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Econometric and volatility analysis of Uganda's maize export dynamics under macroeconomic instability: Evidence from ARIMAX, GARCH, and Structural break models

[1]Kiwanuka Joseph Kakande, *[2]Lekia Nkpordee

[1,2]Department of Mathematics and Statistics, Kampala International University, Uganda

[1]Email Address: kakande.kiwanuka@studmc.kiu.ac.ug

*[*2]Corresponding Author Email: lekia.nkpordee@kiu.ac.ug*

*[*2]Corresponding Author Orcid ID: https://orcid.org/0000-0002-8750-066X*

Corresponding Author: kakande.kiwanuka@studmc.kiu.ac.ug

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Abstract

For Uganda's maize export sector, export quantity and price levels exhibit a high degree of volatility, largely driven by macroeconomic shocks such as exchange rate fluctuations and inflation, which continue to influence production costs and international competitiveness. This study applies an integrated econometric framework combining ARIMAX for modeling the conditional mean, GARCH for volatility dynamics, and structural break tests to capture regime changes over the period 1961 to 2025. The ARIMAX estimation results indicate a weak, positive, and statistically insignificant effect of inflation on export volumes, while exchange rate depreciation also shows a weak, unstable, and statistically insignificant impact on exports. This suggests limited transmission of macroeconomic policy variables to Uganda's agricultural export performance. The autoregressive coefficient from the ARIMAX model is negative and statistically significant at −0.5773, indicating strong mean reversion in export dynamics, where shocks to exports tend to dissipate over time rather than persist indefinitely. The GARCH results further reveal strong volatility persistence, with the sum of the ARCH and GARCH coefficients (α + β) estimated at 0.8843. This indicates that shocks to maize export volatility are highly persistent and influence export variability over extended periods, implying that instability in exports is not short lived but accumulates over time. The structural break analysis identifies a significant regime shift around 1970, confirmed by the Chow test results, which reflects a transition from a highly unstable export structure to a more stable but still volatile regime influenced by evolving policy and institutional changes. The findings indicate that Uganda's maize export performance is characterized by both trend behavior and persistent risk exposure, with long lasting shocks shaping its dynamics over time. Consequently, policy interventions should extend beyond macroeconomic stabilization to include coordinated exchange rate management, agricultural risk mitigation instruments such as insurance schemes, improved storage infrastructure, and enhanced market access systems, in order to reduce export volatility and strengthen long term export resilience.

Nomenclature and units

Q_t	Export Quantity
V_t	Export Value
P_t	Export Price
INF_t	Inflation Rate
EXR_t	Exchange Rate

1.0 Introduction

Maize remains one of the most important agricultural commodities in Uganda because of its contribution to food security, household income generation, agro industrial production, and national economic development. The crop serves both subsistence and commercial purposes, particularly among rural households where a large proportion of smallholder farmers depend on maize production as a major source of livelihood. In recent decades, maize has also emerged as a strategic export commodity within the East African region and beyond, increasing its relevance in agricultural trade and export policy discussions (World Bank, 2023; UBOS, 2024).

Uganda's maize exports contribute significantly to foreign exchange earnings, which are essential for import financing, balance of payment stability, and overall macroeconomic management. Compared with industrial exports, agricultural exports often face relatively lower market entry barriers, thereby creating opportunities for export expansion and regional trade integration. However, the sustainability of export earnings depends largely on the stability of export quantities and prices over time. Persistent fluctuations in export value and volume may weaken producer incentives, reduce income stability, and ultimately limit the contribution of the agricultural sector to economic development (FAO, 2022; Bank of Uganda, 2023).

One major characteristic of Uganda's maize export sector is the persistent instability observed in export quantities and export values across different periods. Historical trends reveal alternating phases of export expansion and sharp decline, indicating substantial volatility within the sector. Such instability affects producer income, export planning, and trade competitiveness. The observed fluctuations may be attributed to production shocks, changing market conditions, climatic variability, trade disruptions, and broader macroeconomic uncertainties that influence export performance over time (World Bank, 2024; NPA, 2023).

Macroeconomic conditions, particularly exchange rate movements, play an important role in determining agricultural export competitiveness. In theory, exchange rate depreciation is expected to improve export performance by reducing the relative international price of domestic commodities, thereby increasing external demand. Nevertheless, excessive exchange rate volatility may discourage export growth by creating uncertainty in foreign exchange earnings and weakening investment confidence within the agricultural export sector. Such instability may also affect long term trade planning and reduce the responsiveness of exporters to international market opportunities (Cameron & Trivedi, 2022; World Bank, 2023).

Inflation also constitutes an important macroeconomic factor influencing export dynamics. Rising inflation increases production and transaction costs through higher prices of agricultural inputs, transportation, storage, and marketing activities. Persistent inflation may further reduce the real value of export earnings and weaken producer incentives to participate actively in export markets. Consequently, prolonged inflationary pressures may negatively affect export competitiveness and reduce the overall performance of agricultural exports (Mishra et al., 2024; Bank of Uganda, 2023).

Although several empirical studies have examined agricultural export performance in developing economies, many existing studies focus primarily on average export behavior while paying limited attention to export volatility and structural changes within the economy. A considerable proportion of earlier studies rely on conventional time series approaches that inadequately capture instability, persistence of shocks, and regime shifts in export behavior. Furthermore, only a few studies have jointly incorporated macroeconomic variables such as inflation and exchange rate within an integrated econometric framework capable of explaining both export dynamics and volatility simultaneously. This limitation restricts deeper understanding of how macroeconomic shocks interact to influence export performance over time (Chikwira et al., 2022; Dercon & Christiaensen, 2022).

