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Modelling of the factor influence of grain market performance indicators on Ukraine's GDP

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▸ **Abstract.** The study addressed the impact of grain market performance indicators on the dynamics of Ukraine's gross domestic product in the context of structural transformations and military challenges. The study aimed to quantitatively determine the strength, direction and nature of the impact of production, export and structural indicators of grain market development on the country's macroeconomic performance, using economic and mathematical tools. The research methods included statistical analysis of the dynamics of indicators for 2010-2025, correlation analysis, and correlation-regression modelling. A distinctive feature of the methodological approach was the use of variational modelling, which involved constructing several alternative models with different sets of factor variables and testing them against criteria of statistical significance. The results of the study showed that Ukraine's grain market has transformed into a highly specialised, export-oriented sector: gross grain harvest increased from 39.27 million tonnes in 2010 to 86.01 million tonnes in 2021, and exports – from 2.47 to USD 12.34 billion. The study established that the most significant impact on GDP was exerted by agricultural exports (r = 0.608), whereas the impact of grain exports was moderate (r = 0.415) and had a negative coefficient in the regression models (-21.4…-23.0), indicating a raw material orientation effect. The study demonstrated that production indicators do not have a direct statistically significant impact (r = 0.104) but are realised through export channels. At the same time, a 1% increase in the share of grain in agricultural exports is accompanied by a USD 335 million decrease in GDP, whereas an increase in the share of grain in total exports leads to a 242 million USD rise in GDP. The application of a variational approach to econometric modelling has revealed that the impact of the grain market on GDP is non-linear and structurally determined, with the decisive factors being not production volumes but the parameters of export integration. The practical significance of the results lies in their potential application in the formulation of state agricultural policy, particularly for the transition from a raw material export model to a model with higher added value, which will contribute to improving the efficiency of the grain sector and strengthening macroeconomic stability

▸ **Keywords:** agricultural sector; agricultural exports; econometric modelling; structural factors; raw material orientation; macroeconomic indicators

▸ Introduction

The development of Ukraine's economy is characterised by the growing role of the agricultural sector as a key factor in macroeconomic stability and international competitiveness. The grain market is a notable element within this structure, ensuring the country's food security, generating a significant share of foreign exchange earnings and export potential, and influencing the country's gross domestic product. At the same time, the grain market operates amid military risks, logistical constraints, instability in global market conditions and structural transformations of the economy. This highlights the need for scientific research into the actual contribution of the grain market to Ukraine's gross domestic product (GDP), in particular through an assessment of the direct and indirect effects of its development. It is necessary to determine whether growth in grain production and exports leads to a corresponding increase in value added. Therefore, research into the factor-level impact of grain market indicators on GDP, using economic and mathematical methods, is both timely and of practical significance.

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Studies on the global significance of grain markets occupy a prominent place in contemporary academic discourse. S. Kozlovskyi *et al.* (2024) argued that disruptions to Ukrainian grain supplies have a negative impact on food security and exacerbate the risks of malnutrition in importing countries. A. Rose *et al.* (2023) quantified the economic consequences of reduced grain exports due to the war and identified a multiplier effect on the global economy. D. Prajapati *et al.* (2022) highlighted the significance of transportation routes and grain supply chain optimisation as a key factor in enhancing the efficiency of the agricultural sector in the context of globalisation. S. Jagtap *et al.* (2022) also confirm that logistical disruptions in the Black Sea region have led to rising global food prices and the destabilisation of global supply chains. P. Khatri *et al.* (2024) expand on this approach, emphasising the interconnected nature of contemporary risks in agriculture and food systems, where geopolitical, climatic and logistical factors reinforce one another. S.R. Tushar *et al.* (2023) highlight the importance of stable grain storage as an element of food security and supply continuity. The study emphasised the impact of geopolitical factors on agricultural markets. For instance, O. Polat *et al.* (2023) established a close correlation between the level of geopolitical tension and the volatility of agricultural commodity markets, confirming the grain sector's high sensitivity to external shocks.

At the same time, an analysis of academic sources has shown that most studies focus either on sector-specific aspects of the grain market's development or on macroeconomic analysis without detailing sector-specific factors. At the same time, issues relating to the comprehensive quantitative assessment of the impact of grain market performance indicators on Ukraine's GDP, incorporating their structural differentiation, remain underdeveloped. In particular, the scientific literature lacks a unified approach to distinguishing between the direct and indirect effects of production and export factors; assessing the role of the structural characteristics of the grain market; and constructing variable econometric models whilst accounting for the problem of multicollinearity. Thus, there is an objective need to deepen research in the direction of a comprehensive economic and mathematical analysis of the impact of grain market performance indicators on macroeconomic outcomes. This justifies the conduct of this study and determines its scientific novelty and practical significance.

