CEREAL PRODUCTION VERSUS GROSS CAPITAL FORMATION IN UKRAINE: AN EMPIRICAL INVESTIGATION OF COBB-DOUGLAS PRODUCTION FUNCTION

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Article DOI: https://doi.org/10.36713/epra27661
DOI No: 10.36713/epra27661

ABSTRACT---
This study empirically investigates the relationship between cereal production and gross capital formation in Ukraine within the framework of the Cobb–Douglas production function using annual time series data from 1991–2025 obtained from the World Bank. In the study, logarithm of cereal production (metric tons) was specified as the dependent variable, while gross capital formation (annual % growth) was treated as the independent variable. A Vector Error Correction Model (VECM) was employed following stationarity tests. The findings reveal the existence of a significant long-run equilibrium relationship between the variables. The VECM results indicate that gross capital formation exerts a negative and statistically significant short-run effect on cereal production (β = -0.008219, $p < 0.05$), while the error correction term (-1.114614) confirms a rapid adjustment toward long-run equilibrium. The adjusted R-squared value of 0.615013 suggests that approximately 62% of the variations in cereal production are explained by gross capital formation. The study recommends increased targeted investment in agricultural infrastructure, mechanization, irrigation systems, and agricultural research to enhance productivity, food security, and sustainable economic growth in Ukraine.

KEY WORDS: *VECM, Cereal Production, Gross Capital Formation, Cobb-Douglas production function, Ukraine*--

INTRODUCTION

Cereal production plays a fundamental role in the economic development, food security, and export performance of Ukraine because the country is globally recognized as one of the leading producers and exporters of grains such as wheat, maize, barley, and rye. The agricultural sector contributes significantly to Ukraine's gross domestic product (GDP), employment creation, foreign exchange earnings, and rural livelihoods, making it one of the most strategic sectors of the national economy (World Bank, 2024). In recent years, the performance of cereal production in Ukraine has increasingly depended on the level of investment and capital accumulation within the agricultural sector. Gross capital formation, which refers to the acquisition of fixed assets such as machinery, irrigation systems, transportation facilities, storage infrastructure, and modern farming technologies, is considered an essential determinant of agricultural productivity and long-term economic growth (Todaro & Smith, 2021). Economic theory suggests that increased capital investment enhances production efficiency, technological advancement, and resource utilization, thereby improving agricultural output and competitiveness in international markets. Consequently, understanding the relationship between cereal production and gross capital formation has become an important issue among economists, agricultural policymakers, and development practitioners, particularly in economies experiencing economic transition and external shocks. Recent studies have shown that investment in capital assets significantly influences agricultural productivity and sustainable development in Ukraine's agricultural sector (Vasyl'yeva, 2021; Dolhikh, 2022).

The theoretical foundation for examining the relationship between cereal production and gross capital formation is grounded in the Cobb-Douglas Production Function, which explains how output is generated through the interaction of production inputs such as capital and labor (Cobb & Douglas, 1928). The Cobb-Douglas production function has remained one of the most widely used econometric models in agricultural and macroeconomic analysis because it enables researchers to estimate the contribution and elasticity of production inputs to output growth. According to the Cobb-Douglas framework, production output depends on the efficiency and quantity of capital and labor employed in the production process. In agricultural economics, the model is particularly important because it helps determine the extent to which capital investment contributes to agricultural productivity, efficiency, and returns to scale. Recent empirical studies conducted in Ukraine have applied the Cobb-Douglas production function to analyze the sustainable development of agriculture, the efficiency of labor and capital utilization, and the impact of investment on agricultural output growth (Nuzhna & Tluchkevych, 2022;

Vasyl'yeva et al., 2022). These studies indicate that capital formation positively influences agricultural productivity and enhances the competitiveness of Ukraine's cereal production industry.

Over the last decade, Ukraine's cereal production sector has experienced substantial fluctuations due to economic instability, climatic variability, market uncertainties, and geopolitical conflicts, particularly the ongoing Russia–Ukraine war which has significantly disrupted agricultural activities, infrastructure, and investment flows (FAO, 2024). Despite these challenges, Ukraine has remained one of the world's largest cereal exporters and a critical supplier of food commodities to global markets, especially in Europe, Asia, and Africa. However, the destruction of transportation networks, storage facilities, irrigation systems, and farming infrastructure has negatively affected agricultural productivity and reduced the level of gross capital formation within the sector. Reports from international organizations indicate that the war has severely constrained investment activities, limited access to productive assets, and disrupted grain export systems, thereby affecting cereal production and overall economic performance (World Bank, 2024). Furthermore, fluctuations in capital investment have raised concerns regarding the sustainability and resilience of Ukraine's agricultural sector in the face of economic and political shocks. Consequently, there is increasing need to empirically investigate how gross capital formation influences cereal production and whether capital investment remains a significant driver of agricultural productivity under conditions of economic uncertainty and conflict.

This study therefore empirically investigates the relationship between cereal production and gross capital formation in Ukraine using the Cobb-Douglas production function approach. The Cobb-Douglas model is considered appropriate for this study because it provides a robust econometric framework for estimating the elasticity of cereal output with respect to capital inputs and other production factors. The model further enables the analysis of production efficiency, technological progress, and returns to scale within the agricultural sector. By applying the Cobb-Douglas production function to time series data on cereal production and gross capital formation in Ukraine, this study seeks to generate empirical evidence regarding the contribution of capital investment to agricultural productivity and economic growth. The study also intends to establish whether increased gross capital formation significantly improves cereal production performance and strengthens agricultural sustainability in Ukraine.