This study addresses these gaps by developing an integrated econometric framework that combines ARIMAX, GARCH, and structural break models to analyze Uganda's maize export dynamics under conditions of macroeconomic instability. The ARIMAX framework is employed to estimate the influence of macroeconomic variables on export performance, while the GARCH model captures volatility persistence and instability within the export series. Structural break analysis is further incorporated to identify major regime shifts and policy related changes affecting export behavior across time. By integrating these approaches, the study provides a more comprehensive understanding of Uganda's maize export performance and offers evidence-based insights relevant for agricultural trade policy and macroeconomic management (Cameron & Trivedi, 2022; World Bank, 2024).

2.0 Literature Review

Theoretical Framework

This study is anchored on the Export Supply Theory, Purchasing Power Parity (PPP) framework, and volatility theory in time series economics. Export Supply Theory explains that export performance is determined by relative prices, production capacity, and macroeconomic conditions that influence competitiveness in international markets. From this theoretical perspective, an exchange rate depreciation is expected to enhance export performance by lowering the relative price of domestically produced goods in international markets, thereby improving export demand and supply conditions.

The Purchasing Power Parity framework provides additional insight by linking inflation to export competitiveness through domestic cost structures. Higher inflation increases the cost of inputs such as seeds, fertilizers, transport, and labor, which reduces profit margins and weakens the ability of producers to supply export markets competitively. In the context of Uganda's maize sector, persistent inflation may therefore reduce export volumes by discouraging production and increasing marketing costs (World Bank, 2023; Food and Agriculture Organization, 2022).

In addition, volatility theory from financial and commodity economics is applied to explain the persistence of shocks in export series. The theory argues that economic and trade series often exhibit volatility clustering, where periods of high instability are followed by further instability. This provides a strong justification for the application of ARCH and GARCH models in analyzing maize export volatility and persistence over time (Ahmed et al., 2025; Nkpordee & Ogolo, 2022).

Conceptual Framework

The conceptual structure of this study is built on the interaction between macroeconomic conditions, structural constraints, and export performance.

The framework assumes that:

i. Inflation and exchange rate are key macroeconomic drivers
ii. These variables influence production cost, export competitiveness, and market stability
iii. Structural and institutional factors moderate these relationships

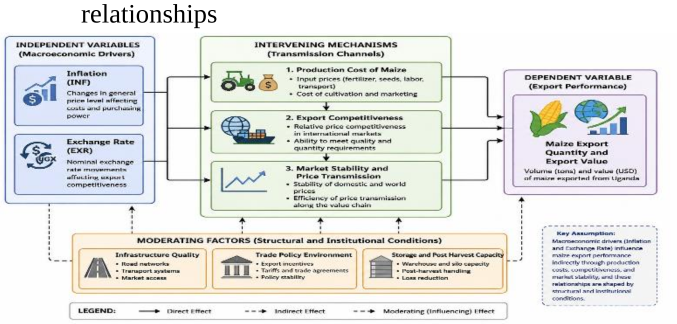

Figure 1: Conceptual Framework of Uganda's Maize Export Dynamics

This structure implies that macroeconomic variables do not affect exports directly in a simple linear form. Instead, their effects are transmitted through production and market mechanisms that are shaped by institutional and structural conditions.

Agricultural Export Modeling

The modeling of agricultural exports has received considerable attention in development economics, particularly in Sub Saharan Africa. This is mainly because agricultural exports represent a major source of foreign exchange earnings and play a significant role in rural livelihoods. Empirical studies consistently identify production capacity, international prices, exchange rates, and trade policy as key determinants of agricultural export performance.

However, recent evidence suggests that export growth in developing economies is not only constrained by production inefficiency but also by structural and macroeconomic instability. Weak market integration, institutional constraints, and price transmission inefficiencies have been identified as major limitations to export competitiveness (World Bank, 2023; Food and Agriculture Organization, 2022). In Uganda, maize exports are largely driven by smallholder farmers whose output is highly variable and strongly influenced by both climatic and market conditions.

A synthesis of empirical studies shows mixed evidence regarding the role of macroeconomic variables. While some studies emphasize strong responsiveness of agricultural exports to exchange rate movements, others report weak or insignificant transmission effects, particularly in economies with structural constraints. This suggests that the effectiveness of macroeconomic policies depends heavily on the level of infrastructure development, market efficiency, and institutional quality (Anderson et al., 2021; Ahmed et al., 2025).

Role of Prices in Agricultural Export Performance

Price remains a central mechanism in agricultural export modeling. It serves both as an incentive for production and a signal for trade allocation. High export prices tend to stimulate production expansion and increase export supply, while low or unstable prices introduce uncertainty that discourages investment and production planning.

Evidence from African economies indicates that fluctuations in world commodity prices and exchange rates significantly affect export performance in both volume and value terms. These fluctuations often lead to instability in export earnings and production decisions (Anderson et al., 2021; Ahmed et al., 2025). From a theoretical perspective, exchange rate depreciation is expected to enhance export competitiveness by making domestic goods cheaper in foreign markets. However, this effect may be weakened or offset by inflationary pressures that increase production costs, thereby reducing the net gain from currency depreciation.

Production Capacity and Structural Constraints

Production capacity is another critical determinant of agricultural export performance. Rainfall variability, factor endowments, and technological advancement significantly influence agricultural output in African economies. Maize production in particular is highly dependent on rainfall, making it vulnerable to climate variability and weather shocks.

Empirical evidence shows that improvements in agricultural productivity, through mechanisms such as improved seed varieties and irrigation systems, enhance export supply capacity. However, failure to address structural supply side constraints results in persistent export shortages and unstable supply responses (Food and Agriculture Organization, 2022; World Bank, 2024). A synthesis of the literature indicates that agricultural export performance cannot be explained solely by price mechanisms. Instead, it is shaped by a combination of demand side factors, supply side constraints, and structural inefficiencies.

Structural and Institutional Determinants of Export Performance

African experiences further demonstrate that agricultural export performance is influenced by a combination of macroeconomic, institutional, and infrastructural factors. Evidence from Kenya, Nigeria, and Ethiopia shows that export performance depends not only on domestic supply and prices but also on institutional quality, infrastructure, and market access conditions.

