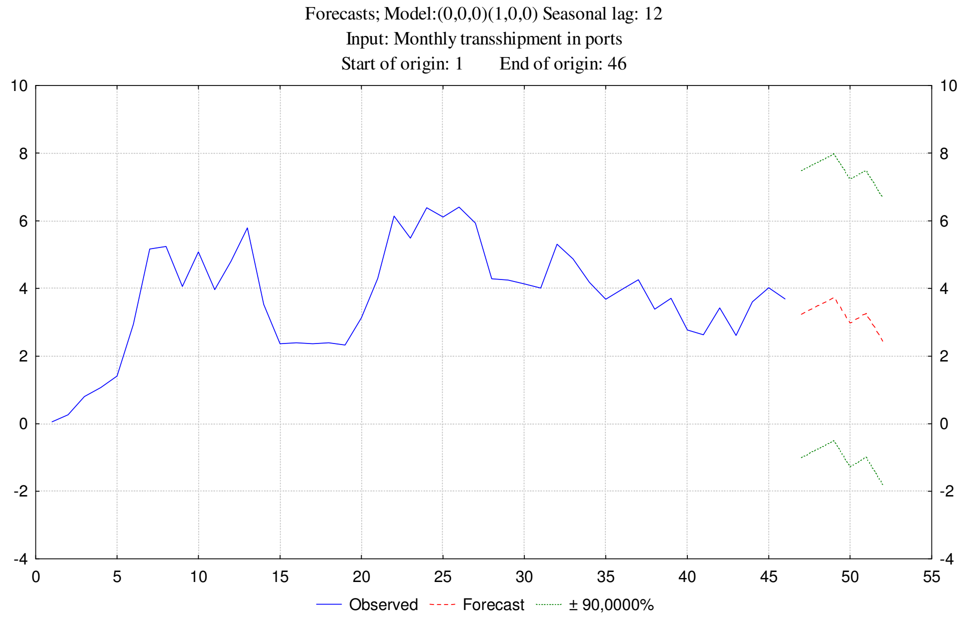
Thus, we observe significantly different scenarios for the possible course of events. Which one is more likely will be determined by the 2025 results once the initial data are officially released.

To study the short-term dynamics of monthly grain transshipment in seaports, a seasonal autoregressive integrated moving average model, ARIMA, with the specification (0,0,0) (1,0,0) was applied. The information base for the study consists of data on the cargo turnover of Ukrainian ports provided by the Center for Transport Strategies for 2022–2024. The chosen model assumes the presence of one seasonal autoregressive parameter with a 12-month lag, corresponding to annual seasonality, without the inclusion of non-seasonal components or integration. This specification indicates that the series is stationary in levels and that a regular seasonal structure dominates the formation of transshipment volumes (Figure 3).

The estimated seasonal autoregressive coefficient is 0.8792 and is statistically significant at a high confidence level ($p < 0.001$). The t-statistic value is 8.51, confirming the robustness of the obtained estimate. The coefficient is close to unity, indicating pronounced seasonal inertia in the process: approximately 88% of the variation in the current monthly transshipment volume is explained by the level of the corresponding month of the previous year.

Figure 3

Dynamics and forecasting of monthly grain cargo transshipment, 2022–2026



Source: compiled by the authors based on statistical data from the Ukrainian Grain Association (2025).

This result is economically justified, as grain transshipment in ports is strictly tied to the cyclical nature of agricultural production, harvest seasons, export contract schedules, and the annual structure of international demand (Table 2).

Based on the estimated model, a forecast of monthly grain transshipment in ports was generated for the first half of 2026. Since the model contains only a seasonal autoregressive component with a 12-month lag, the forecast values are formed primarily through the inertial reproduction of the previous year's seasonal profile (Table 3).

The obtained results indicate the persistence of a wave-like pattern in the dynamics throughout 2026. In the first half of the year, relative stability is expected with minor fluctuations around the average seasonal level. This corresponds to the traditional decline in transshipment intensity during the inter-seasonal period and the partial use of grain stocks accumulated in previous months.