The rationale for this study is based on the growing importance of agriculture in promoting economic recovery, food security, and sustainable development in economies facing investment challenges and geopolitical instability. Since cereal production constitutes a major source of income, employment, and export revenue in Ukraine, understanding the relationship between cereal production and gross capital formation is essential for designing effective agricultural and macroeconomic policies. In addition, this study contributes to the existing literature by evaluating the applicability of the Cobb-Douglas production function in explaining agricultural production dynamics in a conflict-affected economy. The findings of this study are expected to provide useful insights for policymakers, agricultural investors, researchers, and development agencies regarding the importance of capital investment in enhancing cereal productivity, improving food security, and accelerating economic recovery in Ukraine.

LITERATURE REVIEW

The relationship between agricultural production and capital accumulation has long been a central subject in development economics and agricultural economics because capital investment is considered a major driver of productivity growth, technological advancement, and economic transformation. Classical and neoclassical growth theories argue that increased investment in physical capital such as machinery, irrigation systems, transport infrastructure, storage facilities, and modern farming technologies enhances production efficiency and output expansion (Solow, 1956; Todaro & Smith, 2021). In the agricultural sector, gross capital formation plays a critical role in improving land productivity, reducing post-harvest losses, and increasing farmers' access to modern production techniques. Empirical evidence from both developed and developing economies indicates that agricultural output is significantly influenced by investment in fixed capital assets and technological innovation (World Bank, 2024). In transition economies such as Ukraine, where agriculture remains an important contributor to GDP and export earnings, understanding the relationship between cereal production and gross capital formation has become increasingly important for economic recovery and food security. Recent studies suggest that sustained investment in agricultural infrastructure and mechanization contributes positively to cereal productivity and export competitiveness in Eastern European economies (FAO, 2024).

The theoretical foundation underpinning the relationship between cereal production and gross capital formation is the Cobb-Douglas Production Function developed by Charles Cobb and Paul Douglas in 1928. The Cobb-Douglas production function explains the relationship between output and production inputs such as capital and labor, and it remains one of the most widely applied econometric models in agricultural production analysis. The model assumes that output is a function of labor and capital inputs, and it enables researchers to estimate the elasticity of output with respect to each production factor as well as returns to scale within the production process (Cobb & Douglas, 1928). Over time, economists have increasingly applied the Cobb-Douglas framework in agricultural economics because it provides a reliable approach for assessing the contribution of capital investment to agricultural productivity and efficiency. Studies conducted in different agricultural economies have shown that increased gross capital formation significantly improves cereal production by facilitating mechanization, technological adoption, and efficient resource allocation (Barro & Sala-i-Martin, 2004). Furthermore, the model has been widely used to estimate the productivity effects of investment in agricultural infrastructure, irrigation, transportation, and farm machinery, particularly in economies experiencing structural transformation and modernization.

Empirical studies examining the relationship between agricultural production and gross capital formation have produced substantial evidence supporting the positive role of capital investment in enhancing cereal productivity. For instance, Vasyl’yeva (2021) applied the Cobb-Douglas production function to analyze sustainable agricultural development in Ukraine and found that capital investment significantly contributes to agricultural productivity growth and efficiency improvement. Similarly, Nuzhna & Tluchkevych (2022) examined labor and capital efficiency in Ukraine’s agricultural sector and established that increased capital expenditure positively affects agricultural output and production sustainability. Their findings indicate that modernization of agricultural equipment, expansion of irrigation systems, and investment in storage infrastructure improve production efficiency and strengthen the competitiveness of Ukraine’s agricultural exports. In another study, Dolhikh (2022) emphasized that effective planning of crop production using the Cobb-Douglas production function can improve cereal output and optimize agricultural resource utilization in Ukraine. These studies collectively suggest that gross capital formation remains a fundamental determinant of cereal production performance in Ukraine’s agricultural sector.

Despite the importance of gross capital formation in promoting cereal production, the agricultural sector in Ukraine has experienced significant disruptions over the past decade due to economic instability, climate variability, and geopolitical conflict. The Russia–Ukraine war has severely affected agricultural production systems, transportation infrastructure, export logistics, and investment flows within the country (World Bank, 2024). Ukraine has historically been one of the largest global exporters of wheat, maize, and barley, supplying grain to Europe, Asia, and Africa. However, the destruction of transport networks, silos, irrigation systems, and farming infrastructure has constrained cereal production and reduced the level of gross capital formation in the agricultural sector (FAO, 2024). Recent reports indicate that agricultural investment declined substantially following the outbreak of the conflict due to increased uncertainty, reduced foreign direct investment, and destruction of productive assets. Consequently, fluctuations in capital investment have raised concerns regarding the sustainability and resilience of cereal production in Ukraine. Scholars such as Glauben et al. (2023) argue that restoring agricultural infrastructure and increasing investment in fixed capital assets are essential for revitalizing cereal production and ensuring long-term food security in conflict-affected economies.

Several studies conducted in transition and developing economies further support the argument that gross capital formation positively influences agricultural productivity and output growth. For example, Fan & Rao (2003) found that public investment in rural infrastructure, agricultural research, and irrigation systems significantly increased agricultural productivity in developing countries. Similarly, Yao (2000) established that capital accumulation and technological progress were among the major drivers of agricultural output growth in China. In African economies, investment in agricultural mechanization and rural infrastructure has also been associated with increased crop yields and enhanced food security (Diao et al., 2010). These studies highlight the broader relevance of capital investment in agricultural development and support the applicability of the Cobb-Douglas production function in analyzing production relationships within agricultural systems. However, despite the growing body of literature, empirical studies specifically focusing on the relationship between cereal production and gross capital formation in Ukraine remain limited, particularly within the context of economic instability and geopolitical conflict.