For example, in Nigeria, exchange rate fluctuations and inflation have been shown to significantly affect agricultural export performance by influencing production costs and competitiveness (Biu et al., 2023; Nkpordee & Ogolo, 2022). Similarly, in East Africa, inadequate storage facilities and poor road infrastructure contribute to post harvest losses, thereby reducing exportable surplus. These findings highlight that agricultural export models must integrate macroeconomic, structural, and institutional variables to adequately capture real world export behavior.

Time Series and Volatility Models in Trade Analysis

Time series models are widely used in trade analysis because they account for dynamic dependencies and allow forecasting of economic variables. Traditional ARMA models are often used in modeling export series; however, they are limited because they do not incorporate external macroeconomic variables.

To overcome this limitation, ARIMAX models were developed to incorporate exogenous variables such as inflation and exchange rates. Empirical studies show that ARIMAX models provide more realistic and economically meaningful results in export modeling compared to standard ARIMA or ARMA models (Biu et al., 2023; Box et al., 2019).

In developing economies such as Uganda, inclusion of macroeconomic variables is essential because inflation affects production costs while exchange rate movements influence export competitiveness. Studies consistently show that currency depreciation tends to promote exports, although this effect is often moderated by structural constraints and market inefficiencies (World Bank, 2023).

Volatility Modeling in Agricultural Trade

Although ARIMAX models explain mean behavior, they fail to capture volatility clustering, which is a common characteristic of economic and trade data. Volatility clustering refers to the tendency of periods of high variability to be followed by further periods of high variability.

ARCH and GARCH models are widely used to capture this phenomenon by modeling time varying conditional variance. These models are particularly relevant for agricultural exports because they help to assess risk and instability in export earnings over time.

Empirical evidence shows that agricultural export prices and volumes are highly volatile in developing countries, and such volatility has significant implications for income stability and policy formulation (Ahmed et al., 2025; Nkpordee & Ogolo, 2022).

Studies from Nigeria and Somalia further confirm that macroeconomic shocks exhibit persistence over time, meaning that their effects do not dissipate immediately but continue influencing economic variables over multiple periods (Ahmed et al., 2025; Nkpordee & Ogolo, 2022).

Structural Break Analysis in Trade Models

Structural break analysis is essential in time series modeling, especially in economies that have experienced policy reforms, economic transitions, and external shocks. Structural break tests such as the Chow test and Bai Perron tests are used to identify changes in the underlying data generating process.

Empirical studies across African economies show that structural breaks are often associated with trade liberalization policies, currency devaluation, and institutional reforms that significantly alter export behavior (Perron, 2019; World Bank, 2024). Ignoring structural breaks in long time series data may lead to biased estimates and misleading policy conclusions, particularly in export modeling.

Research Gap

Despite extensive literature on agricultural export modeling, several gaps remain.

First, most studies focus on limited variables, often analyzing either export quantity or export price in isolation. Few studies integrate export performance, inflation, and exchange rate within a unified econometric framework. These limits understanding of the full dynamics of export behavior in macroeconomic environments (World Bank, 2023; Anderson et al., 2021).

Second, there is limited country specific empirical research on Uganda's maize export sector. Most existing studies focus on larger economies, leaving a gap in understanding how macroeconomic variables influence Uganda's export performance using advanced econometric techniques (Food and Agriculture Organization, 2022; World Bank, 2024).

Third, volatility-based modeling remains underdeveloped in agricultural export studies. Although instability in export performance is widely acknowledged, few studies apply GARCH based approaches to measure persistence and risk, limiting policy relevance for risk management (Ahmed et al., 2025; Nkpordee & Ogolo, 2022).

Finally, the interaction between structural breaks and volatility has not been sufficiently explored in agricultural export literature. Most models assume parameter stability over time, which is unrealistic for developing economies undergoing policy and institutional changes (Perron, 2019; International Monetary Fund, 2022).

Contribution of the Study

This study addresses these gaps by developing a unified econometric framework that integrates ARIMAX, GARCH, and structural break models. The framework allows simultaneous analysis of mean export behavior, volatility dynamics, and structural changes in Uganda's maize export sector. By combining these approaches, the study provides a more comprehensive understanding of how macroeconomic instability influences both the level and risk of agricultural export performance in developing economies

3.0 Materials and Methods

This analysis focuses on Ugandan maize export response to macroeconomic instability by using a combination econometric approach. Time series analysis and volatility modelling together with structural break analysis was utilized to model the mean dynamic and instability of export performance. The structure of this analysis will comprise six sections namely, data description, tests of stationarity, ARIMAX modelling, GARCH volatility modeling, structural break analysis and model diagnostics.

3.1 Data Description

The empirical analysis is based on annual time series data covering the period 1961 to 2025. This long-time horizon allows the study to capture both short run fluctuations and long-term structural changes in Uganda's maize export performance.

Variables

The study utilizes five key variables:

i. Export Quantity (Q_t) measured in kilograms (kg)
ii. Export Value (V_t) measured in United States dollars
iii. Export Price (P_t) computed as:

$$P_t = \frac{V_t}{Q_t} \tag{1}$$

i. Inflation Rate (INF_t) representing domestic price instability
ii. Exchange Rate (EXR_t) representing currency valuation against major trading currencies

Export quantity and value capture trade performance, while inflation and exchange rate serve as macroeconomic drivers affecting competitiveness and market stability.

