

Statistical Analysis of GDP Dynamics During the War Period and Economic Growth Forecast

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Abstract

The relevance of the study is determined by the need for statistically cautious assessment of Ukraine's macroeconomic dynamics under the conditions of full-scale war and substantial uncertainty. The purpose was to compare GDP dynamics in the pre-war and full-scale war periods, assess its associations with selected macroeconomic indicators and derive an indicative medium-term recovery trajectory. The analysis used annual data for 2010–2024 ($n = 15$) covering GDP, gross fixed capital formation, general government final consumption expenditure, exports and imports. Descriptive statistics, Student's t -test, Mann–Whitney U -test, effect-size estimation, Pearson correlation analysis and exploratory multiple regression were applied. Mean GDP decreased from 101.96 billion constant 2015 US\$ in 2010–2021 to 75.80 billion in 2022–2024. The between-period difference was statistically significant, $t(13) = 5.90$, $p < 0.001$ and substantial in magnitude, with Hedges' $g = 3.59$ (95% CI: 1.75–5.37). Exports showed the strongest positive association with GDP ($r = 0.939$), whereas government consumption expenditure was negatively associated with GDP ($r = -0.722$); these relationships were interpreted as statistical co-movements rather than causal effects. The exploratory regression model produced $R^2 = 0.966$ and adjusted $R^2 = 0.953$, but its predictive interpretation is limited by the small sample and 10 residual degrees of freedom. Consequently, the 2025–2027 estimates were framed as scenario-based projections rather than validated forecasts. Under the baseline scenario, GDP shows a gradual but incomplete recovery. The findings provide an exploratory empirical basis for assessing wartime macroeconomic dynamics while explicitly representing estimation and projection uncertainty.

Keywords: Economic Growth, Gross Domestic Product, Macroeconomic Indicators, Regression and Correlation Analysis, Statistical Regularity, Time Series.

Introduction

In conditions of military conflict, macroeconomic dynamics become less stable and more difficult to interpret, which complicates both the assessment of gross domestic product (GDP) and the construction of medium-term projections. Disruptions in production networks, reduced private investment, migration, infrastructure losses and heightened uncertainty alter the environment in which conventional macroeconomic relationships operate and increase the need for statistical approaches that explicitly account for uncertainty and limited data availability. Empirical studies consistently associate armed conflict with weaker economic growth through

declines in investment, destruction of productive capacity and elevated uncertainty (1). Econometric evidence also indicates that the relationship between conflict and output depends on the intensity and institutional context of the shock (2, 3). From a theoretical perspective, war-related losses of capital and productivity can alter the trajectory of economic growth by weakening capital accumulation and reducing productive efficiency (4). At the same time, the magnitude of economic losses is heterogeneous across territories and depends on regional economic structures, exposure to conflict and the degree of integration into wider markets (3, 5). Modern

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approaches to GDP forecasting increasingly combine econometric and computational methods capable of accommodating nonlinearities and complex interactions among macroeconomic variables (6, 7). However, the simultaneous assessment of wartime GDP dynamics, uncertainty in macroeconomic relationships and medium-term recovery trajectories remains methodologically challenging, particularly when only a short annual time series is available. Much of the existing literature examines either the general macroeconomic consequences of conflict or cross-country patterns, whereas country-specific analysis based on a limited number of observations requires substantially more cautious inferential and predictive claims. The purpose of the study is to identify statistical patterns in Ukraine's GDP dynamics during the pre-war and full-scale war periods, quantify its associations with selected macroeconomic indicators and derive an indicative medium-term trajectory of economic recovery using correlation analysis, exploratory multiple regression and scenario-based projection.

To achieve this purpose, the following tasks were defined: to compare GDP levels and variability between the pre-war and full-scale war periods; to quantify the magnitude and uncertainty of the between-period difference; to assess the relationships between GDP and gross fixed capital formation, general government final consumption expenditure, exports and imports; to estimate an exploratory multiple regression model and evaluate the precision and diagnostics of its coefficients; and to construct scenario-based GDP projections while explicitly accounting for the limitations imposed by the small annual sample.

The conceptual basis of the study is the proposition that a large external shock such as war can alter not only the level of aggregate output but also the observed statistical relationships among investment, public expenditure and foreign trade. Accordingly, GDP dynamics are treated as a process whose empirical associations may be context-dependent and may differ under wartime conditions. This framework does not presume the existence of a formally identified structural break or stable causal effects; instead, it emphasizes comparison of observed periods, estimation uncertainty and the exploratory interpretation of macroeconomic relationships.

Accordingly, the following research questions were formulated:

- a) Is the level of GDP in 2022–2024 statistically distinguishable from that observed during 2010–2021 and what is the magnitude of this difference?
- b) Which selected macroeconomic indicators exhibit the strongest statistical associations with GDP over 2010–2024?
- c) Which of these associations remain statistically distinguishable from zero after simultaneous adjustment in an exploratory multiple regression model?
- d) What indicative medium-term GDP trajectory emerges under a baseline scenario in which the specified recent macroeconomic trends are continued?

Recent research treats the relationship between military conflict and economic growth as complex and dependent on institutional, fiscal and macroeconomic conditions. Military expenditure may crowd out private investment and increase fiscal pressure, although its short-run association with aggregate demand and output can differ across institutional and economic settings (8, 9). Critical reviews of the military expenditure–growth literature likewise show that conclusions are sensitive to model specification, variable selection and country context (10).

The economic consequences of war are also heterogeneous. Conflict intensity, production structure and regional conditions can generate markedly different development trajectories (5). Military shocks may additionally generate cross-border consequences through energy, trade, production and labor-market channels (11, 12). Evidence from ASEAN economies further demonstrates that the military expenditure–growth relationship varies with economic conditions and policy settings (13). More generally, the estimated relationship is sensitive to empirical specification (10), while time-varying analyses indicate that its magnitude may change across periods (14, 15).

Military and political shocks may also have persistent institutional and economic consequences (16). Macroeconomic uncertainty represents another important transmission mechanism because it can delay investment, alter consumption decisions and weaken aggregate activity (17, 18). At the same time, the severity and persistence of

conflict-related losses depend on the structure of the affected economy and its capacity to adapt to prolonged disruption (19, 20).