The study aimed to quantitatively assess the impact of grain market performance indicators on Ukraine's gross domestic product using economic and mathematical modelling, and to identify the key drivers of economic growth in the context of structural transformations and military challenges. Achieving this aim necessitated addressing the following research objectives:

1) to analyse the trends and structural changes in the indicators of the Ukrainian grain market's performance between 2010 and 2025, in particular production, export and structural indicators;

2) to assess the role of the grain market in shaping macroeconomic outcomes by identifying trends in the share of grain exports within GDP and the country's foreign trade structure, and to determine the strength and direction of the relationship between grain market indicators and Ukraine's GDP;

3) to develop and test alternative econometric models (export, export-production and structural-export models), and to assess their parameters, statistical significance and predictive capabilities.

▸ Literature review

The functioning of the grain market and its impact on macroeconomic indicators are the subject of active academic research. Contemporary academic approaches demonstrate that the grain sector is central in ensuring food security, formation export potential and maintaining macroeconomic stability in countries with an agricultural focus. In particular, Yu.O. Voloshchuk & O.V. Shedlovska (2024) argued that Ukraine's grain market is a system-forming element of the agri-food system, the efficiency of which is determined by institutional, organisational and market factors. V. Nedashkivskyi *et al.* (2024) also view the grain market as a key component of Ukraine's agri-food market, emphasising its strategic importance for ensuring the stability of agricultural production. K.V. Bliumska-Danko & M.A. Zaidenko (2023) argue that the development of grain production directly influences the competitiveness of the agricultural sector and the stability of domestic food security. Yu.I. Haida & B.L. Shainiuk (2023), analysing global trends in the development of the grain market, highlight the growing role of international competition and structural transformations in the global trade in grain crops.

A separate area of research focuses on the foreign trade aspects of the grain market. L.O. Kibalnyk & A.V. Cherkashchenko (2025) established that grain exports are one of Ukraine's main sources of foreign exchange earnings, but their effectiveness depends significantly on the state of the logistics infrastructure and the conditions of global markets. G. Filiuk (2025) demonstrates that, in the context of the Russian armed aggression, Ukrainian grain exports have undergone significant changes in terms of geographical concentration, supply routes and foreign trade risks. A. Panfilova *et al.* (2025) also noted that the war caused a transformation in the geography of exports, an increase in transport costs and a reorientation of sales channels. O. Sheremetynska (2025) emphasises that maintaining the export capacity of the grain sector has become one of the key factors in Ukraine's macro-financial stability during the crisis.

A separate area of research concerns the application of economic and mathematical methods to assess the impact of sectoral factors on economic growth. O. Lyutak *et al.* (2024) demonstrate the effectiveness of multi-factor modelling of the impact of economic and structural factors on countries' economic growth. D.L. Tarasenko (2018) emphasises the importance of modelling complex socio-economic processes for the formulation of sound management decisions. The results obtained indicate that export-oriented sectors can be significant for economic development; however, their impact depends on the level of domestic processing, productivity and value added.

▸ Materials and methods

The methodological framework of the study comprised a combination of general scientific and specialised research

methods, which was used for a comprehensive analysis of the impact of grain market performance indicators on Ukraine's gross domestic product. The information base for the study consisted of data from the Official website of the State Statistics Service of Ukraine (n.d.), information materials from the Ministry of Finance (n.d.) and the Ministry of Economy of Ukraine (n.d.), reflecting the retrospective dynamics of the functioning and development of Ukraine's grain market in 2010-2025.

To achieve the stated objective, a range of scientific research methods were used: comparative analysis to assess trends in key indicators (yield, gross harvest, exports, and sub-indicators), as well as their variation over time; correlation analysis to determine the strength and direction of the relationship between indicators of the grain market's development and Ukraine's GDP, as well as to identify multicollinearity among the explanatory variables; econometric (correlation-regression) modelling to quantitatively assess the impact of selected factors on the outcome indicator (GDP), construct functional relationships and determine the strength of influence of individual indicators; a variant approach to modelling, involving the development of several alternative models (export, export-production and structural-export), differing in the composition of their explanatory variables, with the aim of enhancing the reliability of the results and avoiding the problem of multicollinearity; methods of economic and statistical hypothesis testing, in particular, the use of the coefficient of determination (R^2), Fisher's criterion and Student's t-test, p-values and 95% confidence intervals at a significance level of $\alpha = 0.05$ to assess the adequacy of the models and the statistical significance of their parameters; graphical and tabular methods to visualise the research results and summarising the data obtained.

In the modelling process, Ukraine's GDP Y was used as the outcome variable, whilst the explanatory variables comprised indicators of the functioning of the grain market, grouped into three categories: export, production and structural. The general form of the multiple regression model can be expressed as follows:

$$Y_t = \beta_0 + \sum_{i=1}^{n} \beta_i X_{it} + \varepsilon_t, \quad (1)$$

where Y_t – gross domestic product in period t; X_{it} – i-th factor variable; β_0 – free variable; β_i – model parameters; ε_t – random error. Export model:

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \beta_3 X_{3t} + \varepsilon_t, \quad (2)$$

where X_1 – exports of agricultural products; X_2 – total exports of goods; X_3 – grain exports. Export-oriented production model:

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \beta_3 X_{3t} + \beta_4 X_{4t} + \varepsilon_t, \quad (3)$$

where X_4 – gross grain harvest. Structural export model:

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \beta_3 X_{3t} + \beta_4 X_{4t} + \varepsilon_t, \quad (4)$$

where X_1 – grain export; X_2 – proportion of grain in agricultural exports; X_3 – proportion of grain in total exports; X_4 – share of grain exports in GDP.