Table 2

Results of the seasonal autoregressive integrated moving average (ARIMA) model for short-term dynamics of monthly grain transshipment in seaports

	Input: Monthly transshipment in ports (Forecast) Transformation: none Model: (0,0,0)(1,0,0) Seasonal lag: 12 MS Residual=6.3805					
Paramet.	**Param.**	Asympt. Std. Err	Asympt. t(45)	p	Lower 95% Conf	Upper 95% Conf
Ps(1)	**0.879176**	0.103355	8.506392	0.000000	0.671009	1.087344

Source: compiled by the authors.

Table 3

Forecast scenarios for monthly grain exports in ports for 2026

	Forecast; Model: (0,0,0)(1,0,0) Seasonal lag: 12 (Forecast) Input: Monthly transshipment in ports Start of origin: 1 End of origin: 46			
CaseNo.	**Forecast**	Lower 90.0000%	Upper 90.0000%	Std.Err.
47	3.236740	-1.00543	7.478913	2.525964
48	3.488169	-0.75400	7.730342	2.525964
49	3.738475	-0.50370	7.980649	2.525964
50	2.975701	-1.26647	7.217874	2.525964
51	3.255230	-0.98694	7.497403	2.525964
52	2.439862	-1.80231	6.682036	2.525964

Source: compiled by the authors.

In the middle of the year, the forecast shows a gradual increase in transshipment volumes, which corresponds to the period of intensified export operations following the formation of a new harvest and the conclusion of export contracts. However, the model does not predict sharp spikes, which can be explained by the absence of a trend component in the model specification and the assumption of stability in the seasonal structure.

In the second half of the year, a decline in indicators is expected after the seasonal peak has passed. Such dynamics are typical for the annual cycle of grain logistics, where maximum transshipment volumes are concentrated in the post-harvest period and subsequently gradually decrease.

At the same time, the analysis of the forecast confidence intervals indicates considerable variability in the possible actual values. The width of the intervals remains significant throughout the entire forecasting horizon, reflecting a high level of uncertainty under unstable external conditions. This means that although the baseline scenario predicts a seasonally stabilized pattern of transshipment in 2026, the actual volumes may deviate either toward growth or decline.

Thus, the forecast for 2026 indicates the preservation of annual seasonality as the key factor shaping grain transshipment volumes in ports. The model does not predict structural breaks or abrupt changes in trends; however, the high level of uncertainty requires careful interpretation of the results.

Conclusions

The obtained results indicate that the dynamics of grain and oilseed transshipment through Ukrainian seaports during wartime have a complex multi-component structure, combining long-term cyclical fluctuations and short-term seasonal inertia.

The application of spectral analysis based on Fourier series made it possible to identify the presence of hidden cyclicality in the time series. The most pronounced harmonic component corresponds to a cycle of approximately four years, indicating the existence of a medium-term cycle in the dynamics of grain cargo transshipment. Such periodicity may result from a combination of agricultural production cycles, fluctuations in global grain market conditions, logistical constraints, and wartime infrastructure risks. The identified four-year cycle justifies the feasibility of constructing forecasts specifically for the 2025–2028 horizon.

The results of annual forecasting revealed the presence of alternative development scenarios. The most probable scenario predicts a decline in transshipment volumes in 2025–2026, followed by a recovery in 2027–2028 to a level close to the record indicators of 2024. At the same time, the optimistic and pessimistic scenarios demonstrate considerable variability in possible values, confirming the high sensitivity of port logistics to security and market factors.

Monthly forecasting using the ARIMA model confirmed the presence of clearly expressed annual seasonality. The statistically significant seasonal autoregressive coefficient (0.8792) indicates a high level of inertia: almost 88% of the variation in current monthly volumes is explained by the corresponding indicators of the previous year. This demonstrates the dominance of the seasonal factor in shaping the short-term dynamics of grain transshipment.