More recent empirical approaches increasingly employ panel regressions and machine-learning methods to capture complex relationships between macroeconomic variables (21). Yet such methods generally require substantially larger datasets than the 15 annual observations available in the present study. Geopolitical risk also remains relevant because it can influence investment, trade and broader economic performance through multiple channels (22).

Thus, the literature provides substantial evidence on individual mechanisms linking conflict, uncertainty, public expenditure, trade and economic growth, but less attention has been paid to how these relationships should be interpreted when the available national time series is very small. The present study addresses this gap by combining period comparison, effect-size Estimation, confidence intervals, exploratory regression diagnostics and scenario-based projection within a transparent small-sample framework. Rather than treating the resulting estimates as stable causal parameters or statistically validated forecasts, the analysis focuses on the magnitude, direction and uncertainty of the observed relationships in Ukraine during 2010–2024.

Methodology

The study was conducted in 2025 and covered annual macroeconomic indicators for Ukraine over the period 2010–2024. For comparative purposes, the observation period was divided into the pre-war period (2010–2021) and the full-scale war period (2022–2024). This periodization was defined a priori and was used to compare changes in the level and variability of GDP rather than to claim a formally estimated econometric structural break. The object of the study was the dynamics of Ukraine’s gross domestic product (GDP), while the subject concerned the statistical associations between GDP and selected macroeconomic indicators and the possibility of deriving indicative medium-term projections under wartime conditions. The empirical dataset was constructed from World Bank World Development Indicators (WDI) data using a common constant-price measurement framework. The variables included GDP, gross fixed capital formation (GFCF), general government final consumption expenditure (GOV), exports of goods and services (EXP) and imports of goods and services (IMP). All monetary variables were expressed in billion constant 2015 US dollars. The corresponding WDI indicator codes were NY.GDP.MKTP. KD for GDP, NE.GDI.FTOT. KD for GFCF, NE.CON. GOVT. KD for GOV, NE.EXP.GNFS. KD for exports and NE.IMP. GNFS.KD for imports.

For presentation of GDP dynamics, an additional index was calculated using 2010 as the base year, as specified in Equation [1]:

$$\text{GDP Index}_t = (\text{GDP}_t / \text{GDP}_{2010}) \times 100 \quad [1]$$

Where, GDP_t denotes GDP in year t and GDP_{2010} denotes GDP in the base year 2010.

Table A1 in Appendix A presents the complete annual dataset, the calculated GDP index and the definitions of all variables used in the analysis.

The analytical sample comprised $n = 15$ annual observations. This value does not represent the absolute maximum number of macroeconomic observations potentially available for Ukraine at any frequency. Rather, it represents the complete sample within the predefined annual-frequency design covering 2010–2024. Annual observations were retained to preserve a common temporal frequency, consistent variable definitions and comparability across all five macroeconomic series

over the full study horizon. Although higher-frequency observations are available for some individual indicators, constructing a quarterly or monthly dataset would require a different analytical design and a separate harmonization of frequency, seasonal properties, measurement definitions and temporal coverage.

Accordingly, the small sample size was treated as a central methodological constraint. The regression specification contained four explanatory variables and one intercept, resulting in five estimated parameters. Residual degrees of freedom were calculated using Equation [2]:

$$df = n - k - 1 = 15 - 4 - 1 = 10 \quad [2]$$

Where, n denotes the number of observations and k the number of explanatory variables.

Thus, the model is formally identified because the number of observations exceeds the number of estimated parameters. Nevertheless, the observation-to-parameter ratio remains low and limits statistical power, increases sensitivity to influential observations and model specification and restricts the generalizability of the estimated coefficients. For this reason, the regression was treated as exploratory rather than as a high-powered confirmatory or predictive time-series model. Table A2 in Appendix A summarizes the sample size, number of explanatory variables, total number of estimated parameters and model degrees of freedom.

The sample was non-random and purposive and was determined by the availability of complete and methodologically comparable annual observations for all variables. The inclusion criteria were continuity of the series throughout 2010–2024, comparability of measurement across years and absence of unresolved missing observations. No missing-value imputation from alternative data providers was applied. The exact values used in the analysis, including the data-construction note concerning the early GOV observations, are transparently reported in Table A1 in Appendix A. The first analytical stage involved database preparation, verification of indicator consistency and screening for anomalous observations. Descriptive statistics were then calculated to characterize GDP dynamics in the two predefined periods. Measures of central tendency and dispersion were used to assess changes in GDP level and variability between 2010–2021 and 2022–2024.

The Shapiro–Wilk test was used as a diagnostic assessment of distributional properties. Because the war-period subsample contained only three annual observations, normality testing and parametric inference necessarily had very low

statistical power and were interpreted with caution. The difference between the pre-war and war periods was assessed using Student's t -test, with the Mann–Whitney U -test employed as a non-parametric robustness comparison at a significance level of $\alpha = 0.05$. Given the small and unequal subsample sizes, inferential conclusions were not based on p -values alone. The magnitude of the between-period difference was additionally quantified using Hedges' g with a 95% confidence interval, while rank-biserial correlation was reported as the non-parametric effect-size measure associated with the Mann–Whitney comparison.

The application of these tests assumes that observations assigned to the two predefined periods can be compared as distinct groups. Because the underlying data form an annual time series, this represents a simplifying assumption and potential temporal dependence was explicitly considered when interpreting the results.

Relationships between GDP and the selected macroeconomic indicators were assessed using Pearson correlation coefficients. In response to the small sample size, each coefficient was reported together with its 95% confidence interval and p -value. Correlation coefficients were interpreted as measures of statistical co-movement rather than evidence of causal relationships. This distinction is particularly important for macroeconomic time series because common trends may increase the magnitude of observed correlations even when the underlying relationship is unstable.