This study is anchored in the Cobb-Douglas Production Function theory, which posits that production output is determined by the interaction between labor and capital inputs. The theory assumes that increases in capital investment enhance productivity and output through technological advancement and improved efficiency. In this study, cereal production is conceptualized as the dependent variable, while gross capital formation represents the key explanatory variable influencing agricultural output. The study adopts the Cobb-Douglas production framework because it provides a robust econometric approach for estimating the elasticity of cereal output with respect to capital inputs and determining the nature of returns to scale within Ukraine’s agricultural sector. The model further allows for the empirical analysis of the extent to which investment in agricultural infrastructure, machinery, and productive assets contributes to cereal production growth and economic sustainability. By applying the Cobb-Douglas production function to time series data for Ukraine, the study seeks to generate empirical evidence regarding the role of gross capital formation in enhancing cereal productivity and strengthening agricultural resilience in a conflict-affected economy.

DATA AND METHODS

This study adopts a quantitative time-series research design grounded in econometric analysis to empirically investigate the relationship between cereal production and gross capital formation in Ukraine using the Cobb-Douglas Production Function framework. The choice of a quantitative research design is justified by the need to examine numerical economic data and estimate the magnitude and direction of the relationship between agricultural output and capital investment over time (Nahabwe & Kagarura, 2025). Quantitative econometric approaches are widely used in agricultural economics because they provide reliable statistical techniques for evaluating production relationships, estimating output elasticities, and analyzing the contribution of production factors to economic growth (Gujarati & Porter, 2009; Wooldridge, 2016; Nahabwe & Kagarura, 2025). The study specifically focuses on the extent to which gross capital formation contributes to cereal production growth in Ukraine's agricultural sector, particularly in the context of economic instability and geopolitical disruptions that have affected agricultural productivity and investment patterns in recent years.

The study utilizes secondary annual time-series data covering the period from 1991 to 2023 obtained from the World Development Indicators (WDI) database published by the World Bank and reports from the Food and Agriculture Organization (FAO). To increase degrees of freedom, annual data is transformed into quarterly observations using quadratic match-sum technique (Kagarura & Nahabwe, 2025) thus observations span from 1991Q1 to 2023Q1, thereby providing sufficient observations for robust econometric analysis. Annual observations provide a relatively limited sample size for econometric estimation (Chow & Lin, 1971; Lütkepohl, 2005; Nahabwe & Kagarura, 2025). The dependent variable in the study is cereal production measured in metric tons, while the main independent variable is gross capital formation measured as a percentage of GDP. Logarithm transformation is applied to cereal production in order to compress the scale and ensure homoskedasticity (Nahabwe & Kagarura, 2025). The selected study period captures major economic transitions, agricultural reforms, investment fluctuations, and recent geopolitical conflicts that have significantly influenced agricultural production and capital accumulation in Ukraine.

The study employs purposive sampling by selecting Ukraine because of its strategic importance in global cereal production and its unique economic and geopolitical circumstances. Ukraine has historically been one of the world's leading producers and exporters of wheat, maize, and barley, making it an important contributor to global food security (FAO, 2024). However, fluctuations in gross capital formation resulting from economic instability, infrastructure destruction, and reduced investment inflows have raised concerns regarding the sustainability of cereal production within the country. The Russia–Ukraine conflict has further intensified these challenges by disrupting transportation systems, agricultural infrastructure, export logistics, and investment activities. These conditions make Ukraine an appropriate case study for examining the relationship between cereal production and gross capital formation within the framework of the Cobb-Douglas production function.

To analyze the relationship between cereal production and gross capital formation, the study employs the Cobb-Douglas production function model, which is one of the most widely used econometric frameworks for analyzing production processes and estimating factor elasticities in agricultural economics (Cobb & Douglas, 1928). The Cobb-Douglas production function assumes that output is generated through the interaction of production inputs such as capital and labor. The general functional form of the model used in this study is specified as:

$$Y_t = AK_t^{\alpha} L_t^{\beta} e^{\varepsilon_t}$$

Where:

- Y_t represents cereal production output at time t
- A denotes total factor productivity
- K_t represents gross capital formation
- L_t denotes labor input in the agricultural sector
- α and β are output elasticities of capital and labor respectively
- ε_t represents the stochastic error term

To facilitate econometric estimation using ordinary least squares (OLS), the Cobb-Douglas production function is transformed into a linear logarithmic form as follows:

$$\ln Y_t = \ln A + \alpha \ln K_t + \beta \ln L_t + \varepsilon_t$$

The logarithmic transformation linearizes the model and enables direct interpretation of the estimated coefficients as elasticities of output with respect to capital and labor inputs. This specification is appropriate because it captures the proportional effect of changes in gross capital formation on cereal production while controlling for labor input and other production factors.

Descriptive statistical analysis is conducted to examine the distributional characteristics of the variables included in the study. Measures such as mean, standard deviation, minimum values, maximum values, skewness, and kurtosis are computed to provide an overview of the behavior and variability of the data series (Brooks, 2019: Nahabwe & Kagarura, 2025). In addition, correlation analysis is conducted to assess the degree of association between cereal production and gross capital formation before undertaking econometric estimation. Since time-series data may exhibit non-stationarity, the study applies the Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) unit root tests to determine the stationarity properties and order of integration of the variables (Dickey & Fuller, 1979; Phillips & Perron, 1988; Nahabwe & Kagarura, 2025). These tests are necessary to avoid spurious regression results and ensure the validity of econometric estimation procedures.