The forecast for 2026 demonstrates the continuation of the wave-like pattern of dynamics without signs of sharp structural changes. The average forecast level of transshipment remains within a stable range, while the amplitude of seasonal fluctuations is moderate. At the same time, the considerable width of the confidence intervals indicates a high level of uncertainty, caused by wartime risks, the condition of port infrastructure, crop yields, global prices, the functioning of export corridors, regulatory decisions, and geopolitical risks.

Thus, the combination of Fourier spectral analysis and ARIMA modeling made it possible to comprehensively assess both the medium-term cyclical patterns and the short-term seasonal structure of grain transshipment. Fourier analysis revealed a fundamental four-year cycle, while the ARIMA model confirmed the annual seasonal inertia of the process. The obtained results provide a methodological basis for scenario forecasting and strategic planning of the development of Ukraine's export logistics under conditions of wartime instability.

Acknowledgements

This work was supported by the Erasmus+ program of the European Union (project 101239881 – EUROWUNU – ERASMUS-JMO-2025-HEI-TCH-RSCH "Jean Monnet Chair of European Integration at West Ukrainian National University" (EUROWUNU)). The European Commission support for the publication of this article does not constitute an endorsement of the contents, which reflects the views of the authors only, and the Commission cannot be held responsible for any use, which may be made of the information contained therein.

References

Ay, H. M., & Söylemez, A. (2023). Grain corridor agreement and Turkey's role in the Russia-Ukraine war. *Journal of Islamic World and Politics*, *7*(1), 1–10. https://doi.org/10.18196/jiwp.v7i1.27

Bernal, M. L., Choi, Y.-S., Krivoshapkina, M., & Yeo, G.-T. (2025). Analysis of the competitive structure of the grain terminal in the West Coast region of South Korea. *The Asian Journal of Shipping and Logistics*, *41*(3), 119–128. https://doi.org/10.1016/j.ajsl.2025.06.001

Bezpartochnyi, M., & Britchenko, I. (2022). Export logistics of agricultural products of Ukraine in the context of ensuring food security during martial law. In *Current issues of security management during martial law* (pp. 163–184). University of Security Management in Košice. https://philpapers.org/archive/BEZELO.pdf

Bodnar, O., Halchynska, Yu., Larina, Ya., Filatova, A., & Stepanets, I. (2024). Logistics transformation on grain and oilseeds markets during the war in

Ukraine: Marketing approaches and strategies. *Scientific Horizons*, *27*(9), 134–147. https://doi.org/10.48077/scihor9.2024.134

Caramuta, C., Grosso, A., & Longo, G. (2023). Logistics chain responsiveness to war impacts: A case study in North Adriatic Region. *Case Studies on Transport Policy*, *14*, Article 101086. https://doi.org/10.1016/j.cstp.2023.101086

Centre for Transport Strategies. (2023, December 21). *The Ukrainian maritime corridor – a key breakthrough of 2023* [in Ukrainian]. https://cfts.org.ua/ articles/ukranskiy_morskiy_koridor __klyuchoviy_uspikh_2023_roku_

Cheremisina, S., Rossokha, V., Selinnyi, M., Balan, O., & Nahornyi, V. (2025). Assessment of structural changes in exports and price situation on the Ukrainian grain market during the war. *Ekonomika APK*, *32*(2), 50–62. https://doi.org/10.32317/ekon.apk/2.2025.50

Devadoss, S., & Ridley, W. (2024). Impacts of the Russian invasion of Ukraine on the global wheat market. *World Development*, *173*, Article 106396. https://doi.org/10.1016/j.worlddev.2023.106396

Feng, F., Jia, N., & Lin, F. (2023). Quantifying the impact of Russia–Ukraine crisis on food security and trade pattern: Evidence from a structural general equilibrium trade model. *China Agricultural Economic Review*, *15*(2), 241–258. https://doi.org/10.1108/CAER-07-2022-0156