At the next stage, an exploratory multiple linear regression model was estimated to assess conditional associations between GDP and the four selected macroeconomic indicators. The regression specification is presented in Equation [3]:

$$GDP_t = \beta_0 + \beta_1 GFCF_t + \beta_2 GOV_t + \beta_3 EXP_t + \beta_4 IMP_t + \varepsilon \quad [3]$$

Where, GDP_t denotes gross domestic product in period t ; $GFCF_t$ is gross fixed capital formation; GOV_t is general government final consumption expenditure; EXP_t is exports of goods and services; IMP_t is imports of goods and services; β_0 is the intercept; β_1 – β_4 are regression coefficients; and ε_t is the error term.

The parameters of Equation [3] were estimated using ordinary least squares. Because of the

limited sample, the coefficients were interpreted as conditional statistical associations within the

observed dataset and not as estimates of causal effects. Regression reporting included the unstandardized coefficient (B), standard error (SE), t-statistic, p-value and 95% confidence interval for each estimated coefficient.

Model fit was evaluated using R^2 , adjusted R^2 and the overall F-test. R^2 was treated exclusively as an in-sample goodness-of-fit measure and was not interpreted as evidence of predictive accuracy. This distinction was necessary because a high R^2 obtained from a small sample of macroeconomic time series may partly reflect common temporal variation.

Multicollinearity among the explanatory variables was assessed using the variance inflation factor (VIF). Potential residual autocorrelation was evaluated using the Durbin–Watson statistic, while heteroscedasticity was assessed using the Breusch–Pagan test. These diagnostic procedures were included because conventional standard errors and significance tests may be affected by residual dependence or non-constant variance. Table A3 in Appendix A presents the complete regression estimates, confidence intervals, VIF values, model-fit statistics and residual diagnostics.

Out-of-sample validation was considered but was not used as a formal test of predictive performance. With only 15 annual observations, withholding even a small validation subsample would reduce the estimation sample to a level at which a four-predictor regression would become still more unstable. For example, reserving three observations for testing would leave only 12 observations for estimating five parameters. Consequently, a conventional train-test split would not provide a sufficiently reliable basis for establishing out-of-sample predictive validity. The absence of independent out-of-sample validation is therefore treated explicitly as a limitation of the study rather than being interpreted as evidence of forecast reliability.

At the final stage, the estimated relationships were used to derive indicative scenario-based projections rather than statistically robust forecasts. The values of the explanatory variables for the projection horizon were derived by extrapolating their historical trajectories under a baseline assumption of gradual macroeconomic stabilization. The resulting GDP estimates therefore represent conditional projections based

on continuation of the assumed relationships and should not be interpreted as unconditional predictions of future economic performance. They do not explicitly incorporate unforeseen military escalation, changes in external financial assistance, institutional shocks, population displacement, reconstruction intensity, or other exogenous disturbances that may materially alter Ukraine's economic trajectory.

All calculations were performed using IBM SPSS Statistics for Windows, Version 29.0 (IBM Corp., Armonk, NY, USA) and Microsoft Excel 365 (Microsoft Corp., Redmond, WA, USA).

Several methodological restrictions should therefore be considered when interpreting the empirical results. First, $n = 15$ provides limited statistical power for a regression model containing four explanatory variables. Second, only three observations represent the full-scale war period, which limits the precision of direct between-period comparisons. Third, annual data cannot capture short-term intra-year fluctuations. Fourth, common trends and temporal dependence may affect correlation and regression estimates. Fifth, the absence of an independent out-of-sample validation sample prevents claims of statistically validated predictive performance. Accordingly, the regression results are interpreted as exploratory and the future values as scenario-based projections. These limitations constrain the generalizability of the findings and indicate that future research should use harmonized quarterly or monthly data when sufficiently consistent series become available.

Results

Comparative Statistical Analysis of GDP Dynamics in the Pre-war and War Periods

The comparative analysis was based on annual observations for Ukraine covering 2010–2024, with 2010–2021 defined as the pre-war period and 2022–2024 as the full-scale war period. The comparison was intended to identify changes in the level and variability of GDP between the two predefined periods. Given that no dedicated structural-break test was applied, the observed difference is interpreted as a marked shift in GDP dynamics rather than as a formally identified econometric structural break.

As shown in Table 1, the descriptive statistics demonstrate a pronounced reduction in GDP during the full-scale war period. Mean GDP decreased from 101.96 billion constant 2015 US\$ in 2010–2021 to 75.80 billion constant 2015 US\$ in 2022–2024. The corresponding median values were 101.20 and 76.31 billion constant 2015 US\$, respectively. The standard deviation declined from

7.33 to 3.27 billion constant 2015 US\$. Therefore, the revised data do not indicate greater within-period dispersion during 2022–2024. Instead, they show a substantial downward shift in the level of economic activity accompanied by relatively limited variation across the three available war-period observations.

Table 1: Descriptive Statistical Characteristics of GDP in the Pre-war and War Periods

Indicator	2010–2021	2022–2024
Number of observations	12	3
Mean	101.96	75.80
Median	101.20	76.31
Standard deviation	7.33	3.27
Minimum	91.03	72.31
Maximum	112.20	78.79

Note: GDP values are expressed in billion constant 2015 US\$. The complete annual dataset is reported in Appendix A, Table A1.

The Shapiro–Wilk diagnostic did not indicate a statistically detectable departure from normality for GDP in either the pre-war or war subsample. However, the war-period result is not treated as substantive evidence of normality because it is based on only three observations. Consequently, the parametric comparison was supplemented with a non-parametric test and effect-size measures.

The mean difference between the two periods was 26.15 billion constant 2015 US\$, with a 95% confidence interval from 16.59 to 35.72 billion. Student’s t-test indicated a statistically significant between-period difference, $t(13) = 5.90$, $p < 0.001$. Importantly, the magnitude of this difference was also large in standardized terms: Hedges’ $g = 3.59$, with a 95% CI of 1.75 to 5.37.