In the econometric analysis, Ukraine's gross domestic product was used as the dependent variable (Y). To assess the impact of the grain market, three variable models with different sets of explanatory variables were employed. In the export model, the factors included were: X_1 – agricultural exports, X_2 – total merchandise exports, X_3 – grain exports. In the export-production model, the production factor X_4 – gross grain harvest – was additionally covered. The structural-export model utilised the following variables: X_1 – grain exports, X_2 – the share of grain in agricultural exports, X_3 – the share of grain in the country's total merchandise exports, X_4 – the share of grain exports in Ukraine's GDP. These factors were selected considering the economic significance of the indicators, the results of correlation analysis, and the need to minimise multicollinearity between variables. The practical implementation of calculations, statistical data processing, and the construction of econometric models was conducted using the Microsoft Excel software package.

Results

An analysis of trends in indicators of the Ukrainian grain market's performance between 2010 and 2025 reveals the presence of distinct structural transformations, reflecting both internal shifts in production and the influence of external economic and institutional factors. First and foremost, it is worth noting that the area under grain crops remained relatively stable throughout the period under review (14.5-15.9 million hectares in 2010-2021), indicating an extensively stabilised pattern of land use. At the same time, since 2022, there has been a significant reduction in sown areas (to 11.8 million hectares) due to the war and the loss of some agricultural land. A gradual recovery is projected for 2024-2025 (to 11.6 million hectares), although figures remain below pre-war levels (Table 1).

Table 1. Trends in indicators of the Ukrainian grain market, 2010-2025

Indicators	2010	2012	2014	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Area harvested for grain crops, thousand hectares	14576	14792	14627	14337	14560	14794	15292	15283	15948	11773	10836	11106	11572
Gross grain harvest, million tonnes	39.27	46.22	63.86	66.09	61.69	70.06	75.14	64.93	86.01	53.86	59.77	56.25	60.79
Gross wheat harvest, million tonnes	16.85	15.76	24.11	26.04	26.16	24.61	28.37	24.88	32.15	20.73	21.63	22.44	23.51
Gross corn harvest, million tonnes	11.95	20.96	28.5	28.01	25.67	35.8	35.88	30.29	42.11	26.19	31.03	26.86	29.06
Yield of cereal crops, tonnes per hectare	26.9	31.2	43.7	46.1	42.5	47.4	49.1	42.5	53.9	45.8	55.2	50.6	52.5

Table 1, Continued

Indicators	2010	2012	2014	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Grain exports, billion USD	2.47	7	6.54	6.07	6.5	7.24	9.63	9.41	12.34	9.11	8.31	9.42	7.27
including wheat	0.91	2.36	2.29	2.72	2.76	3	3.66	3.6	5.07	2.68	2.94	3.74	2.99
corn	0.79	3.89	3.35	2.65	2.99	3.51	5.22	4.88	5.89	5.93	4.97	5.07	3.9
Share of grain in agricultural exports, %	24.9	39.2	39.2	39.8	36.6	38.9	43.5	42.4	44.5	38.9	37.8	38.1	30
Share of wheat and corn in grain exports, %	68.8	89.3	86.2	88.5	88.5	89.9	92.2	90.1	88.8	94.5	95.2	93.5	94.8
Share of grain in total exports, %	4.8	10.17	12.13	16.69	15.03	15.3	19.2	19.1	18.1	20.6	23	22.5	18
Grain production per business entity, tonnes	682.7	945.6	1262.1	1314.1	1135.6	1360.5	1467.6	1279.6	1741	1494.5	1365.1	1404.4	1533.1
Exports of agricultural products, USD	9.93	17.87	16.67	15.27	17.76	18.62	22.14	22.19	27.73	23.42	21.98	24.72	24.23
Total merchandise exports, USD	51.43	68.81	53.9	36.37	43.26	47.32	50.16	49.27	68.18	44.22	36.13	41.87	40.39
GDP, USD	134.9	175.5	132.2	95.4	112.1	131.9	147.9	155.2	203.4	143.5	176.3	189.2	215.2
Share of grain exports in the country's GDP, %	1.83	3.99	4.95	6.36	5.8	5.49	6.51	6.06	6.07	6.35	4.71	4.98	3.38

Source: compiled based on State Statistics Service of Ukraine (n.d.), Ministry of Finance of Ukraine (n.d.) and Ministry of Economy of Ukraine (n.d.)