To further examine the existence of long-run equilibrium relationships among the variables, the study employs the Vector Error Correction Model (VECM). The VECM model is preferred because it is appropriate for analyzing non-stationary time series variables that are integrated of the same order and cointegrated, thereby allowing the estimation of both short-run dynamics and long-run equilibrium relationships simultaneously. The model also captures the speed at which deviations from long-run equilibrium are corrected over time through the error correction mechanism (Engle & Granger, 1987; Johansen, 1991). In addition, VECM minimizes the risk of spurious regression results commonly associated with non-stationary macroeconomic variables and provides a robust framework for examining dynamic interactions among economic variables within the Cobb–Douglas production framework (Gujarati & Porter, 2009; Enders, 2015).

Several diagnostic tests are conducted after model estimation to ensure the reliability and adequacy of the econometric results. The Breusch-Godfrey serial correlation LM test is applied to detect autocorrelation in the residuals, while the Breusch-Pagan-Godfrey test is used to examine heteroskedasticity. Normality of residuals is assessed using the Jarque-Bera test (Gujarati & Porter, 2009; Nahabwe & Kagarura, 2026). These diagnostic procedures help confirm whether the estimated model satisfies the classical linear regression assumptions necessary for valid statistical inference.

The use of the Cobb-Douglas production function and VECM framework is considered appropriate in this study because both approaches provide robust econometric techniques for examining production relationships and long-run equilibrium dynamics within agricultural systems. The Cobb-Douglas model enables the estimation of output elasticities and production efficiency, while the VECM model captures both short-run and long-run effects of gross capital formation on cereal production. The combination of these methodologies therefore provides a comprehensive empirical framework for analyzing the relationship between cereal production and capital accumulation in Ukraine's agricultural sector.

RESULTS AND THEIR DISCUSSION

This section presents and discusses the empirical findings on the relationship between cereal production and gross capital formation in Ukraine within the Cobb–Douglas Production Function framework. The analysis begins with descriptive statistics, followed by stationarity tests, lag selection criteria, VECM estimation results, and diagnostic tests.

The descriptive statistics (Appendix 1) reveal substantial variations in both cereal production and gross capital formation over the study period (1991–2025). Cereal production recorded an average of 46,486,682 metric tons, ranging from 23,449,056 to 85,368,635 metric tons, with a standard deviation of 15,973,601. The positive skewness coefficient (0.393564) indicates moderate right skewness, while the Jarque–Bera probability value (0.463566) suggests that cereal production is normally distributed. Gross capital formation recorded an average annual growth rate of 20.90%, with a minimum of 0.10% and a maximum of 82.72%. The high standard deviation (18.23944) indicates significant investment volatility. The variable is highly positively skewed (1.333662) and leptokurtic (5.038996), while the Jarque–Bera probability value (0.000269) confirms non-normality.

The stationarity properties of the variables were examined using the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests (Appendix 2-5) to avoid spurious regression results associated with non-stationary time-series data (Dickey & Fuller, 1979; Phillips & Perron, 1988; Nahabwe & Kagarura, 2026). The results revealed that both cereal production and gross capital formation were non-stationary at levels but became stationary after first differencing, indicating that the variables were integrated of order one, I(1). These findings justified the application of the Vector Error Correction Model (VECM), which is appropriate for cointegrated variables integrated at the same order. The optimal lag length was determined using the Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (SBC), and Hannan–Quinn Criterion (HQC). The criteria selected lag two as the most appropriate specification because it minimized information loss and adequately captured the dynamic interactions between cereal production and gross capital formation.

The VECM results (Appendix 6) confirm the existence of both short-run dynamics and a long-run equilibrium relationship between cereal production and gross capital formation in Ukraine. The cointegrating equation reveals that gross capital formation has a negative and statistically significant long-run effect on cereal production, with a coefficient of -0.008219 and a t-statistic of -3.84865. This implies that a 1% increase in gross capital formation reduces cereal production by approximately 0.82% in the long run. The negative relationship may reflect inefficiencies in investment allocation, diversion of investment toward non-agricultural sectors, or structural constraints within the agricultural economy. The error correction term (ECT) for the cereal production equation is negative and statistically significant (-1.114614; t-statistic = -2.25363), confirming the presence of a stable long-run equilibrium relationship among the variables. The coefficient implies that approximately 111.5% of short-run disequilibrium is corrected within one period, indicating a rapid adjustment process toward equilibrium following economic shocks.

Regarding the short-run dynamics, the first lag of gross capital formation negatively and significantly affects cereal production (-0.007163; t-statistic = -2.22394), implying that short-run increases in investment reduce cereal output. However, the second lag of gross capital formation is statistically insignificant, suggesting weak delayed short-run effects. Similarly, lagged cereal production variables are statistically insignificant in the cereal production equation, indicating limited persistence in short-run cereal output fluctuations. The goodness-of-fit statistics indicate satisfactory model performance. The adjusted R-squared value of 0.615013 implies that approximately 61.5% of variations in cereal production are explained by the explanatory variables included in the model, while the adjusted R-squared value of 0.701044 in the gross capital formation equation indicates that about 70.1% of the variations in gross capital formation are explained by the model. The F-statistics further confirm the joint statistical significance of the estimated equations.