The Mann–Whitney analysis produced $U = 0$, with an exact two-sided p-value of 0.004. The corresponding rank-biserial correlation was 1.00 when defined in the direction of higher pre-war GDP relative to the war-period observations. This value reflects complete separation of the observed GDP values between the two subsamples. Nevertheless, because only three observations represent the full-scale war period, the magnitude of both parametric and non-parametric estimates should be interpreted cautiously. A detailed assessment of the between-period difference, including the parametric and non-parametric effect-size estimates, is presented in Table 2. A detailed effect-size assessment of the between-period GDP difference is provided in Table A4 in Appendix A.

Table 2: Between-Period Comparison of GDP with Effect-size Estimates

Statistic	Estimate	95% CI	p-value
Mean difference	26.15	16.59 to 35.72	–
Student’s t	5.90	–	<0.001
Degrees of freedom	13	–	–
Hedges’ g	3.59	1.75 to 5.37	–
Mann–Whitney U	0	–	0.004
Rank-biserial correlation	1.00	–	–

Note: Hedges’ g was used because it applies a small-sample correction. The Mann–Whitney p-value is exact and two-sided.

Taken together, the results indicate a substantial difference in the observed GDP level between 2010–2021 and 2022–2024. However, the evidence should be interpreted as a comparison between two predefined periods rather than as a formal causal estimate of the economic effect of war or as proof of an econometrically estimated breakpoint.

Correlation Analysis of GDP and Macroeconomic Indicators

The next stage examined the statistical co-movement of GDP with gross fixed capital formation, general government final consumption expenditure, exports and imports. Because the total sample comprised only 15 annual observations, correlation coefficients were

evaluated together with their 95% confidence intervals rather than being interpreted primarily on the basis of statistical significance.

The strongest association was observed between GDP and exports of goods and services, $r = 0.939$, 95% CI [0.823, 0.980], $p < 0.001$ detailed assessment between the GDP and Selected Macroeconomic Indicators. This result indicates a very strong positive co-movement between GDP and exports within the observed sample.

GDP was negatively correlated with general government final consumption expenditure, $r = -0.722$, 95% CI [-0.901, -0.332], $p = 0.002$. The direction of this relationship differs from the positive association reported in the previous specification and reflects the revised harmonized constant-price dataset. In the context of the present observational design, this coefficient should not be interpreted as evidence that government expenditure reduces GDP. Rather, the

negative coefficient indicates that periods of lower GDP within the sample, particularly the full-scale war period, coincided with relatively higher government consumption expenditure.

A moderate positive relationship was found between GDP and imports, $r = 0.568$, 95% CI [0.078, 0.837], $p = 0.027$. By contrast, the relationship between GDP and gross fixed capital formation was substantially weaker, $r = 0.248$, 95% CI [-0.303, 0.674], $p = 0.373$. The confidence interval for GFCF crossed zero, indicating considerable uncertainty regarding the direction and magnitude of this association within the available 15 observations. The correlations between GDP and all selected macroeconomic indicators are summarized in Table 3. The complete correlation estimates with 95% confidence intervals are reported in Table A5 in Appendix A.

Table 3: Correlations Between GDP and Selected Macroeconomic Indicators

Relationship	Pearson r	95% CI	p-value
GDP – GFCF	0.248	-0.303 to 0.674	0.373
GDP – GOV	-0.722	-0.901 to -0.332	0.002
GDP – EXP	0.939	0.823 to 0.980	<0.001
GDP – IMP	0.568	0.078 to 0.837	0.027

Note. GFCF – gross fixed capital formation; GOV – general government final consumption expenditure; EXP – exports of goods and services; IMP – imports of goods and services; CI – 95% confidence interval.

The correlation results should be interpreted as evidence of statistical co-movement only. They neither identify causal effects nor establish the direction of economic influence. This qualification is especially important because the variables are annual macroeconomic time series and may share common temporal patterns.

As an additional sensitivity assessment, rank-based correlations were directionally consistent for GFCF, exports and imports. The relationship involving government expenditure was less stable under the rank-based specification, reinforcing the need for caution in interpreting the Pearson estimate as a persistent underlying relationship rather than a sample-specific association.

Overall, the revised correlation analysis identifies exports as the variable most consistently associated with GDP in the observed period. Imports also demonstrate a positive association, whereas GFCF does not show a statistically distinguishable linear relationship with GDP within the available sample. Government consumption expenditure exhibits a negative

sample correlation whose interpretation is strongly conditioned by the wartime structure of the data.

Exploratory Multiple Regression Analysis of GDP

A multiple linear regression model was subsequently estimated with GDP as the dependent variable and GFCF, general government final consumption expenditure, exports and imports as explanatory variables. The model was estimated from 15 annual observations. With four predictors and an intercept, five parameters were estimated, leaving 10 residual degrees of freedom. Because the observation-to-parameter ratio is low, the model was treated as exploratory. The regression coefficients quantify conditional associations within the analyzed sample and should not be interpreted as causal effects or as stable population parameters.

The revised regression estimates are presented in Table 4. Exports remained positively associated with GDP after simultaneous adjustment for the

other included variables, $B = 0.481$, $SE = 0.072$, $t = 6.665$, $p < 0.001$, 95% CI [0.320, 0.642]. The confidence interval did not include zero.

General government final consumption expenditure showed a negative conditional association with GDP, $B = -2.154$, $SE = 0.487$, $t = -4.426$, $p = 0.001$, 95% CI [-3.239, -1.070]. As with the bivariate correlation, this estimate must not be interpreted causally. The coefficient reflects the conditional relationship observed within a sample that includes an exceptional wartime period characterized simultaneously by lower GDP and higher government consumption expenditure.

The coefficient for GFCF was positive but statistically imprecise, $B = 0.294$, $SE = 0.337$, $t = 0.873$, $p = 0.403$, 95% CI [-0.456, 1.044]. Similarly, imports had a positive coefficient, $B = 0.261$, $SE = 0.151$, $t = 1.731$, $p = 0.114$, but the corresponding 95% confidence interval [-0.075, 0.596] included zero. Therefore, the revised analysis does not support claims that GFCF or imports have independently significant conditional associations with GDP after adjustment for the remaining variables.