In contrast to harvested areas, the gross harvest of cereal crops was characterised by greater fluctuations during the period under review. Production volumes rose from 39.27 million tonnes in 2010 to 86.01 million tonnes in 2021, before falling to 53.86 million tonnes in 2022 and partially recovering to 60.79 million tonnes in 2025. This trend indicates that grain production is highly sensitive to a combination of economic, technological and external factors. Grain crop yields during this period rose from 26.9 cwt/ha in 2010 to 53.9 cwt/ha in 2021, reaching a peak of 55.2 cwt/ha in 2023, which may indicate an increase in production efficiency and the growing role of intensive factors in the sector's development. Wheat and maize dominate the structure of production and exports, with their combined share of grain exports consistently exceeding 85%, reaching 94-95% in 2022-2025, which characterises a high level of market specialisation.

A key focus of the analysis was the export component of the grain market. The value of grain exports rose from USD 2.47 billion in 2010 to USD 12.34 billion in 2021, indicating a significant increase in the role of foreign markets in the sector's development. In 2022-2025, the indicator showed volatile trends within the range of USD 7.27-9.42 billion, which was due to logistical constraints, changes in supply routes and fluctuations in global market conditions.

The grain market is substantial in shaping the country's foreign trade potential. The share of grain in agricultural exports has ranged from 35% to 45% over the years, whilst its share in total goods exports has risen from 4.8% in 2010 to over 20% in 2022-2024, indicating the growing importance of the grain sector in the national economy. The share of grain exports in GDP, which rose from 1.83% in 2010 to over 6% in 2015-2022 is noteworthy. This reflects the growing role of the grain market in generating export revenues and ensuring the country's macroeconomic stability. At the same time, in 2023-2025, this figure decreased to 3.38%, driven by a decline in export volumes and a relative recovery in GDP. Further evidence of structural changes is the growth in grain production per business entity – from 682.7 tonnes in 2010 to 1,741 tonnes in 2021, which may indicate the consolidation of agricultural production and an increase in the concentration of resources.

During the period under review, Ukraine's grain market evolved from a relatively stable, extensive model to an intensive, export-oriented system characterised by a high degree of specialisation and a significant contribution to GDP. Despite the significant destabilising factors of the war period, the sector has demonstrated its ability to adapt, confirming the relevance of further research into the impact of its indicators on the country's macroeconomic performance.

An analysis of trends in indicators of the Ukrainian grain market's performance has revealed significant structural changes in both the production and export components of the sector and has confirmed its significant role in shaping macroeconomic outcomes, particularly gross domestic product. The identified trends – rising yields, intensification of production, a strong export orientation and a significant share of grain exports in GDP – highlight a potentially close correlation between indicators of the grain market's development and the dynamics of the country's economic growth.

At the same time, the descriptive analysis is predominantly qualitative in nature and does not provide a quantitative assessment of the strength, direction and

statistical significance of the impact of individual factors on GDP. In particular, the question remains as to which specific indicators (production, structural or external economic) make the greatest contribution to changes in macroeconomic parameters, and to what extent this influence is stable across different periods, including the pre-crisis and wartime periods.

The construction of correlation matrices for various groups of factors was used for a preliminary quantitative assessment of the strength and direction of the relationships between indicators of the grain market's performance and Ukraine's gross domestic product, as well as the identification of potential multicollinearity issues in subsequent modelling. Analysis of the correlation matrix shows that the indicator of agricultural exports (r = 0.608) has the strongest direct statistical relationship with Ukraine's GDP, indicating a moderately high positive correlation between these variables. At the same time, the correlation between GDP and grain exports (r = 0.415), as well as total goods exports (r = 0.398), is moderate, indicating a direct but less pronounced relationship between the indicators (Table 2). The conclusions regarding the strength of the factors' influence on the resulting indicator are confirmed by the results of further regression analysis and the testing of the statistical significance of the model parameters.

Table 2. Correlation matrix showing the relationship between the factors influencing grain market performance indicators and Ukraine's GDP (export model)

Factors	Ukrainian GDP, billion USD	Exports of agricultural products, USD	Total merchandise exports, USD	Grain exports, billion USD
Ukrainian GDP, billion USD	1	-	-	-
Exports of agricultural products, USD	0.60833	1	-	-
Total merchandise exports, USD	0.39751	-0.09288	1	-
Grain exports, billion USD	0.414517	0.935252	-0.02307	1

Source: calculated by the author

At the same time, within the factor space, there is a high degree of multicollinearity between grain exports and agricultural exports (r = 0.935), which is entirely logical given the dominant role of grain products in the structure of agricultural exports. This limits the possibility of simultaneously including these variables in a single regression model without prior transformation or selection. Overall, the results confirm that export indicators have a significant but heterogeneous impact on GDP formation, and their influence requires further differentiation in the modelling process.