Variable Definition and Measurement Issues

Table 1: Operational Definition of Variables

Variable	Symbol	Measurement	Expected Effect
Export Quantity	Q_t	Kilograms of maize exports	Dependent
Export Value	V_t	USD export earnings	Dependent
Export Price	P_t	Export value divided by quantity	Positive
Inflation Rate	INF_t	Annual CPI percentage change	Negative
Exchange Rate	EXR_t	UGX per USD	Positive

Data Collection Procedure

The study relied exclusively on secondary annual time series data obtained from international and national statistical repositories. Export quantity and export value data were obtained from international trade databases, while macroeconomic variables such as inflation and exchange rate were sourced from the World Bank Development Indicators and the Bank of Uganda statistical reports. Data extraction was conducted systematically to ensure consistency across the study period from 1961 to 2025. Summary indicators such as latest value, highest value, and frequency are drawn from aggregated trade statistics platforms (Key Stats, 2024). Macroeconomic variables are aligned with standard national and international reporting systems.

Data Handling and Imputation

Given the long-time span, the dataset contains missing observations and repeated values, particularly in earlier decades. To ensure continuity, the study applies mean imputation, defined as:

$$X_t^* = \begin{cases} X_t, & \text{if observed} \\ \bar{X}, & \text{if missing} \end{cases} \tag{2}$$

where:

X_t^* is the adjusted value
X_t is the observed value
$\bar{X}$ is the sample mean of the variable

Justification for Mean Imputation

Mean imputation is adopted because:

1. The study focuses on aggregate trends rather than micro level variation
2. It preserves the overall distributional structure of the data
3. It ensures compatibility with time series modeling techniques that require complete observations

Limitations of Data Handling

Despite its advantages, mean imputation introduces potential biases:

i. It may reduce variability in the dataset
ii. It can underestimate volatility, especially in earlier years
iii. It assumes missing data are randomly distributed, which may not fully hold

Data Credibility and Transparency

It is important to acknowledge that:

i. Early period data (1960s to 1980s) may contain measurement inconsistencies
ii. Some repeated values may reflect reporting limitations rather than true economic behavior

These limitations are explicitly recognized to ensure transparency and to strengthen the credibility of the empirical results.

Data Reliability and Validation

To ensure reliability, data from multiple repositories were cross validated using official macroeconomic and trade statistics. Variables were standardized into consistent units and transformed into logarithmic form to improve comparability and reduce heteroskedasticity.

Assumptions of the ARIMAX and GARCH Models

The ARIMAX model assumes stationarity after differencing, absence of serial correlation in residuals, and linear dependence between the dependent and explanatory variables. The GARCH model assumes conditional heteroskedasticity and volatility clustering in the residual series.

Diagnostic tests including the Augmented Dickey Fuller test, Ljung Box test, and ARCH test were conducted to verify model adequacy.

3.2 Stationarity Testing

Time series modeling requires that variables be stationary to avoid spurious regression results. Stationarity is tested using the Augmented Dickey Fuller (ADF) test.

The ADF regression is specified as:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{k} \delta_i \Delta Y_{t-i} + \varepsilon_t \quad (3)$$

where:

Δ is the first difference operator

t is a time trend

k is the lag length

ε_t is white noise

Hypotheses

Null hypothesis (H_0): $\gamma = 0$(unit root, non stationary)

Alternative hypothesis (H_1): $\gamma < 0$(stationary)

Decision Rule

If the test statistic is less than the critical value, the null hypothesis is rejected, indicating stationarity.

Order of Integration

Variables are classified as:

i. $I(0)$ if stationary at level
ii. $I(1)$ if stationary after first differencing

Only stationary variables or appropriately differenced series are used in model estimation.

3.3 ARIMAX Model Specification

To capture both internal dynamics and external macroeconomic influences, the study employs an Autoregressive Integrated Moving Average with Exogenous Variables (ARIMAX) model.

The general form is:

$$Y_t = \alpha + \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=0}^{q} \beta_j X_{t-j} + \varepsilon_t \quad (4)$$

where:

Y_t is export quantity or value

X_t includes inflation and exchange rate

ϕ_i are autoregressive coefficients

β_j measure the impact of macroeconomic variables

ε_t is white noise

Why ARIMAX Instead of ARIMA

The ARIMA model assumes that current values depend only on past values. However, export performance in Uganda is strongly influenced by macroeconomic conditions. ARIMAX extends ARIMA by incorporating:

i. Exchange rate effects on export competitiveness
ii. Inflation effects on cost structure and pricing

Economic Interpretation

i. A positive exchange rate coefficient implies that currency depreciation enhances export competitiveness
ii. A negative inflation coefficient suggests that domestic price increases reduce export value

3.4 Volatility Modeling Using GARCH

Export data often exhibit periods of high and low variability, known as volatility clustering. To capture this, the study applies the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model.

The GARCH(1,1) specification is:

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 \quad (5)$$

where:

σ_t^2 is conditional variance

ω is constant variance

α measures short run shock effects

β measures persistence of volatility

Interpretation

i. High αindicates that shocks strongly affect export variability
ii. High βindicates that volatility is persistent over time

Economic Relevance

Volatility in maize exports reflects:

i. Price instability
ii. Market uncertainty
iii. Production risks

This instability affects:

i. Farmer income stability
ii. Export planning
iii. Government revenue forecasts

3.5 Structural Break Analysis

To account for regime changes, the study applies structural break tests using the Chow test and Bai Perron multiple breakpoint test.

Chow Test Specification

$$F = \frac{(RSS_p - (RSS_1 + RSS_2))/k}{(RSS_1 + RSS_2)/(n_1 + n_2 - 2k)} \quad (6)$$

where:

RSS_p is pooled residual sum of squares

RSS_1, RSS_2 are segment residual sums

k is number of parameters

Purpose of Structural Break Analysis

This test identifies:

i. Economic reforms
ii. Trade liberalization periods
iii. Policy regime shifts

Economic Interpretation

Breakpoints correspond to:

i. Changes in export policy
ii. Exchange rate reforms
iii. Market restructuring

3.6 Model Diagnostics and Validation

Model adequacy is assessed using several diagnostic tools to ensure robustness and reliability.