Goedhals-Gerber, L. (2016). Predicting the throughput of grain products at the multipurpose terminal at the Port of Cape Town. *Journal of Transport and Supply Chain Management*, *10*(1), Article a249. https://doi.org/10.4102/jtscm.v10i1.249

Goyal, R., & Steinbach, S. (2023). Agricultural commodity markets in the wake of the black sea grain initiative. *Economics Letters*, *231*, Article 111297. https://doi.org/10.1016/j.econlet.2023.111297

Iegorov, B., Kravchyk, Y., Rybalko, S., Ivashkiv, I., & Chub, A. (2021). The methodical approach of the substantiation of the evaluation indicators system of the agro-industrial complex development. *Universal Journal of Agricultural Research*, *9*(5), 191–199. https://doi.org/10.13189/ujar.2021.090506

Ihle, R., Bar-Nahum, Z., Nivievskyi, O., & Rubin, O. D. (2022). Russia's invasion of Ukraine increased the synchronisation of global commodity prices. *The Australian Journal of Agricultural and Resource Economics*, *66*(4), 775–796. https://doi.org/10.1111/1467-8489.12496

Ivashkiv, I., Korol, S., Lyashenko, O., Sadovska, I., & Nadvynychnyy, S. (2021). Financial and economic evaluation of agricultural insurance market in Ukraine. *Agricultural and Resource Economics International Scientific E-Journal*, *7*(3), 44–59. https://doi.org/10.51599/are.2021.07.03.03

Ivashkiv, I., Kupalova, H., Goncharenko, N., Khrutba, Y., & Vovk, I. (2019). Optimization of commodity flows: The case of bakery enterprises of Ukraine.

Montenegrin Journal of Economics, *15*(3), 205–216. https://doi.org/10.14254/1800-5845/2019.15-3.15

Jagtap, S., Trollman, H., Trollman, F., Garcia-Garcia, G., Parra-López, C., Duong, L., Martindale, W., Munekata, P. E. S., Lorenzo, J. M., Hdaifeh, A., Hassoun, A., Salonitis, K., & Afy-Shararah, M. (2022). The Russia-Ukraine conflict: Its implications for the global food supply chains. *Foods*, *11*(14), Article 2098. https://doi.org/10.3390/foods11142098

Jeong, S.-H., Choi, Y.-S., Listan Bernal, M., & Yeo, G.-T. (2024). Analysis of obstacles to lowering demurrage at grain terminals in South Korea. *The Asian Journal of Shipping and Logistics*, *40*(1), 30–35. https://doi.org/10.1016/j.ajsl.2023.12.003

Kakabadze, M. (2023). *The Black Sea Grain Initiative: Analysing the emerging, implementation and challenges* [Master's thesis, World Maritime University]. The Maritime Commons. https://commons.wmu.se/cgi/viewcontent.cgi?article=3271&context=all_dissertations

Karakas, S., Kirmizi, M., Gencer, H., & Cullinane, K. (2024). A resilience assessment model for dry bulk shipping supply chains: The case of the Ukraine grain corridor. *Maritime Economics & Logistics*, *26*, 391–413. https://doi.org/10.1057/s41278-023-00277-7

Karbivska, U., Kunychak, G., Dutchak, O., Karpuk, L., Tatarchuk, L., Kashtanova, T., Shelenko, D., Hryhoriv, Y., Gniezdilova, V., & Sluchyk, I. (2024). Application of biologization elements in buckwheat organic cultivation technology. *Ecological Engineering & Environmental Technology*, *25*(5), 235–242. https://doi.org/10.12912/27197050/186125

Kishchak, I. T., & Porudieieva, A. V. (2018). Sea ports of Ukraine in the context of improving their competitiveness [in Ukrainian]. *Pryazovskyi Economic Herald*, *6*(11), 42–46. http://pev.kpu.zp.ua/journals/2018/6_11_uk/10.pdf