Extension of the model to include a production indicator – gross grain harvest – addressed the relationship between production and macroeconomic outcomes. The results show that the direct relationship between gross grain harvest and GDP is weak (r = 0.104), indicating that production volumes have no direct impact on economic growth. This means that production potential alone does not automatically translate into a macroeconomic effect without the effective sale of products on external markets (Table 3). At the same time, gross harvest has a significant correlation with grain exports (r = 0.664) and agricultural exports (r = 0.538), confirming its role as the resource base for export potential. Thus, the results of the analysis concluded that the impact of production factors on GDP is indirect, via export channels, which is of fundamental importance for the construction of econometric models.

Table 3. Correlation matrix of the interrelationships between the factors influencing the indicators of the grain market's performance and Ukraine's GDP (export-production model)

Factors	Ukrainian GDP, billion USD	Exports of agricultural products, USD	Total merchandise exports, USD	Grain exports, billion USD	Gross grain harvest, million tonnes
Ukrainian GDP, billion USD	1				
Exports of agricultural products, USD	0.60833	1			
Total merchandise exports, USD	0.39751	-0.09288	1		
Grain exports, billion USD	0.414517	0.935252	-0.02307	1	
Gross grain harvest, million tonnes	0.10384	0.537708	0.062273	0.664497	1

Source: calculated by the author

An analysis of structural indicators addressed not only the volume but also the quality and extent of the grain market's integration into the country's economy. In particular, the study established that the correlation between GDP and grain exports is moderate (r = 0.415); structural indicators (the share of grain in agricultural exports and total exports) show a weak or even negative relationship with GDP (r = -0.120; r = 0.155); the ratio of grain exports to GDP has a moderate inverse relationship (r = -0.393) (Table 4).This finding is notable and suggests that an increase in the relative importance of grain exports is not always accompanied by GDP growth; in some cases, it may reflect structural imbalances in the economy, particularly a growing reliance on raw materials. Furthermore, within this model, there is a significant correlation between the structural indicators themselves (up to 0.874), which also highlights the risk of multicollinearity and requires caution when including them in regression equations.

Table 4. Correlation matrix of the interrelationships between the factors influencing grain market performance indicators and Ukraine's GDP (structural-export model)

Factors	Ukrainian GDP, billion USD	Grain exports, billion USD	Share of grain in agricultural exports, %	Share of grain in total exports, %	Share of grain exports in the country's GDP, %
Ukrainian GDP, billion USD	1				
Grain exports, billion USD	0.414517	1			
Share of grain in agricultural exports, %	-0.11984	0.767047	1		
Share of grain in total exports, %	0.154959	0.7926	0.603123	1	
Share of grain exports in the country's GDP, %	-0.39286	0.657028	0.874053	0.707836	1

Source: calculated by the author

The results obtained justify the continued use of variational correlation-regression modelling, incorporating the identified relationships and multicollinearity constraints, which will provide a more accurate identification of the key drivers of the grain market's influence on the country's macroeconomic dynamics. The results of the correlation-regression modelling indicate a substantial and statistically significant impact of grain market performance indicators on the dynamics of Ukraine's gross domestic product. The variational models constructed can be used for the assessment of both direct and indirect effects of various groups of factors (Table 5).

Table 5. Performance metrics of the correlation and regression analysis of the factor effects of grain market performance indicators on Ukraine's GDP

Equation	Multiple correlation coefficient R	Coefficient of determination R^2	Fisher's coefficient (F-test)	Student's t-test	Influencing factors
Export model					
$Y = -65.9994 + 15{,}628X_1 + 1.759X_2 - 23.002X_3$	0.925	0.856	factual: 23.828 critical 3.490	$tx_1 = 6.58$ $tx_2 = 4.97$ $tx_3 = 4.82$ $t_{critical}$ 2.13	x_1 – Exports of agricultural products, billion USD x_2 – Total merchandise exports, billion USD x_3 – Grain exports, billion USD
Export-oriented production model					
$Y = -53.437 + 15{,}23X_1 + 1.7665X_2 - 21.432X_3 - 0.274X_4$	0.927	0.860	factual: 16.83 critical 3.36	$tx_1 = 5.92$ $tx_2 = 4.83$ $tx_3 = -3.69$ $tx_4 = -0.51$ $t_{critical}$ 2.13	x_1 – Exports of agricultural products, billion USD x_2 – Total merchandise exports, billion USD x_3 – Grain exports, billion USD x_4 – Gross grain harvest, million tonnes
Structural export model					
$Y = -5.23 + 0{,}019X_1 - 0.335X_2 + 0.242X_3 + 0.152_4$	0.934	0.872	factual: 18.69 critical 3.36	$tx_1 = 0.87$ $tx_2 = -2.21$ $tx_3 = 4.82$ $tx_4 = 3.02$ $t_{critical}$ 2.13	x_1 – Grain exports, billion USD x_2 – Share of grain in agricultural exports, % x_3 – Share of grain in total exports, % x_4 – Share of grain exports in the country's GDP, %

Source: calculated by the author

The resulting regression equation, within the context of the export model, is characterised by high-quality indicators: the multiple correlation coefficient is 0.925, and the coefficient of determination $R^2 = 0.856$, indicating that 85.6% of the variation in GDP is explained by the selected influencing factors. The actual value of Fisher's L-test statistic (23.828) significantly exceeds the critical value (3.490), confirming the overall statistical significance of the model.