3.6.1 Information Criteria

Model selection is based on:

$$AIC = -2\ln(L) + 2k \quad (7)$$

$$BIC = -2\ln(L) + k\ln(n) \quad (8)$$

where:

L is likelihood

k is number of parameters

n is sample size

Lower values indicate better model fit.

3.6.2 Residual Autocorrelation Test

The **Ljung Box test** is used:

$$Q = n(n+2)\sum_{k=1}^{m}\frac{\hat{\rho}_k^2}{n-k} \quad (9)$$

This tests whether residuals are independently distributed.

3.6.3 ARCH Test

To confirm volatility presence:

$$\varepsilon_t^2 = \alpha_0 + \sum_{i=1}^{q}\alpha_i\,\varepsilon_{t-i}^2 + u_t \quad (10)$$

Significance indicates heteroskedasticity.

3.6.4 Forecast Accuracy Measures

Forecast performance is evaluated using:

$$RMSE = \sqrt{\frac{1}{n}\sum(Y_t - \hat{Y}_t)^2} \quad (11)$$

$$MAPE = \frac{100}{n}\sum\left|\frac{Y_t - \hat{Y}_t}{Y_t}\right| \quad (12)$$

Table 2: Model Diagnostic Summary

Test	Statistic	Decision
ADF Test	t value	Stationarity confirmed
Ljung Box	Q value	No autocorrelation
ARCH Test	χ^2 value	Volatility present
AIC	Value	Model selected
BIC	Value	Model validated

Ethical Considerations

The study utilized publicly available secondary macroeconomic and trade data. Since no human participants were involved, formal ethical approval was not required. However, all data sources were appropriately acknowledged and used strictly for academic purposes

4.0 Results and Discussions

In this section we discuss results from an econometric and volatility modeling exercise. We begin by investigating the data's characteristics and move to an estimation of model parameters, volatility dynamics, regime switching and the forecasting ability of the models. We stress economic intuition over mere statistical documentation.

4.1 Unit Root and Stationarity Test

Unit root tests were conducted prior to model estimation to examine the stochastic properties of the variables and to ensure appropriate model specification. This is necessary to avoid spurious regression results and to determine the order of integration of each series.

Table 3: Augmented Dickey Fuller (ADF) Unit Root Test

Variable	Test Statistic	P value	Order of Integration	Decision
Log Export Quantity (kg)	-2.4886	0.1183	I(1)	Non stationary
Log Export Value (USD)	-2.2494	0.1888	I(1)	Non stationary
Log Export Price (USD per kg)	-3.0466	0.0308	I(0)	Stationary
Log Exchange Rate (UGX per USD)	-1.7710	0.3949	I(2)	Non stationary
Log Inflation (%)	-7.6839	0.0000	I(0)	Stationary
Δ Log Export Quantity (kg)	-19.0319	0.0000	I(0)	Stationary
Δ Log Export Value (USD)	-19.1702	0.0000	I(0)	Stationary

Δ² Log Exchange Rate	-7.6606	0.0000	I(0)	Stationary

Note: Δ represents first differencing and Δ² represents second differencing. Export quantity is measured in kilograms, export value in United States dollars, exchange rate in Uganda shillings per United States dollar, and inflation in percentage terms.

The results in Table 3 show a mixed order of integration across variables. Export quantity and export value are non-stationary at levels but become stationary after first differencing, indicating that shocks to maize export performance are persistent and do not dissipate quickly. This suggests that Uganda's maize export sector is influenced by long run structural forces rather than purely short run fluctuations. The exchange rate is integrated of order two, indicating a highly persistent and unstable adjustment process. This reflects structural rigidity in the foreign exchange market and suggests that exchange rate shocks have long lasting effects on trade competitiveness. In contrast, inflation and export price are stationary at levels, implying that these variables revert to their long run mean and their shocks are relatively temporary.

These findings justify the use of a differenced ARIMAX specification where export quantities are modeled in growth form while macroeconomic variables are included in stationary or appropriately differenced form. Failure to account for these properties would lead to biased and inconsistent parameter estimates.

4.2 Trend Analysis of Maize Export Dynamics

The long-term behavior of Uganda's maize export quantity and value reveals distinct structural phases characterized by shifts in volatility and growth patterns.

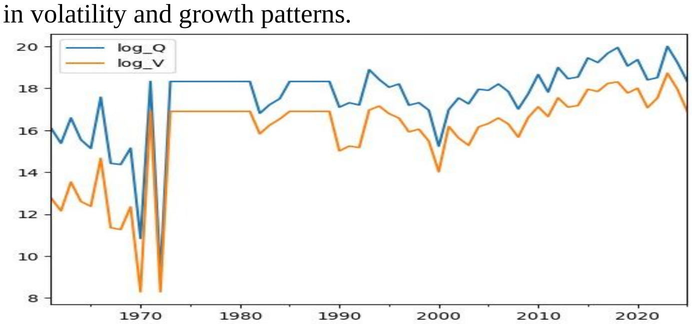

Figure 2: Trend of Log Export Quantity and Log Export Value (1961 to 2025)

From Figure 2, three main phases are observed. The first phase, covering the 1960s to early 1970s, is characterized by high instability in both export quantity and value. This reflects weak institutional capacity, limited market integration, and high exposure to political and macroeconomic shocks. Export performance during this period is highly erratic, indicating low predictability and weak structural support for trade. The second phase, spanning the mid-1970s to late 1990s, shows partial recovery with intermittent fluctuations. Although export volumes begin to recover, volatility remains high, suggesting that structural constraints such as inflationary pressures and exchange rate distortions continued to influence export outcomes. The third phase, from the early 2000s to 2025, reflects relatively stable and sustained growth in export performance. This indicates improved macroeconomic management, increased market integration, and gradual strengthening of Uganda's agricultural export systems.

However, the persistence of fluctuations indicates that underlying vulnerability has not been completely eliminated.