Table 4: Exploratory Multiple Regression Estimates for GDP

Variable	B	SE	t	p-value	95% CI	VIF
Constant	88.305	10.163	8.689	<0.001	65.660 to 110.949	–
GFCF	0.294	0.337	0.873	0.403	–0.456 to 1.044	2.29
GOV	–2.154	0.487	–4.426	0.001	–3.239 to –1.070	1.80
EXP	0.481	0.072	6.665	<0.001	0.320 to 0.642	2.66
IMP	0.261	0.151	1.731	0.114	–0.075 to 0.596	3.29

Model statistics: $R^2 = 0.966$; adjusted $R^2 = 0.953$; $F(4,10) = 71.38$, $p < 0.001$; Durbin–Watson = 1.61.

Residual heteroscedasticity: Breusch–Pagan LM = 2.11, $p = 0.716$.

Note: B = Unstandardized Regression Coefficient, SE = Standard Error, CI = 95% Confidence Interval, VIF = Variance Inflation Factor.

The model accounted for a large proportion of in-sample GDP variation, $R^2 = 0.966$, with an adjusted R^2 of 0.953. The overall model test was statistically significant, $F(4,10) = 71.38$, $p < 0.001$. However, these statistics describe model fit within the 15 observed annual data points and should not be interpreted as evidence of out-of-sample predictive accuracy.

The VIF values ranged from 1.80 to 3.29 and therefore did not indicate severe multicollinearity under the conventional threshold of 5. The Durbin–Watson statistic was 1.61, which does not indicate an extreme residual autocorrelation pattern, although the small sample limits the precision of this diagnostic. The Breusch–Pagan test was not statistically significant, LM = 2.11, $p = 0.716$, providing no evidence of detectable heteroscedasticity in the residuals.

The model diagnostics therefore do not reveal an obvious violation sufficient to invalidate the fitted specification within the sample. Nevertheless, the small number of observations remains the dominant limitation. In particular, 10 residual degrees of freedom provide only a narrow basis for stable multivariable parameter estimation. The regression results should consequently be interpreted as exploratory estimates of conditional association.

Scenario-based Assessment of the Medium-term GDP Trajectory

The final analytical stage was revised to avoid presenting the model as a statistically validated forecasting system. Given $n = 15$, conventional out-of-sample validation would require withholding observations from an already small estimation sample. For example, reserving three annual observations as a test set would leave only 12 observations for estimating four predictors and an intercept. Such a split would materially increase parameter instability and would not provide a sufficiently reliable basis for establishing predictive performance.

Consequently, no claim of validated out-of-sample forecast accuracy is made. Instead, the regression model was used to construct an indicative baseline scenario for 2025–2027. For this scenario, the trajectories of the explanatory variables observed during 2022–2024 were extended linearly to obtain conditional inputs for the projection horizon. This approach does not imply that these paths are expected to occur. It provides a transparent mechanical scenario showing what GDP values would be associated with continuation of the recent trajectories within the estimated regression specification. The resulting conditional projections are presented in Table 5.

Table 5: Indicative Scenario-based GDP Projections for 2025–2027

Year	Projected GFCF	Projected GOV	Projected EXP	Projected IMP	GDP Projection, Billion Constant 2015 US\$	GDP Index, 2010 = 100	95% Model-Based Prediction Interval for GDP Index
2025	27.81	22.25	26.56	75.06	80.89	76.17	67.92 to 84.42
2026	32.40	22.68	27.04	80.21	82.87	78.04	68.22 to 87.85
2027	36.98	23.12	27.51	85.36	84.86	79.90	68.25 to 91.55

Note: Predictor values represent linear continuation of their observed 2022–2024 trajectories. The reported values are conditional scenario-based projections, not statistically validated forecasts. Prediction intervals reflect model-based uncertainty conditional on the assumed explanatory-variable trajectories and do not incorporate additional uncertainty concerning future military, institutional, demographic, financial, or policy shocks.

Under the baseline scenario, the conditional GDP estimate increases from approximately 80.89 billion constant 2015 US\$ in 2025 to 84.86 billion in 2027. Expressed relative to 2010, the corresponding GDP index increases from 76.17 to 79.90.

The point trajectory therefore suggests a gradual partial recovery rather than a return to the pre-war GDP level. More importantly, uncertainty increases over the projection horizon. The 95% model-based prediction interval for the GDP index extends from approximately 67.92–84.42 in 2025 to 68.25–91.55 in 2027. The widening interval illustrates the limited precision of longer-horizon inference from a model estimated using only 15 annual observations.

These intervals should not be interpreted as fully calibrated macroeconomic forecast intervals because the model has not undergone independent out-of-sample validation and because uncertainty in the future explanatory variables is only partially represented. The scenario also excludes potentially decisive exogenous factors, including changes in military intensity, international financial assistance, reconstruction expenditure, migration, institutional adjustment, infrastructure losses and external demand.

Accordingly, the scenario exercise supports only a limited conclusion: under continuation of the specified recent trajectories and the estimated historical relationships, a gradual improvement in GDP is possible over 2025–2027. The exercise does not establish that this trajectory will occur and should not be used as a statistically robust unconditional forecast.

Discussion

The revised results indicate a pronounced change in the level of Ukraine’s GDP after the beginning of the full-scale war, but they do not provide a basis for claiming a formally identified structural break.

The comparison of the predefined periods shows that mean GDP decreased from 101.96 billion constant 2015 US\$ in 2010–2021 to 75.80 billion in 2022–2024. The mean difference of 26.15 billion was accompanied by a large standardized effect, Hedges’ $g = 3.59$, with a 95% confidence interval of 1.75–5.37. The non-parametric comparison produced the same substantive conclusion, with Mann–Whitney $U = 0$ and a rank-biserial correlation of 1.00. Taken together, these estimates indicate a substantial separation between the observed pre-war and full-scale war GDP levels. At the same time, the very small war-period subsample means that the magnitude of the estimated effect should be interpreted cautiously rather than treated as a precise population parameter.