All factors are statistically significant ($t > t_{cr}$), which are therefore eligible for economic interpretation. Thus, the modelling revealed that agricultural exports (X_1) have the greatest positive impact – a USD 1 billion increase in this indicator is accompanied by a USD 15.63 billion rise in GDP, confirming its role as a key driver of the economy. The dynamics of total goods exports (X_2) also have a positive impact on GDP, although the effect is less pronounced – a USD 1 billion increase in this indicator leads to a USD 1.76 billion rise in GDP. At the same time, the grain export indicator (X_3) shows a negative coefficient (-23.002), indicating possible structural imbalances, in particular the effect of "raw material specialisation", where growth in exports of low-value-added products does not provide an adequate increase in value added. Thus, the export model reflects the contradictory nature of the impact of grain exports on economic growth.

Expansion of the model by including the production indicator yielded the following equation:

$$Y_t = -54{,}437 + 15{,}23X_1 + 1{,}7665X_2 - 21{,}432X_3 - 0{,}274X_4. \quad (5)$$

The quality of the corresponding export-production model remains high – $R = 0.927$, $R^2 = 0.860$, and the actual value of Fisher's L-test statistic is 16.83, which is five times higher than the critical value (3.36). At the same time, analysis of the t-statistic indicates that agricultural exports and total exports remain statistically significant

factors; grain exports retain a negative influence and are significant, whereas gross grain harvest (X_4) is statistically insignificant ($t = -0.51 < t_{cr}$). This formed a fundamental conclusion – grain production volumes do not have an independent impact on GDP, but their role is implemented indirectly, through export channels. The negative coefficient in the equation (-0.274) for X_4 further confirms that increasing production without corresponding sales efficiency does not ensure economic growth. The construction of a corresponding structural-export model, which includes the grain export growth rate and a set of relevant structural indicators (the share of grain in agricultural exports, in total exports and in the country's GDP) as influencing factors, yielded the following equation:

$$Y_t = -5{,}23 + 0{,}019X_1 - 0{,}335X_2 + 0{,}24X_3 + 0{,}152X_4, \quad (6)$$

This model demonstrated the highest level of explanatory power. The obtained multiple correlation and determination coefficients were 0.934 and 0.872, respectively, and the actual value of the Fisher's F-test exceeded the critical level by a factor of 5.7 ($F_{fact} = 18.69 > F_{cr} = 3.36$). However, not all variables are statistically significant. Thus, the trend in grain exports (X_1) is insignificant (t = 0.87), the share of grain in agricultural exports (X_2) has a negative and significant effect (t = -2.21), the share of grain in total exports (X_3) and the share of grain exports in GDP (X4) are positive and significant.

The results obtained formed the following structural conclusions:

- The rise in the relative share of grain in agricultural exports has a negative impact on GDP, highlighting the risks of excessive specialisation (a 1% increase in the share of grain in agricultural exports reduces GDP by USD 335 million).
- At the same time, the growing role of the grain sector in total exports and GDP could act as a driver of economic growth, provided there is effective integration into the economy (an increase in the share of grain in total merchandise exports leads to a rise in the country's GDP of USD 242 million, whilst a corresponding increase in the share of grain exports in GDP boosts this macroeconomic indicator by USD 152 million);
- The lack of significance in the dynamics of grain exports confirms that it is not the volume but the structural role of Ukraine's grain sector that is decisive.

Thus, the model that accounts for structural and export parameters is the most appropriate from an economic perspective, as it can show not only the quantitative but also the qualitative aspects of the grain market's functioning. The results of the correlation-regression modelling indicate the presence of a stable but heterogeneous influence of grain market performance indicators on Ukraine's gross domestic product. The high values of the multiple correlation coefficients for all the models constructed (R = 0.925-0.934) and coefficients of determination (R^2 = 0.856-0.872) confirm the significant explanatory power of the selected explanatory variables, which can be used to interpret the results as statistically reliable.

At the same time, a comparative analysis of the model parameters reveals fundamental differences in the nature of the impact of individual factors. Within the export model, it has been established that agricultural exports ($\beta_1 = 15.628$) and total merchandise exports ($\beta_2 = 1.759$) have a positive impact on GDP, which is consistent with the classical view of exports as a driver of economic growth. At the same time, the coefficient for the grain export variable has a negative value ($\beta_3 = -23.002$), indicating the presence of a structural imbalance: growth in the volume of raw material exports does not translate into a corresponding increase in gross value added.