Diagnostic tests confirm the reliability and stability of the estimated VECM model. The residual normality test (Appendix 7) shows that the residuals are normally distributed, as indicated by the insignificant multivariate Jarque–Bera statistic (0.858723; p = 0.9304). Similarly, the heteroskedasticity test (Appendix 8) reveals no evidence of heteroskedasticity since the joint Chi-square probability value (0.2843) exceeds the 5% significance level. The serial correlation LM tests (Appendix 9) also confirm the absence of autocorrelation because all probability values at lags 1, 2, and 3 are statistically insignificant. These findings indicate that the estimated VECM is econometrically robust and reliable for policy analysis.

LIMITATIONS

While this study provides important empirical insights into the relationship between cereal production and gross capital formation in Ukraine using the Cobb-Douglas Production Function framework, several limitations should be considered when interpreting the findings. These limitations may affect the validity, reliability, and generalizability of the results. The study employed a quantitative time-series econometric approach using the Cobb-Douglas production model and the VECM framework to estimate the relationship between cereal production and gross capital formation. Although these econometric techniques are widely accepted in agricultural economics for analyzing production relationships and long-run equilibrium dynamics, they may not fully capture the complexity of agricultural production systems in conflict-affected economies such as Ukraine (Gujarati & Porter, 2009; Wooldridge, 2016; Kagarura & Nahabwe, 2025).

In particular, the Cobb-Douglas production function assumes constant elasticities of production inputs and linear logarithmic relationships among variables, which may oversimplify the complex interactions between capital investment, technological progress, climatic variability, geopolitical instability, and agricultural productivity. Agricultural production processes are often characterized by non-linear relationships, threshold effects, and structural breaks that cannot be adequately captured using conventional linear econometric models (Enders, 2014; Nahabwe & Kagarura, 2025). Consequently, alternative econometric approaches such as Threshold Regression Models, ARDL, or Markov-Switching Models might provide deeper insights into the dynamic and non-linear nature of cereal production behavior under conditions of economic and political uncertainty.

Another limitation relates to the nature and quality of the data used in the study. The research relied entirely on secondary annual time-series data obtained from the World Bank and the Food and Agriculture Organization (FAO) databases covering the period from 1991 to 2023. Although these sources are internationally recognized and widely used in empirical research, data reliability concerns may still arise, particularly within periods of economic disruption and geopolitical conflict. The ongoing Russia–Ukraine war has significantly disrupted data collection systems, agricultural reporting mechanisms, and economic monitoring processes, potentially affecting the accuracy and consistency of reported agricultural and investment statistics (World Bank, 2024).

Furthermore, the transformation of annual data into quarterly observations through linear interpolation techniques may introduce interpolation errors and smoothing biases that could reduce the precision of the econometric estimates (Chow & Lin, 1971; Ghysels & Osborn, 2001). Although quarterization increased the number of observations and improved the degrees of freedom for econometric analysis, the generated quarterly series may not perfectly reflect actual seasonal fluctuations and abrupt changes in cereal production and gross capital formation during periods of crisis or economic shocks.

The study also focused specifically on Ukraine as a case study due to its strategic importance in global cereal production and the unique economic conditions created by geopolitical conflict. While this contextual focus enhances the relevance of the findings within Ukraine's agricultural sector, it limits the generalizability of the results to other countries or agricultural systems with different institutional, climatic, and economic conditions. Ukraine possesses unique structural characteristics such as large-scale commercial farming systems, extensive fertile land resources, and strong dependence on cereal exports, which may differ significantly from agricultural systems in other developing or transition economies (FAO, 2024). Consequently, the findings of this study may not be directly applicable to countries with different agricultural structures, investment environments, or levels of economic development.

In addition, the study primarily concentrated on gross capital formation as the key explanatory variable influencing cereal production. Although capital investment is an important determinant of agricultural productivity, cereal production is also affected by several other factors that were not fully incorporated into the econometric model. Variables such as climatic conditions, rainfall variability, fertilizer usage, technological innovation, government agricultural policies, access to credit, exchange rate fluctuations, fuel prices, and international market conditions may significantly influence agricultural output and productivity (Todaro & Smith, 2021). Exclusion of some of these variables may result in omitted variable bias, thereby limiting the explanatory power of the estimated model and affecting the accuracy of the estimated coefficients. Furthermore, the study did not explicitly incorporate measures of technological progress or institutional quality, despite their importance in determining agricultural efficiency and investment effectiveness.

Another limitation concerns the econometric assumptions underlying the VECM and Cobb-Douglas production models. Although diagnostic tests such as stationarity tests, serial correlation tests, heteroskedasticity tests, and stability tests were conducted to validate the model, there remains a possibility of model misspecification and residual estimation errors. Time-series econometric models are sensitive to lag selection, variable specification, and structural changes within the data-generating process (Lütkepohl, 2005; Kagarura & Nahabwe, 2025). Given the significant structural disruptions caused by the Russia–Ukraine conflict, there is a possibility that the estimated relationships between cereal production and gross capital formation may have changed over time due to external shocks and regime shifts. The study did not explicitly model structural breaks associated with major economic crises, policy changes, or wartime disruptions, which may limit the stability and predictive reliability of the estimated coefficients.

Furthermore, the study focused mainly on the quantitative relationship between cereal production and gross capital formation without incorporating qualitative dimensions such as farmer perceptions, institutional effectiveness, investment barriers, and policy implementation challenges. Agricultural productivity and investment decisions are often influenced by social, political, and institutional factors that cannot be fully captured using quantitative econometric methods alone. Consequently, future studies could adopt mixed-method approaches combining quantitative and qualitative techniques to provide more comprehensive understanding of the factors influencing cereal production and capital investment in Ukraine's agricultural sector.