An important correction to the previous interpretation concerns GDP variability. The updated dataset does not show higher within-period volatility during 2022–2024. The standard deviation declined from 7.33 billion constant 2015 US\$ in the pre-war period to 3.27 billion during the full-scale war period. Thus, the empirical pattern is better described as a sharp downward displacement of GDP followed by a relatively narrow range of observations at a substantially lower level, rather than as an increase in annual dispersion. This distinction is methodologically relevant. The economic disruption associated with war may be severe even when a three-observation subsample does not exhibit high statistical variance. Evidence on Ukraine’s socio-economic resilience under wartime shocks similarly demonstrates that war can substantially alter economic conditions and recovery trajectories even when adaptation mechanisms partly stabilize particular indicators (20). More broadly, cross-country research confirms that armed conflict is systematically associated with substantial output

losses, although their magnitude varies across economic and institutional settings (1).

The revised correlation analysis also changes the interpretation of the macroeconomic relationships. Exports demonstrated the strongest association with GDP, $r = 0.939$, 95% CI [0.823, 0.980], whereas imports showed a more moderate positive relationship, $r = 0.568$, 95% CI [0.078, 0.837]. These findings are consistent with the importance of foreign trade channels for an open economy exposed to wartime disruption. The destruction of logistical infrastructure, restrictions on transport routes, changes in external demand and disruptions in production chains can simultaneously affect export capacity and aggregate output. Research on Ukraine's foreign economic security under wartime conditions likewise emphasizes the sensitivity of trade flows to military and geopolitical shocks (23).

By contrast, gross fixed capital formation showed only a weak positive correlation with GDP, $r = 0.248$ and its 95% confidence interval ranged from -0.303 to 0.674 . The association was not statistically significant at the conventional level, $p = 0.373$. This result does not imply that investment is economically unimportant. Rather, it shows that within this specific 15-observation annual sample, GFCF did not exhibit a sufficiently stable linear relationship with GDP to distinguish its correlation from zero with adequate precision. Wartime investment dynamics may be affected by reconstruction spending, sectoral reallocation, delayed private investment, public capital expenditure and changes in the composition of fixed capital formation. These mechanisms are unlikely to be captured fully by a single annual aggregate series. Comparative evidence likewise shows that the relationship between capital formation and GDP depends on model specification, country characteristics and the structure of the analyzed data (21).

A particularly important result concerns general government final consumption expenditure. The bivariate correlation with GDP was negative, $r = -0.722$, 95% CI $[-0.901, -0.332]$ and the conditional regression coefficient was also negative, $B = -2.154$, 95% CI $[-3.239, -1.070]$, $p = 0.001$. This finding requires careful interpretation. It should not be read as evidence that government expenditure causes GDP to decline. The analyzed period includes an exceptional wartime regime in

which GDP contracted sharply while the fiscal role of the state increased. Higher government consumption and lower GDP can therefore occur simultaneously as consequences of the same underlying shock. In practice, the negative coefficient may partly reflect countercyclical fiscal behavior, wartime expenditure requirements and changes in the composition of public spending rather than an adverse causal effect of government expenditure itself. This interpretation is compatible with research emphasizing the growing scale and structural importance of defence expenditure in Ukraine under wartime conditions (24). More generally, the military expenditure-growth literature shows that the direction and magnitude of the relationship depend strongly on specification, institutional setting and the composition of expenditure (8, 9, 10).

The multiple regression results reinforce the need to distinguish statistical association from causal inference. Exports remained the most precisely estimated positive predictor, $B = 0.481$, 95% CI [0.320, 0.642], $p < 0.001$. Government consumption retained a negative conditional association with GDP, while the coefficients for GFCF and imports were not statistically distinguishable from zero after simultaneous adjustment for the other variables. GFCF produced $B = 0.294$, $p = 0.403$ and imports $B = 0.261$, $p = 0.114$. Consequently, the revised model does not support the earlier interpretation that all selected macroeconomic variables contribute independently and significantly to GDP variation.

The regression model demonstrated a high in-sample fit, $R^2 = 0.966$ and adjusted $R^2 = 0.953$, with $F(4,10) = 71.38$, $p < 0.001$. Nevertheless, these values should not be interpreted as evidence of strong predictive validity. Only 15 annual observations were available, while five parameters, including the intercept, were estimated, leaving 10 residual degrees of freedom. Under these conditions, R^2 can be sensitive to the composition of the sample and to common temporal patterns among macroeconomic variables. The high coefficient of determination therefore describes how closely the model reproduces variation within the observed dataset; it does not establish that the same parameter relationships would remain stable outside that sample.

The available diagnostics do not reveal an obvious technical failure of the regression specification. VIF values ranged from 1.80 to 3.29, which does not indicate severe multicollinearity under the conventional threshold of 5. The Durbin–Watson statistic of 1.61 does not suggest an extreme pattern of positive residual autocorrelation, while the Breusch–Pagan test, $LM = 2.11$, $p = 0.716$, did not detect heteroscedasticity. These diagnostics strengthen the internal interpretability of the fitted model, but they do not eliminate the fundamental small-sample problem. With only 10 residual degrees of freedom, diagnostic tests themselves have limited power and the absence of a statistically detected violation cannot be equated with proof that all classical regression assumptions hold.

This qualification is particularly important for the projection component. The revised analysis does not treat the estimated 2025–2027 values as statistically validated forecasts. Instead, they represent scenario-based projections conditional on continuation of the specified trajectories of the explanatory variables. Under the baseline scenario, projected GDP increases from 80.89 billion constant 2015 US\$ in 2025 to 84.86 billion in 2027, corresponding to an increase in the GDP index from 76.17 to 79.90 relative to 2010. The trajectory therefore suggests only partial recovery during the projection horizon.

The uncertainty surrounding this trajectory is substantial. The model-based 95% prediction interval for the GDP index is approximately 67.92–84.42 in 2025 and widens to 68.25–91.55 by 2027. This widening is analytically more informative than the point projections alone because it demonstrates how rapidly uncertainty accumulates when a small-sample annual model is extended beyond the observed period. More sophisticated forecasting approaches, including machine-learning and deep-learning frameworks, can accommodate nonlinearities, dynamic dependencies and complex interactions among predictors (6, 7). Their application, however, generally requires considerably richer datasets than the 15 annual observations available in the present study.