The inclusion of the production factor (gross grain harvest) in the export-production model did not lead to a significant increase in the model's explanatory power (R^2 rose only from 0.856 to 0.860), and the coefficient itself proved to be statistically insignificant (t = -0.51 < t-crit). This provides grounds for asserting that an increase in grain production volumes is not a determining factor of economic growth, which is consistent with the concept of the limited effectiveness of the raw materials-export model of economic development.

The structural-export model demonstrated the highest explanatory power ($R^2 = 0.872$), highlighting the decisive role of structural characteristics of exports. In particular, the share of grain in total exports ($\beta_3 = 0.242$; t = 4.82) and the share of grain exports in GDP ($\beta_4 = 0.152$; t = 3.02) have a statistically significant positive impact, whilst the share of grain in agricultural exports ($\beta_2 = -0.335$; t = -2.21) demonstrates a negative effect. This indicates the presence of an over-specialisation effect, whereby an increase in the concentration of the grain segment within the structure of agricultural exports reduces the overall efficiency of the sector.

Discussion

The findings of this study confirm that Ukrainian grain markets remain central in shaping the country's macroeconomic performance; however, the nature of this influence is more complex than a simple correlation between production or export volumes and GDP trends. The econometric modelling showed that, alongside absolute indicators, the structural characteristics of the market are significant, in particular the share of grain in agricultural exports, the share of grain exports in total goods exports, and the ratio of grain exports to GDP. This highlights that the grain sector should be viewed not merely as a source of foreign exchange earnings, but as a multi-factor system whose impact on the economy is mediated by the internal structure of value-added creation.

The findings generally align with the position of Yu.O. Voloshchuk & O.V. Shedlovska (2024), identifying the Ukrainian grain market as a systemic element of the agri-food system. Indeed, the results of this study have shown the existence of a statistically significant correlation between key indicators of the grain market and Ukraine's GDP. At the same time, the analysis conducted reveals a broader picture: the system-forming role of the industry is determined not only by the scale of production but also by the quality of the sector's integration into the national economy. Therefore, the assertion that increasing grain exports has an unquestionably positive effect appears somewhat simplistic, as growth in raw material exports is not always accompanied by an equivalent increase in domestic value added.

A similar line of reasoning was presented by K.V. Bliumska-Danko & M.A. Zaidenko (2023), which highlights the importance of grain production for the competitiveness of the agricultural sector. The findings of this study support this conclusion, but also provide a different perspective on it. It is advisable to assess the competitiveness of the grain market not only in terms of production volumes, but also in terms of the sector's ability to generate a sustainable macroeconomic effect. In this context, structural indicators proved to be more informative than individual absolute production parameters.

It is necessary to compare this with studies focusing on the external economic aspects of the grain market. For instance, L.O. Kibalnyk & A.V. Cherkashchenko (2025) argued that grain exports are one of Ukraine's leading sources of foreign exchange earnings. The results obtained fully confirm this conclusion, as the growth in grain exports was accompanied by an increase in its share of the country's total merchandise exports. However, the analysis conducted above paints a different picture regarding the macroeconomic effect: the foreign exchange significance of grain exports is not equivalent to its long-term impact on economic growth. The reason for the differing interpretations may lie in the fact that the foreign trade effect is short-term, whereas the impact on GDP depends on the level of product processing, the tax multiplier and the domestic investment cycle.

Similar findings were reported by O. Sheremetynska (2025), which highlights Ukraine's role as a key player in the global grain market. This assertion is notable as Ukraine has traditionally held a significant position in the global trade in grain crops. However, the findings of this study indicate that the status of a major exporter does not guarantee maximum domestic economic benefit. This does not contradict previous research, but shifts the focus from Ukraine's global role to the issue of domestic efficiency in utilising export potential.

A comparison with the studies by S. Jagtap *et al.* (2022), A. Panfilova *et al.* (2025) and I. Savchuk (2025), which examine the impact of the war and logistical shocks on the grain market, is noteworthy. The conclusions drawn by these authors are entirely relevant, as the results of the analysis also revealed a sharp decline in certain export indicators in 2022 and instability in subsequent years. At the same time, the conducted modelling demonstrates that even under conditions of logistical constraints, the grain market maintained a statistically significant link with macroeconomic indicators. This indicates the sector's high adaptive potential and its ability to rapidly restructure export routes and market behaviour.

The findings of this study also align with the conclusions of A. Rose *et al.* (2023) and S. Kozlovskyi *et al.* (2024), who highlight the global implications of the decline in Ukrainian grain exports for food security and the global economy. However, this paper emphasised the reverse direction of analysis – the impact of the grain market on Ukraine's domestic economy. This approach complements existing academic definitions and views the grain sector simultaneously as both a global and a domestic economic factor.

The methodological aspect of the study is of particular significance. In contrast to the studies by O. Makarenko & M. Kurchenko (2023), A. Azarova *et al.* (2024), and I. Fedyshyn & N. Harmatii (2024), which primarily assess the impact of foreign trade on GDP as a whole, this study employs a variant approach to modelling, distinguishing between export, export-production and structural-export models. This addressed the problem of multicollinearity and compared the informative value of different groups of factors. This approach can be regarded as a methodological advantage of the present study.