4.3 ARIMAX Model Estimations

The ARIMAX model was estimated using the differenced log of export quantity as the dependent variable, while inflation and exchange rate were included as exogenous variables. This specification allows the model to capture both internal dynamics and macroeconomic influences.

Table 4: ARIMAX(1,0,1) Estimation Results for Maize Export Quantity (kg)

Variable	Coef.	SE	z	P	Interpretation
Inflation (log INF, %)	0.0360	0.058	0.623	0.533	Weak and insignificant
Exchange Rate (Δ² log EXR, UGX per USD)	0.1357	1.008	0.135	0.893	Positive but unstable and insignificant
AR(1)	-0.5773	0.085	-6.765	0.000	Strong mean reversion
MA(1)	-0.2977	0.162	-1.843	0.065	Weak short run adjustment
Sigma squared	2.1410	0.247	8.661	0.000	Residual variance

Note: Coef. = Coefficient, SE = Standard Error. Export quantity is measured in kilograms. Exchange rate is measured in Uganda shillings per United States dollar. Inflation is measured in percentage change. Δ² indicates second differencing.

From Table 4 above, the AR(1) coefficient is negative and statistically significant, indicating strong mean reversion in export dynamics. This suggests that shocks in maize exports are not permanent but are corrected over time through adjustment in production, market supply, and trade flows. In economic terms, this reflects a self-correcting mechanism in Uganda's maize export system. The MA(1) term is weakly significant, indicating that short run shocks have limited persistence but are partially transmitted to the next period. This implies that export fluctuations are not fully absorbed within a single period but gradually fade out.

The inflation coefficient is positive but statistically insignificant. This finding suggests that domestic price movements do not directly determine maize export performance. Instead, maize exports in Uganda appear to be more strongly influenced by structural supply side constraints such as post-harvest losses, storage inefficiencies, transport costs, and limited value chain integration.

These structural bottlenecks reduce the sensitivity of exports to macroeconomic price signals. Similarly, the exchange rate coefficient is positive but highly insignificant with a large standard error. Although economic theory suggests that currency depreciation should enhance export competitiveness, the results indicate weak transmission from exchange rate movements to export performance. This implies that non price factors such as infrastructure limitations, weak export logistics, and market access constraints dominate the export decision process.

The Ljung Box test confirms that residuals are not serially correlated, indicating that the mean equation is correctly specified. However, evidence of conditional heteroskedasticity justifies the application of a GARCH model to capture volatility dynamics.

4.4 Volatility Analysis Using GARCH Model

To capture time varying volatility in maize export performance, a GARCH(1,1) model was estimated.

Table 5: GARCH(1,1) Volatility Model Results for Maize Export Dynamics

Parameter	Coefficient	Std Error	t Statistic	P value
Omega	0.0925	0.072	1.278	0.201
ARCH Effect (Alpha)	0.2966	0.200	1.485	0.138
GARCH Effect (Beta)	0.5877	0.174	3.375	0.001

Note: Volatility is modeled on export quantity measured in kilograms.

From Table 5 above, the ARCH term captures the immediate impact of shocks, while the GARCH term captures persistence in volatility over time. The estimated sum of the coefficients is:

$$\alpha + \beta = 0.2966 + 0.5877 = 0.8843 \quad (13)$$

This value being close to one indicates strong volatility persistence in Uganda’s maize export sector.

Economically, this implies that shocks such as drought, price collapse, or policy changes do not dissipate quickly but continue to influence export performance over several periods. This persistence introduces sustained uncertainty in export earnings, affecting farmer income stability and long-term investment decisions.

The ARCH test confirms significant heteroskedasticity, reinforcing the suitability of the GARCH framework. From a policy perspective, this suggests that stabilization policies alone are insufficient. Risk management instruments such as agricultural insurance, price stabilization mechanisms, and export risk pooling are necessary to reduce vulnerability in the sector.

4.5 Structural Break Analysis

Structural stability was examined using the Chow test to identify regime changes in export behavior.

Table 6: Structural Break Test Results for Maize Export Value (USD)

Break Year	F statistic	P value	Decision
1970	12.6487	0.0000	Structural break exists

The results in Table 6 confirm a statistically significant structural break around 1970, indicating a major shift in the underlying export generation process.

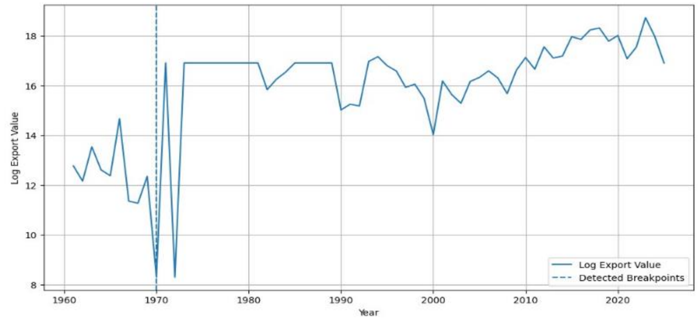

Figure 3: Structural Break in Uganda’s Maize Export Value (USD)

Before 1970, export performance is highly unstable with irregular fluctuations, reflecting weak institutional and market structures as observed in Figure 3 above. After 1970, the pattern becomes more stable, although still subject to moderate fluctuations. This structural break suggests a regime change driven by institutional reforms, trade policy shifts, and macroeconomic restructuring. Ignoring this break would lead to biased parameter estimates and misleading inference about export behavior.

4.6 Forecast Performance and Model Evaluation

Forecasts were generated using the estimated ARIMAX model to assess short term predictive performance.

Table 7: Forecasted Maize Export Value (USD)

Year	Forecast Value (USD)
2026	227,029,060.8
2027	227,029,059.6
2028	227,029,060.3
2029	227,029,059.9
2030	227,029,060.0

Note. Forecast accuracy: RMSE = 1.4718

The RMSE value indicates that the model provides reasonably accurate short-term forecasts, although some level of uncertainty remains due to inherent volatility in export behavior. The relatively stable forecast values in Table 7 suggest that Uganda’s maize export system is converging toward a more predictable long run trajectory. However, the persistence of minor fluctuations reflects continued exposure to macroeconomic and structural shocks. From a policy perspective, this implies that while long term stabilization has improved, short term volatility remains an important concern that requires active management through risk reduction strategies and structural reforms.