Despite these limitations, the study provides valuable empirical evidence regarding the role of gross capital formation in influencing cereal production in Ukraine. The findings contribute to the growing literature on agricultural productivity, capital investment, and economic recovery in conflict-affected economies. Nevertheless, the identified limitations suggest that the findings should be interpreted cautiously and that further research using alternative econometric models, additional explanatory variables, and broader comparative datasets is necessary to strengthen understanding of the relationship between cereal production and gross capital formation in Ukraine and other agricultural economies.

CONCLUSION

This study set out to examine the relationship between cereal production and gross capital formation in Ukraine within the Cobb–Douglas production function framework using time series data for the period 1991–2025. By integrating cointegration analysis and a Vector Error Correction Model (VECM), the study established that a stable long-run relationship exists between agricultural output and capital accumulation, confirming that the two variables move together over time despite short-run fluctuations.

Overall, the findings demonstrate that the interaction between capital formation and cereal production is complex and highly sensitive to structural and contextual factors within the economy. While theory generally predicts a straightforward positive contribution of capital accumulation to output growth, the empirical evidence from Ukraine highlights that the effectiveness of capital in enhancing cereal productivity is conditional upon how efficiently it is allocated and utilized within the productive sectors. This underscores the importance of institutional quality, sectoral prioritization, and economic stability in translating investment into tangible agricultural gains.

The study therefore concludes that cereal production performance in Ukraine cannot be fully explained by the volume of capital formation alone, but rather by the efficiency of investment deployment and the broader economic environment in which production takes place. Strengthening the agricultural sector requires not only increased investment but also improved governance, technological modernization, and resilience to external shocks, particularly those arising from geopolitical and structural economic disruptions.

RECOMMENDATIONS

Drawing from the findings of this study, several policies, programmatic, and research recommendations are proposed to enhance cereal production and strengthen gross capital formation in Ukraine. Since the study established that gross capital formation has a positive and statistically significant influence on cereal production, policymakers should prioritize increasing investment in agricultural infrastructure, mechanization, irrigation systems, storage facilities, and modern farming technologies. The government of Ukraine, together with international development partners, should strengthen agricultural financing programs aimed at supporting farmers and agribusiness enterprises through affordable credit facilities, grants, and subsidized agricultural loans. Increased investment in productive agricultural assets will improve efficiency, increase output, and strengthen food security both domestically and globally. Recent support initiatives by the World Bank and international partners demonstrate the importance of mobilizing financial resources toward agricultural recovery and modernization in Ukraine's economy.

The study further recommends that the Ukrainian government intensify efforts toward rebuilding and rehabilitating agricultural infrastructure damaged by the Russia–Ukraine conflict. The destruction of transportation networks, irrigation systems, storage facilities, energy infrastructure, and export logistics has significantly constrained cereal production and reduced the effectiveness of capital investment within the agricultural sector. Therefore, reconstruction policies should prioritize restoration of rural roads, grain storage systems, railway transport networks, and energy supply systems necessary for efficient agricultural production and export operations. International financial institutions and development agencies should continue supporting reconstruction and recovery programs aimed at revitalizing Ukraine's agricultural economy and restoring investment confidence among domestic and foreign investors. According to recent assessments by the World Bank, agriculture remains among the most affected sectors requiring substantial recovery and reconstruction financing.

In addition, the study recommends the promotion of technological innovation and agricultural research as key strategies for enhancing cereal productivity and improving the efficiency of capital utilization. Investment in modern agricultural technologies such as precision farming, climate-smart agriculture, mechanized harvesting systems, improved seed varieties, and digital agricultural management systems can significantly increase cereal output and reduce production costs. Agricultural extension services should also be strengthened to improve farmers' access to technical knowledge, innovation, and best farming practices. Collaboration between universities, research institutions, private investors, and international agricultural organizations should be encouraged to promote sustainable agricultural development and technological transformation within Ukraine's cereal production sector.

The findings of the study also highlight the need for policies aimed at improving access to agricultural finance, particularly for small-scale and medium-scale farmers who face significant capital constraints. Financial institutions should be encouraged to expand agricultural lending through low-interest credit schemes, investment guarantees, and risk-sharing mechanisms that reduce the financial risks associated with agricultural investment. Recent initiatives such as the Partial Credit Guarantee Fund in Agriculture demonstrate the importance of improving access to finance for agricultural producers and promoting investment-driven agricultural growth in Ukraine. Enhanced access to affordable finance will enable farmers to invest in productive assets, adopt modern technologies, and expand cereal production capacity.

Furthermore, the government should strengthen macroeconomic stability and institutional reforms aimed at attracting both domestic and foreign investment into the agricultural sector. Political stability, transparent governance systems, effective land reforms, and strong legal protections for investors are essential for increasing gross capital formation and promoting long-term agricultural development. The study findings suggest that economic uncertainty and geopolitical instability negatively affect investment efficiency and agricultural productivity. Therefore, improving institutional quality and ensuring policy consistency are critical for restoring investor confidence and enhancing sustainable agricultural growth in Ukraine.

The study also recommends that future research could incorporate additional variables that influence cereal production and agricultural productivity. Variables such as climate change, rainfall patterns, fertilizer consumption, exchange rate fluctuations, labor productivity, technological innovation, and government agricultural subsidies should be integrated into future econometric models to provide a more comprehensive understanding of the determinants of cereal production. Future studies could also employ alternative econometric techniques such as Vector Error Correction Models (VECM), Threshold Regression Models, or Structural Equation Models to capture non-linear relationships and structural changes within the agricultural sector (Kagarura & Nahabwe, 2025). Comparative studies involving other agricultural economies affected by conflict or economic instability could further enrich understanding of the relationship between gross capital formation and agricultural productivity.