Out-of-sample validation was not performed because a conventional train-test split would further reduce the already limited estimation sample. Withholding three observations, for

example, would leave only 12 annual observations for estimating four explanatory variables and an intercept. Such a procedure would not provide a stable basis for either estimation or validation. The inability to conduct meaningful independent validation is therefore treated as a substantive limitation rather than being obscured by the high in-sample R^2 . The resulting scenario projections should accordingly be interpreted as conditional illustrations of a possible trajectory rather than predictions with demonstrated external accuracy. More broadly, the findings support the view that wartime macroeconomic dynamics cannot be reduced to stable relationships derived from ordinary periods. The direction and strength of associations may change when government expenditure, trade flows, investment behavior, production capacity, migration and external financing are simultaneously affected by a military shock. This interpretation is consistent with evidence showing that geopolitical risk and crisis conditions influence economic performance through multiple, context-dependent channels (22, 25, 26).

Several limitations therefore define the boundaries of the conclusions. First, the sample contains only 15 annual observations and only three observations for the full-scale war period. This sharply limits statistical power and the precision with which period-specific effects can be estimated. Second, the annual frequency suppresses intra-year variation and prevents examination of short-term responses to specific military, fiscal, or trade shocks. Quarterly or monthly data would substantially increase the number of observations and permit more appropriate dynamic specifications.

Third, the model contains four predictors despite the restricted sample, leaving only 10 residual degrees of freedom. Although the specification is formally identified, parameter stability cannot be assumed. Fourth, the analysis uses aggregate macroeconomic variables and does not explicitly incorporate foreign financial assistance, reconstruction expenditure, direct infrastructure losses, population displacement, energy-system disruptions, security intensity, monetary-policy changes, or institutional adjustments. Omitted variables may therefore contribute to the relationships attributed to the included indicators.

Fifth, the use of levels of macroeconomic time series creates a risk that common temporal movements contribute to the observed correlations and regression fit. The present exploratory specification does not include formal cointegration analysis, unit-root testing, lag structures, or error-correction mechanisms because the available annual sample is too small to support these procedures reliably. Sixth, the assumed linearity of the relationships is a simplification. Wartime economic processes may contain thresholds, regime changes, asymmetric responses and nonlinear adjustment mechanisms that cannot be represented adequately by a small-sample linear regression.

Finally, the absence of independent out-of-sample validation substantially limits the predictive interpretation of the model. The scenario-based projections depend on assumed future trajectories of GFCF, government expenditure, exports and imports and do not incorporate the full uncertainty surrounding those explanatory variables. Accordingly, neither the point projections nor their model-based intervals should be interpreted as unconditional forecasts of Ukraine's future GDP.

Despite these restrictions, the revised analysis provides a transparent exploratory description of how Ukraine's GDP and selected macroeconomic indicators co-moved over 2010–2024. Its principal contribution lies not in claiming stable causal parameters or high forecast accuracy, but in quantifying the magnitude of the observed pre-war versus full-scale-war GDP difference, identifying which macroeconomic associations remain visible under a harmonized constant-price dataset and explicitly representing the uncertainty surrounding the regression estimates and medium-term scenario trajectory.

Further research should therefore prioritize the construction of harmonized quarterly or monthly datasets. A larger number of observations would permit formal testing for structural breaks, unit roots and cointegration, the inclusion of lagged effects, more reliable residual diagnostics and genuine out-of-sample validation. It would also allow institutional, security, reconstruction and external-support variables to be integrated into the empirical specification. Such an extension is necessary before stronger claims can be made regarding causal mechanisms or statistically robust forecasting of Ukraine's economic recovery.

Conclusion

The analysis identified a pronounced downward shift in Ukraine's GDP during the full-scale war period compared with 2010–2021. Mean GDP decreased from 101.96 to 75.80 billion constant 2015 US\$, while the standardized between-period difference was large, with Hedges' $g = 3.59$. At the same time, the study does not claim a formally established structural break, since no dedicated structural-break test was applied. The observed pattern should therefore be interpreted as a substantial change in GDP level between the predefined periods rather than as proof of a statistically identified regime shift.

The relationships between GDP and the selected macroeconomic indicators were heterogeneous. Exports showed the strongest positive association with GDP, whereas imports demonstrated a more moderate positive relationship. Gross fixed capital formation was weakly associated with GDP and its confidence interval included zero. General government final consumption expenditure showed a negative association with GDP in both the correlation and regression analyses. This result should not be interpreted causally, since wartime GDP contraction and increased government consumption may reflect a common underlying shock and countercyclical fiscal adjustment.

The exploratory multiple regression model demonstrated high in-sample fit, with $R^2 = 0.966$ and adjusted $R^2 = 0.953$. However, the model was estimated from only 15 annual observations with four explanatory variables and an intercept, leaving 10 residual degrees of freedom. Accordingly, the regression coefficients should be regarded as sample-specific estimates of conditional statistical association rather than stable causal parameters. The high R^2 likewise cannot be treated as evidence of out-of-sample predictive accuracy.

The scientific contribution of the study lies in combining period comparison, effect-size estimation, uncertainty intervals, correlation analysis, regression diagnostics and scenario-based projection within a transparent small-sample framework. Particular attention was paid to reporting the uncertainty surrounding the estimates rather than relying exclusively on p -values or goodness-of-fit statistics.

The 2025–2027 estimates should be interpreted as indicative scenario-based projections rather than

statistically validated forecasts. Under the baseline assumptions, GDP demonstrates a gradual partial recovery, but the widening prediction intervals indicate substantial uncertainty over the medium term. Because independent out-of-sample validation was not feasible without materially reducing the already limited estimation sample, no claim of robust forecasting performance is made. The main limitations arise from the small annual sample, the presence of only three observations for the full-scale war period, the low observation-to-parameter ratio and the inability of annual data to capture short-term macroeconomic fluctuations. In addition, the model does not explicitly account for foreign financial assistance, reconstruction expenditure, infrastructure losses, migration, security intensity, institutional changes, or other wartime shocks. Common temporal movements and potential nonlinear relationships may also influence the estimated associations. Further research should therefore prioritize harmonized quarterly or monthly datasets, which would increase the number of observations and permit more rigorous dynamic modeling, formal structural-break testing, lagged specifications, cointegration analysis and genuine out-of-sample validation. Incorporating institutional, security, reconstruction and external-support variables would also allow a more comprehensive assessment of the mechanisms shaping Ukraine's economic recovery.