Discussion and Policy Implications

The empirical findings from the ARIMAX, GARCH, and structural break models provide important insights into how macroeconomic instability shapes Uganda's maize export performance over time. The results suggest that although maize exports have experienced a long-term upward trajectory, this growth is not smooth or stable. Instead, it is interrupted by recurring macroeconomic shocks and structural changes that influence both the level and variability of exports. The weak statistical significance of key macroeconomic variables further suggests that export performance is not primarily driven by short run policy signals, but rather by deeper structural conditions within the agricultural economy. This helps explain why export outcomes remain uneven despite periods of macroeconomic reform.

From the ARIMAX estimates presented in Table 4, exchange rate movements show a positive but statistically insignificant effect on maize export quantity, while inflation also displays a weak and statistically insignificant relationship with export performance. In economic terms, exchange rate depreciation is expected to improve export competitiveness by lowering the foreign currency price of domestic goods, thereby encouraging higher export supply. However, the weak transmission effect observed in this study indicates that currency movements do not fully translate into changes in export behavior. This disconnect suggests that Uganda's maize export sector may be operating under structural constraints that limit responsiveness to price incentives. These constraints are likely linked to poor transport infrastructure, inadequate storage systems, weak regional market integration, and inefficient export logistics, all of which reduce the ability of producers and traders to respond to favorable exchange rate signals.

A similar explanation is provided by the Bank of Uganda (2003) and the World Bank (2003), which emphasize that macroeconomic stabilization policies alone are insufficient to improve export performance when real sector bottlenecks remain binding. Comparable evidence from Biu et al. (2023) also shows that exchange rate effects on agricultural exports in developing economies tend to be weak when infrastructure and supply chain inefficiencies dominate market responses.

The insignificant effect of inflation further indicates that domestic price instability does not play a strong direct role in shaping maize export dynamics. Economically, inflation is expected to reduce export competitiveness by increasing production costs, especially for inputs such as seeds, fertilizers, transport, and labor. However, the findings suggest that Uganda's maize export sector may be influenced more by physical supply conditions and market access constraints than by general price level changes. This implies that even when inflation increases production costs, export volumes may not respond strongly if production and export capacity are already constrained by structural inefficiencies.

This interpretation is consistent with Mishra et al. (2024), who argue that inflation may have limited influence on agricultural exports in developing economies where production constraints dominate market behavior. However, the results differ from Biu et al. (2023), who found that inflation significantly affects export performance in some developing countries. The difference may be explained by variations in institutional strength, market integration, and the level of infrastructure development across countries, which determine whether price signals are effectively transmitted into production and export decisions.

A key contribution of this study is revealed through the volatility analysis. The GARCH results in Table 5 indicate a high degree of volatility persistence, with the sum of the ARCH and GARCH coefficients equal to 0.8843. This finding implies that shocks to maize exports do not dissipate quickly but instead persist over time, influencing export behavior across multiple periods. From an economic perspective, this means that disturbances such as droughts, climate variability, sudden price changes, or macroeconomic instability have long lasting effects on export performance. In practical terms, once a shock occurs in the maize export sector, its impact is carried forward into future periods, creating prolonged uncertainty in production and trade outcomes. This persistent uncertainty reduces predictability in export earnings and weakens incentives for long term investment by farmers, traders, and exporters, who may perceive the sector as high risk.

The evidence of persistent volatility is consistent with Ahmed et al. (2025) and Nkpordee and Ogolo (2022), who also report strong volatility persistence in agricultural export systems across African economies. These studies similarly argue that agricultural exports in developing countries are highly sensitive to shocks that have long lasting effects due to weak risk absorption capacity in production systems. In addition, Dercon and Christiaensen (2022) emphasize that repeated exposure to risk and uncertainty reduces investment in agricultural productivity, leading to stagnation in output growth. The present findings therefore reinforce the view that volatility is not a temporary disturbance in Uganda's maize export sector, but a structural characteristic that affects long term development outcomes.

The structural break analysis further strengthens this interpretation by showing that Uganda's maize export system has undergone significant regime changes over time. The results presented in Table 6 indicate a statistically significant structural break around 1970, suggesting that the underlying export process before and after this period is fundamentally different. Economically, the pre 1970 period is characterized by high instability and irregular export movements, which may reflect weak institutional structures, limited market integration, and heightened exposure to political and economic uncertainty. In contrast, the post 1970 period shows relatively more stable and structured export behavior, although volatility is not completely eliminated. This suggests that institutional and policy reforms over time have contributed to improved export organization, but have not fully resolved underlying structural weaknesses.

This finding aligns with Perron (2019), who argues that ignoring structural breaks in time series analysis can lead to biased estimates and misleading policy conclusions. It is also consistent with Anderson et al. (2021), who highlight that agricultural export performance is highly sensitive to institutional quality and policy regime changes. The implication is that export behavior in Uganda cannot be treated as stable over time, and any policy analysis that ignores regime shifts may fail to capture the true dynamics of the system.

The forecast results indicate a gradual improvement in export stability in recent years, although short term fluctuations remain evident. From an economic standpoint, this suggests that Uganda's maize export sector is becoming more integrated into regional and international markets, possibly due to improved trade linkages and macroeconomic management. However, the persistence of short-term instability indicates that exposure to shocks has not been eliminated. Instead, the system appears to have shifted from extreme instability in earlier periods to moderate but persistent volatility in recent years. This partial improvement suggests progress in macroeconomic and trade policy, but also highlights the continuing importance of risk management and structural reform.