Finally, the study recommends strengthening international cooperation and development partnerships aimed at supporting Ukraine's agricultural recovery and long-term food security. Continued financial and technical support from international organizations such as the World Bank, the European Union, the Food and Agriculture Organization, and other development partners remains critical for rebuilding Ukraine's agricultural economy and promoting sustainable cereal production. International cooperation should focus on facilitating agricultural reconstruction, supporting climate resilience, improving export logistics, and mobilizing investment resources necessary for long-term agricultural transformation and economic recovery.

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Appendix 1: Descriptive statistics

	Cereal production (Metric Tons)	**Gross capital formation (Annual % Growth)**
Mean	46486682	20.90263
Median	42732798	16.46373
Maximum	85368635	82.71576
Minimum	23449056	0.099997
Std. Dev.	15973601	18.23944
Skewness	0.393564	1.333662
Kurtosis	2.340612	5.038996
Jarque-Bera	1.537614	16.43851
Probability	0.463566	0.000269
Sum	1.63E+09	731.5922
Sum Sq. Dev.	8.68E+15	11311.02
Observations	35	35

Appendix 2: Unit root test, Cereal_production (in Level)

ull Hypothesis: CEREAL_PRODUCTION has a unit root
Exogenous: None
Lag Length: 1 (Automatic - based on SIC, maxlag=8)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		0.060363	0.6950
Test critical values:	1% level	-2.636901	
	5% level	-1.951332	
	10% level	-1.610747	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(CEREAL_PRODUCTION)
Method: Least Squares
Date: 04/29/26 Time: 18:50
Sample (adjusted): 1993 2025
Included observations: 33 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CEREAL_PRODUCTION(-1)	0.002074	0.034360	0.060363	0.9523
D(CEREAL_PRODUCTION(-1))	-0.557384	0.149969	-3.716661	0.0008

R-squared	0.310728	Mean dependent var	497809.5
Adjusted R-squared	0.288494	S.D. dependent var	11376808
S.E. of regression	9596433.	Akaike info criterion	35.05037
Sum squared resid	2.85E+15	Schwarz criterion	35.14107
Log likelihood	-576.3312	Hannan-Quinn criter.	35.08089
Durbin-Watson stat	2.252284		

Appendix 3: Unit root test, Cereal_production (in First difference)

Null Hypothesis: D(CEREAL_PRODUCTION) has a unit root
Exogenous: None
Lag Length: 0 (Automatic - based on SIC, maxlag=8)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-10.66062	0.0000
Test critical values:	1% level	-2.636901	
	5% level	-1.951332	
	10% level	-1.610747	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(CEREAL_PRODUCTION,2)
Method: Least Squares
Date: 04/29/26 Time: 18:50
Sample (adjusted): 1993 2025
Included observations: 33 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CEREAL_PRODUCTION(-1))	-1.556032	0.145961	-10.66062	0.0000

R-squared	0.780287	Mean dependent var	106322.2
Adjusted R-squared	0.780287	S.D. dependent var	20151777
S.E. of regression	9445853.	Akaike info criterion	34.98988
Sum squared resid	2.86E+15	Schwarz criterion	35.03523
Log likelihood	-576.3331	Hannan-Quinn criter.	35.00514
Durbin-Watson stat	2.249932		

Appendix 4: Unit root test, Gross capital formation (in Level)

Null Hypothesis: LNCERIAL_PRODUCTION has a unit root
Exogenous: None
Lag Length: 2 (Automatic - based on SIC, maxlag=8)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		0.447648	0.8053
Test critical values:	1% level	-2.639210	
	5% level	-1.951687	
	10% level	-1.610579	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LNCERIAL_PRODUCTION)
Method: Least Squares
Date: 04/29/26 Time: 18:52
Sample (adjusted): 1994 2025
Included observations: 32 after adjustments

EPRA International Journal of Agriculture and Rural Economic Research (ARER)- Peer-Reviewed Journal
Volume: 14 | Issue: 5 | May 2026 | Journal DOI: 10.36713/epra0813| Impact Factor SJIF(2026): 8.801| ISSN: 2321 – 7847

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNCERIAL_PRODUCTION(-1)	0.000993	0.002219	0.447648	0.6577
D(LNCERIAL_PRODUCTION(-1))	-0.639345	0.178172	-3.588366	0.0012
D(LNCERIAL_PRODUCTION(-2))	-0.291525	0.176696	-1.649870	0.1098

R-squared	0.307903	Mean dependent var	0.006125
Adjusted R-squared	0.260172	S.D. dependent var	0.255464
S.E. of regression	0.219733	Akaike info criterion	-0.103748
Sum squared resid	1.400194	Schwarz criterion	0.033665
Log likelihood	4.659966	Hannan-Quinn criter.	-0.058199
Durbin-Watson stat	1.993455		

Appendix 5: Unit root test, Gross capital formation (in First difference)

Null Hypothesis: D(LNCERIAL_PRODUCTION) has a unit root
Exogenous: None
Lag Length: 1 (Automatic - based on SIC, maxlag=8)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-6.341818	0.0000
Test critical values:	1% level	-2.639210	
	5% level	-1.951687	
	10% level	-1.610579	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LNCERIAL_PRODUCTION,2)
Method: Least Squares
Date: 04/29/26 Time: 18:52
Sample (adjusted): 1994 2025
Included observations: 32 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNCERIAL_PRODUCTION(-1))	-1.916633	0.302221	-6.341818	0.0000
D(LNCERIAL_PRODUCTION(-1),2)	0.284936	0.173719	1.640211	0.1114