Abbreviations

ASEAN: Association of Southeast Asian Nations, GDP: Gross Domestic Product, OECD: Organization for Economic Co-operation and Development, VIF: variance inflation factors.

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Author Contributions

All authors contributed equally to the conception and design of the study, data collection and analysis, interpretation of results, drafting and revising the manuscript and approval of the final version for publication. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The data used in the study are publicly available on the official websites of the World Bank, OECD and Eurostat.

Declaration of Artificial Intelligence (AI) Assistance

The authors declare that generative artificial intelligence and AI-assisted technologies were not used to generate the scientific content, analytical interpretations, or conclusions of the manuscript. The authors take full responsibility for the content's originality, interpretation and accuracy.

Ethics Approval

This study is based solely on an analysis of publicly available sources and did not require ethics approval.

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APPENDIX A: Supplementary Statistical Information**Table A1:** Annual Macroeconomic Dataset Used in the Analysis, 2010–2024

Year	GDP index, 2010 = 100	GDP	GFCF	GOV	EXP	IMP
2010	100.00	106.20	18.79	17.53*	74.00	67.08
2011	105.45	111.98	20.02	17.06*	76.31	78.74
2012	105.61	112.15	20.68	17.79*	72.13	81.77
2013	105.65	112.20	19.03	17.66*	66.77	78.91
2014	95.01	100.89	13.58	16.94*	55.14	60.31
2015	85.72	91.03	12.33	17.23	47.88	50.26
2016	87.81	93.25	14.85	17.14	47.01	54.93
2017	89.89	95.45	17.24	18.02	48.85	62.03
2018	93.02	98.78	20.10	18.01	48.19	63.76
2019	96.00	101.94	22.46	15.56	51.71	67.42
2020	92.39	98.12	17.66	15.44	48.71	63.14
2021	95.58	101.50	19.31	15.57	44.53	72.11
2022	68.09	72.31	12.78	20.46	25.81	59.55
2023	71.86	76.31	21.20	22.34	24.27	64.87
2024	74.19	78.79	21.95	21.33	26.76	69.85

Note: GDP = Gross Domestic Product, GFCF = Gross Fixed Capital Formation, GOV = General Government Final Consumption Expenditure, EXP = Exports of Goods and Services, IMP = Imports of Goods and Services. Monetary variables are expressed in billion constant 2015 US\$. The GDP index was calculated as $GDP_t / GDP_{2010} \times 100$. World Bank WDI indicator codes: GDP – NY.GDP.MKTP.KD; GFCF – NE.GDI.FTOT.KD; GOV – NE.CON.GOV.T.KD; EXP – NE.EXP.GNFS.KD; IMP – NE.IMP.GNFS.KD. The 2010–2014 GOV levels were reconstructed from the corresponding World Bank WDI constant-price annual growth series anchored to the 2015 WDI level and should be replaced by the direct WDI level observations in the final single-snapshot dataset before submission.

Table A2: Sample Size and Regression Model Specification

Indicator	Value
Number of observations (n)	15
Number of explanatory variables (k)	4
Intercept	1
Total estimated parameters	5
Model degrees of freedom	4
Residual degrees of freedom	10
Total degrees of freedom	14

Note: Residual degrees of freedom: $df = n - k - 1 = 15 - 4 - 1 = 10$.

Table A3: Multiple Regression Estimates

Variable	B	SE	t	p-value	95% CI	VIF
Constant	88.305	10.163	8.689	<0.001	65.660 to 110.949	–
GFCF	0.294	0.337	0.873	0.403	–0.456 to 1.044	2.29
GOV	–2.154	0.487	–4.426	0.001	–3.239 to –1.070	1.80
EXP	0.481	0.072	6.665	<0.001	0.320 to 0.642	2.66
IMP	0.261	0.151	1.731	0.114	–0.075 to 0.596	3.29

Model statistics: $R^2 = 0.966$; adjusted $R^2 = 0.953$; $F(4,10) = 71.38$, $p < 0.001$; Durbin–Watson = 1.61.

Residual heteroscedasticity: Breusch–Pagan LM = 2.11, $p = 0.716$.

Note: B = Unstandardized Regression Coefficient, SE = Standard Error, CI = Confidence Interval, VIF = Variance Inflation Factor, R^2 = Sample Goodness of Fit and should not be interpreted as evidence of out-of-sample predictive accuracy.

Table A4: Effect-size Assessment of GDP Differences Between the Pre-war and War Periods

Statistic	Estimate
Pre-war period, 2010–2021 (n)	12
War period, 2022–2024 (n)	3
Mean GDP, pre-war, billion constant 2015 US\$	101.96
Mean GDP, war period, billion constant 2015 US\$	75.80
Mean difference	26.15
95% CI for mean difference	16.59 to 35.72
Student's t	5.90
Degrees of freedom	13
p-value	<0.001

Hedges' g	3.59
95% CI for Hedges' g	1.75 to 5.37
Mann-Whitney U	0
Exact two-sided p-value	0.004
Rank-biserial correlation	1.00

Note: Hedges' g is reported as the standardized effect size because it applies a small-sample correction. The non-parametric result is additionally reported because the war-period subsample contains only three observations.

Table A5: Correlations between GDP and Macroeconomic Indicators with Uncertainty Intervals

Relationship	Pearson r	95% CI	p-value
GDP – GFCF	0.248	–0.303 to 0.674	0.373
GDP – GOV	–0.722	–0.901 to –0.332	0.002
GDP – EXP	0.939	0.823 to 0.980	<0.001
GDP – IMP	0.568	0.078 to 0.837	0.027

Note: CI = 95% Confidence Interval. Correlation coefficients indicate statistical co-movement and should not be interpreted as causal effects.