Maksymova, I., Kurylyak, V., Mietule, I., Arbidane, I., & Kurilyak, M. (2024). Digitally driven model of a climate-neutral economy in terms of global financial capacity. *Financial and Credit Activity: Problems of Theory and Practice, 3*(56), 334–349. https://doi.org/10.55643/fcaptp.3.56.2024.4399

Martins, A. M. (2024). Short-term market impact of Black Sea Grain Initiative on four grain markets. *The Journal of Futures Markets, 44*(4), 619–630. https://doi.org/10.1002/fut.22481

Ministry for Communities and Territories Development of Ukraine. (2025, August 16). *Two years of resilience of the Ukrainian corridor: Over 137 million tons of cargo transported by sea* [in Ukrainian]. https://mindev.gov.ua/news/dva-roky-stiikosti-ukrainskoho-korydoru-morem-perevezeno-ponad137-mln-tonn-vantazhiv

Mottaleb, A. K., Kruseman, G., & Snapp, S. (2022). Potential impacts of Ukraine-Russia armed conflict on global wheat food security: A quantitative exploration. *Global Food Security*, *35*, Article 100659. https://doi.org/10.1016/j.gfs.2022.100659

Mulyk, T., & Mulyk, Y. (2022). Exports of Ukrainian agricultural products to the European union: Analytical assessment, problems and prospects. *Three Seas Economic Journal*, *3*(3), 49–57. https://doi.org/10.30525/2661-5150/2022-3-8

Munim, Z., Fiskin, C., Nepal, B., & Chowdhury, M. (2023). Forecasting container throughput of major Asian ports using the Prophet and hybrid time series models. *The Asian Journal of Shipping and Logistics*, *39*(2), 67–77. https://doi.org/10.1016/j.ajsl.2023.02.004

Rose, A., Chen, Z., & Wei, D. (2023). The economic impacts of Russia-Ukraine war export disruptions of grain commodities. *Applied Economic Perspectives and Policy, 45*(2), 645–665. https://doi.org/10.1002/aepp.13351

Rusnak, A., Nadtochii, I., & Lomonosov, D. (2021). Factors of formation of competitiveness and sustainable development of seaports in Ukraine [in Ukrainian]. *Ekonomika ta Derzhava*, (2), 24–28. https://doi.org/10.32702/2306-6806.2021.2.24

Shelenko, D., Kijek, A., & Shpykuliak, O. (2023). Determination of organizational and economic determinants of the current state and development trends of agricultural producers in Poland and Ukraine. *Journal of Vasyl Stefanyk Precarpathian National University, 10*(4), 17–30. https://doi.org/10.15330/jpnu.10.4.17-30

Shpykuliak, O., Humeniuk, M., Shelenko, D., Nemish, D., & Balaniuk, S. (2025). Management of farm development and their role in the socio-economic recovery of rural areas. *Journal of Vasyl Stefanyk Precarpathian National University*, *12*(2), 101–115. https://doi.org/10.15330/jpnu.12.2.101-115

Stukalo, N. V., Lytvyn, M. V., Petrushenko, Y. M., Pylypenko, Y. I., & Kolinets, L. B. (2021). The concept of sustainable development of Ukraine in the context of global threats. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *2021*(3), 178–183. https://doi.org/10.33271/nvngu/2021-3/178

Ukrainian Grain Association. (2025). *The state of foreign trade in agricultural products*. https://uga.ua/eksportni-pokazniki/

Yanovska, V., Król, M., & Pittman, R. (2025). The logistics of grain exports from wartime Ukraine: What are the highest priority areas to address? *Transportation Research Interdisciplinary Perspectives, 30*, Article 101363. https://doi.org/10.1016/j.trip.2025.101363

Received: October 3, 2025.
Reviewed: March 9, 2026.
Accepted: March 17, 2026.