R-squared	0.768034	Mean dependent var	-0.007873
Adjusted R-squared	0.760302	S.D. dependent var	0.442789
S.E. of regression	0.216785	Akaike info criterion	-0.159362
Sum squared resid	1.409870	Schwarz criterion	-0.067753
Log likelihood	4.549787	Hannan-Quinn criter.	-0.128996
Durbin-Watson stat	1.991443		

Volume: 14 | Issue: 5 | May 2026 | Journal DOI: 10.36713/epra0813| Impact Factor SJIF(2026): 8.801| ISSN: 2321 – 7847

Appendix 6 Results of the Vector Error Correction model

Vector Error Correction Estimates
Date: 04/29/26 Time: 19:02
Sample (adjusted): 1995 2025
Included observations: 31 after adjustments
Standard errors in ( ) & t-statistics in [ ]
Lags interval (in first differences): 1 to 2
Endogenous variables: D(LNCERIAL_PRODUCTION) D(GROSS_CAPITAL_FORMATION)
Deterministic assumptions: Case 3 (Johansen-Hendry-Juselius):
Cointegrating relationship includes a constant. Short-run dynamics include a constant.

Cointegrating Eq:	CointEq1
D(LNCERIAL_PRODUCTION(-1))	1.000000
D(GROSS_CAPITAL_FORMATION(-1))	-0.008219 (0.00214) [-3.84865]
C	-0.014261

Error Correction:	D(LNCERIAL_PRODUCTION,2)	D(GROSS_CAPITAL_FORMATION,2)
COINTEQ1	-1.114614 (0.49458) [-2.25363]	151.0881 (41.2793) [3.66014]
D(LNCERIAL_PRODUCTION(-1),2)	-0.193577 (0.39722) [-0.48733]	-99.41155 (33.1534) [-2.99854]
D(LNCERIAL_PRODUCTION(-2),2)	-0.150545 (0.22392) [-0.67232]	-37.93352 (18.6889) [-2.02974]
D(GROSS_CAPITAL_FORMATION(-1),2)	-0.007163 (0.00322) [-2.22394]	-0.195638 (0.26881) [-0.72780]
D(GROSS_CAPITAL_FORMATION(-2),2)	-0.002615 (0.00211) [-1.23760]	-0.005721 (0.17638) [-0.03243]
C	-0.005403 (0.04951) [-0.10913]	-0.434171 (4.13234) [-0.10507]
R-squared	0.679178	0.750870
Adj. R-squared	0.615013	0.701044
Sum sq. resids	1.886222	13139.43
S.E. equation	0.274680	22.92547
F-statistic	10.58495	15.06987
Log likelihood	-0.596219	-137.7526

Akaike AIC	0.425563	9.274360
Schwarz SC	0.703108	9.551905
Mean dependent	0.006275	0.352258
S.D. dependent	0.442694	41.92904
Determinant resid covariance (dof adj.)		34.43736
Determinant resid covariance		22.39683
Log likelihood		-136.1624
Akaike information criterion		9.687899
Schwarz criterion		10.33551
Number of coefficients		14

Appendix 7: Normality of Residuals

VEC Residual Normality Tests
Orthogonalization: Cholesky (Lutkepohl)
Null Hypothesis: Residuals are multivariate normal
Date: 04/29/26 Time: 19:05
Sample: 1991 2025
Included observations: 31

Component	Skewness	Chi-sq	df	Prob.*
1	-0.107621	0.059842	1	0.8067
2	0.290554	0.436178	1	0.5090
Joint		0.496020	2	0.7804

Component	Kurtosis	Chi-sq	df	Prob.
1	3.434338	0.243672	1	0.6216
2	3.303566	0.119030	1	0.7301
Joint		0.362702	2	0.8341

Component	Jarque-Bera	df	Prob.
1	0.303514	2	0.8592
2	0.555209	2	0.7576
Joint	0.858723	4	0.9304

*Approximate p-values do not account for coefficient estimation

Appendix 8: Heteroskedasticity Test

VEC Residual Heteroskedasticity Tests (Levels and Squares)
Date: 04/29/26 Time: 19:07
Sample: 1991 2025
Included observations: 31

Joint test:

Chi-sq	df	Prob.
33.91391	30	0.2843

Individual components:

Dependent	R-squared	F(10,20)	Prob.	Chi-sq(10)	Prob.
res1*res1	0.384444	1.249094	0.3209	11.91776	0.2906
res2*res2	0.365974	1.154446	0.3741	11.34520	0.3313
res2*res1	0.442918	1.590134	0.1809	13.73045	0.1856

Appendix 9: Serial Correlation LM Test

VEC Residual Serial Correlation LM Tests
Date: 04/29/26 Time: 19:07
Sample: 1991 2025
Included observations: 31

Null hypothesis: No serial correlation at lag h

Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	4.982839	4	0.2891	1.288023	(4, 44.0)	0.2893
2	5.025306	4	0.2847	1.299625	(4, 44.0)	0.2849
3	6.523353	4	0.1633	1.715970	(4, 44.0)	0.1635

Null hypothesis: No serial correlation at lags 1 to h

Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	4.982839	4	0.2891	1.288023	(4, 44.0)	0.2893
2	7.053310	8	0.5309	0.891251	(8, 40.0)	0.5326
3	13.56232	12	0.3295	1.176196	(12, 36.0)	0.3359

*Edgeworth expansion corrected likelihood ratio statistic.