Thus, the findings of this study indicate that the grain market's impact on Ukraine's GDP is shaped by a combination of production, export and structural factors. In contrast to the common approach, which regards export volumes or gross harvest as the primary indicator of the sector's success, the analysis has highlighted the importance of the market's structural characteristics. This provides a basis for the conclusion that government policy in the grain sector should be geared not only towards increasing production, but also towards developing processing, diversifying the export basket and increasing the share of value added in Ukraine's agricultural economy.

▸ Conclusions

The study established that indicators of the functioning of Ukraine's grain market have a significant, though varied, impact on macroeconomic dynamics. The econometric models constructed demonstrate a high level of explanatory power ($R^2 = 0.856$-0.872), confirming the relevance of the selected set of factors for analysing the impact on GDP. The most significant positive impact comes from agricultural exports ($\beta = 15.628$), whilst total goods exports have a moderate stimulating effect ($\beta \approx 1.76$).

At the same time, a structural imbalance has been identified: grain exports are characterised by a negative coefficient within the baseline model ($\beta = -23.002$), indicating the limited capacity of commodity exports to generate added value and ensure sustainable economic growth. This result confirms the hypothesis of the existence of a "resource trap", in which an increase in the physical volume of exports does not translate into corresponding GDP growth.

The study also determined that the inclusion of the production factor (gross grain harvest) has no statistically significant impact on the outcome variable ($t = -0.51$), indicating that production parameters are secondary in shaping the macroeconomic effect. Instead, the structural characteristics of exports are of decisive importance: in particular, the share of grain in total exports ($\beta = 0.242$) and the share of grain exports in GDP ($\beta = 0.152$) demonstrate a statistically significant positive impact, whereas an increase in the share of grain in agricultural exports ($\beta = -0.335$) has a negative effect, indicating the risks of excessive sectoral concentration.

The findings formulated a fundamentally relevant conclusion: the decisive factor in the grain market's impact on economic growth is not so much the scale of production or exports as their structural quality and the degree of integration into value-added chains. In this context, the current model of the Ukrainian grain market is characterised by a structural paradox, whereby

quantitative growth is not accompanied by a qualitative transformation of economic outcomes.

Future research should refine econometric tools, in particular the use of dynamic models (VAR/VECM), analyse lag effects, and consider institutional and geopolitical factors, which will provide a more comprehensive analysis of the mechanisms underlying the interaction between the grain market and macroeconomic dynamics.

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Моделювання факторного впливу індикаторів функціонування зернового ринку на ВВП України

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► **Анотація.** У статті досліджено вплив індикаторів функціонування зернового ринку на динаміку валового внутрішнього продукту України в умовах структурних трансформацій та воєнних викликів. Метою дослідження було кількісне визначення сили, напряму та характеру впливу виробничих, експортних і структурних показників розвитку зернового ринку на макроекономічні результати країни на основі застосування економіко-математичного інструментарію. Методи дослідження включали статистичний аналіз динаміки показників за 2010-2025 рр., кореляційний аналіз, а також кореляційно-регресійне моделювання. Особливістю методичного підходу було використання варіативного моделювання, що передбачало побудову декількох альтернативних моделей із різними наборами факторних змінних та їх перевірку за критеріями статистичної значущості. Результати дослідження засвідчили, що зерновий ринок України трансформувався у високоспеціалізований експортно орієнтований сектор: валовий збір зерна зріс з 39,27 млн т у 2010 р. до 86,01 млн т у 2021 р., а експорт – з 2,47 до 12,34 млрд дол. США. Встановлено, що найбільш вагомий вплив на ВВП мав експорт агропродукції (r = 0,608), тоді як вплив експорту зерна був помірним (r = 0,415) і в регресійних моделях мав від'ємний коефіцієнт (-21,4…-23,0), що свідчить про ефект сировинної орієнтації. Доведено, що виробничі показники не мають прямого статистично значущого впливу (r = 0,104), а реалізуються через експортні канали. Водночас зростання частки зерна в агроекспорті на 1 % супроводжується зниженням ВВП на 335 млн дол. США, тоді як підвищення частки зерна у загальному експорті забезпечує його приріст на 242 млн дол. Застосування варіативного підходу до економетричного моделювання, який дозволило виявити, що вплив зернового ринку на ВВП має нелінійний та структурно зумовлений характер, а визначальними є не обсяги виробництва, а параметри експортної інтеграції. Практична значущість отриманих результатів полягає у можливості їх використання при формуванні державної аграрної політики, зокрема для переходу від сировинної моделі експорту до моделі з вищою доданою вартістю, що сприятиме підвищенню ефективності зернового сектору та зміцненню макроекономічної стабільності

► **Ключові слова:** аграрний сектор; експорт агропродукції; економетричне моделювання; структурні фактори; сировинна орієнтація; макроекономічні показники