The policy implications of these findings are multidimensional. First, while exchange rate stability remains important, the results suggest that macroeconomic policy alone cannot significantly enhance export performance without addressing structural constraints. In particular, improvements in rural infrastructure, transport systems, storage facilities, and export logistics are necessary to strengthen the transmission of macroeconomic incentives into actual export responses. Without these improvements, producers may remain unable to respond effectively to favorable price signals in international markets.

Second, the high persistence of volatility highlights the importance of agricultural risk management policies. Instruments such as minimum export price guarantees, buffer stock systems, and stabilization mechanisms may help reduce income uncertainty among farmers and traders during periods of adverse shocks. In addition, strengthening agricultural insurance systems would provide a mechanism for absorbing risk associated with climate variability and market fluctuations.

Third, improving post-harvest handling, storage infrastructure, and supply chain coordination is essential for reducing export losses and enhancing market efficiency. The weak responsiveness of exports to exchange rate movements observed in this study may partly reflect inefficiencies in the supply chain that prevent the full transmission of price incentives. Strengthening trade facilitation systems, export certification processes, and regional market integration would further enhance Uganda's competitiveness in maize export markets.

This study contributes to the literature by showing that macroeconomic stability alone is insufficient to explain agricultural export performance in developing economies characterized by structural inefficiencies and persistent volatility. Unlike many previous studies that rely on a single econometric framework, this study integrates ARIMAX, GARCH, and structural break models to provide a more complete understanding of both mean behavior and volatility dynamics. The findings therefore support a policy framework that combines macroeconomic stability with structural reforms, infrastructure development, and agricultural risk management in order to achieve sustainable export growth in Uganda's maize sector

5.0 Conclusions

This study examined the dynamics of Uganda's maize exports under conditions of macroeconomic instability using an integrated econometric framework consisting of ARIMAX, GARCH, and structural break models. The empirical findings indicate that export quantity and export value are non-stationary at levels but become stationary after first differencing, suggesting that shocks affecting maize exports are largely persistent rather than temporary. The ARIMAX estimates reveal strong autoregressive adjustment behavior, implying that export performance is characterized by mean reversion over time. Although inflation exhibited a weak and statistically insignificant relationship with export quantity, exchange rate movements demonstrated limited transmission effects on Uganda's maize export performance. This finding suggests that structural constraints within the agricultural sector may reduce the responsiveness of exports to macroeconomic policy adjustments.

The volatility analysis further revealed substantial persistence in export instability, with the combined ARCH and GARCH coefficients approaching unity. This indicates that shocks arising from droughts, price fluctuations, and broader macroeconomic disturbances tend to exert prolonged effects on export performance. The structural break analysis identified a significant regime shift around 1970, reflecting a transition from a highly unstable export structure toward a relatively more organized and policy influenced export system. Forecast results showed moderate predictive performance and continued short run volatility despite evidence of gradual long-term stabilization in export dynamics.

Methodologically, the study contributes to the literature on agricultural export modeling in developing economies by integrating ARIMAX, GARCH, and structural break techniques within a unified analytical framework. While ARIMAX captured the mean behavior and macroeconomic relationships influencing export performance, the GARCH specification provided insights into volatility persistence and risk dynamics. The structural break analysis further improved understanding of regime changes affecting Uganda's maize export system across different policy environments. The combined application of these models provides a more comprehensive representation of export behavior than reliance on a single econometric technique. The study therefore demonstrates that export instability in developing economies cannot be fully explained through conventional mean based econometric models alone. By integrating ARIMAX, GARCH, and structural break analysis, the study provides deeper insight into both average export behavior and the persistence of volatility under macroeconomic instability. This integrated modeling framework strengthens empirical understanding of agricultural trade dynamics in economies characterized by policy uncertainty, market imperfections, and structural vulnerabilities.

The findings carry important policy implications for Uganda's agricultural export sector. The weak responsiveness of maize exports to exchange rate movements suggests that macroeconomic stabilization alone may be insufficient to improve export competitiveness. This may be attributed to supply side constraints such as inadequate transportation infrastructure, poor storage capacity, limited market integration, and post-harvest losses. The high persistence of export volatility also indicates substantial income risk exposure for farmers and traders. Consequently, policies aimed at strengthening agricultural insurance systems, improving market access, enhancing storage infrastructure, and reducing supply chain inefficiencies are essential for promoting export stability and resilience. In addition, the identified structural break highlights the importance of institutional reforms and trade policy adjustments in shaping long term export performance. Overall, the findings emphasize that sustainable export growth in Uganda requires not only macroeconomic stabilization policies but also coordinated structural reforms aimed at improving agricultural resilience, strengthening trade institutions, reducing market inefficiencies, and enhancing the adaptive capacity of producers within the maize value chain.

Despite these contributions, the study has several limitations. First, some observations from earlier periods required imputation due to missing historical records. Although the imputation procedure ensured continuity of the time series, it may have introduced measurement errors capable of affecting parameter stability and volatility estimation. Second, the study relied on aggregate annual data, which limits the ability to capture behavioral differences among farmers, traders, and other actors within the maize value chain. Furthermore, the study did not explicitly incorporate climatic variables such as rainfall variability and drought intensity, which may also influence agricultural export performance.

Future research should therefore incorporate farmer and trader level microdata to better explain behavioral responses to price movements, macroeconomic shocks, and export risks. Additional studies may also examine regional variations and value chain specific responses within Uganda's maize sector. Incorporating climatic indicators and broader institutional variables into future econometric frameworks may further improve understanding of agricultural export dynamics and support the design of more targeted export promotion policies.

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Declaration of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. The study was conducted independently without any financial, commercial, or personal relationships that could be interpreted as influencing the research outcomes. All authors contributed equally to the conceptualization, data analysis, interpretation of results, and preparation of the manuscript. The manuscript has not been submitted to or published in any other journal or academic platform, and is not under consideration elsewhere.

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