South African Journal of Economic and Management Sciences
ISSN: (Online) 2222-3436, (Print) 1015-8812

Heterogeneous effects of real effective exchange rates on agricultural exports

Authors:
Tselane C. Nthebe[1]
Teboho J. Mosikari[1]

Affiliations:
[1]School of Economics, Faculty of Economic and Management Sciences, North-West University, Mmabatho, South Africa

Corresponding author:
Tselane Nthebe,
confidence.nthebe@nwu.ac.za

Dates:
Received: 15 Jan. 2025
Accepted: 25 Apr. 2025
Published: 18 Aug. 2025

How to cite this article:
Nthebe, T.C. & Mosikari, T.J., 2025, 'Heterogeneous effects of real effective exchange rates on agricultural exports', *South African Journal of Economic and Management Sciences* 28(1), a6082. https://doi.org/10.4102/sajems.v28i1.6082

Background: Enhancing South Africa-Southern African Development Community (SADC) intra-regional trade can strengthen economic connections, foster shared growth, and lessen reliance on external market shocks.

Aim: The study aimed to determine the conditional effect of real exchange rate on agricultural export.

Setting: The study used a panel of SADC countries for the period 2010 to 2022.

Method: A Method of Moment Regression (MMQR) was used to determine the flow of agricultural exports between South Africa and SADC countries.

Results: The MMQR results revealed valuable insights into how different quantiles of agricultural export flows change with varying levels of exchange rates in the region. The real effective exchange rates analysis indicated that all quantiles are significant. This showed that a depreciating currency can have a positive impact on agricultural exports in the SADC region, making agricultural products more competitive in international markets.

Conclusion: These findings correlate with the quantile MMQR graphs that, upon observation, indicate a wider U-shape, which implies higher variability in the real effective exchange rates, with significant fluctuations in both directions because of the instability of markets that can negatively affect agricultural exports. Therefore, the SADC region must maintain a stable exchange rate and diversify its agricultural exports to remain competitive in the market.

Contribution: The study contributes to the literature on exchange rate and agricultural sector in the region. Also, it provides a fresh perspective on quantile conditional effects of agricultural exports and real exchange rates between South Africa and SADC region.

Keywords: MMQR; agricultural exports; exchange rates; SADC; panel data; intra-trade.

Introduction

Agriculture is irrefutably a fundamental pillar of the global economy. According to the Food and Agriculture Organization (FAO) (2022) of the United Nations and Ryu (2023), the agricultural sector employs roughly 26% of the world's workforce and contributes about 6% to the global gross domestic product. Furthermore, the changes in exchange rates affect sectors differently, with agricultural exports subject to varied impacts. Chen, Polemis and Stengos (2019) highlights that exchange rates can influence different agricultural products in diverse ways because of factors such as the price and cost structures prevalent in their respective markets.

The proportion of intra-Southern African Development Community (SADC) exports of agricultural products reduced from 36.28% in 2015 to 30.76% in 2022, which signifies a reduced engagement in regional agricultural trade (SADC 2023). This indicates issues potentially arising from exchange rate fluctuations, increased import demand and rising input costs. Therefore, a decrease in agricultural exports in the SADC region affects the trade balance, food security and economic growth of SADC countries. This decrease led to poor export revenues, loss of competitiveness, slower growth and vulnerability within the agricultural sector among these member states. To support the SADC economies and enhance food security in the region, as indicated in goal two of the Sustainable Development Goals (SDGs) promoting agriculture, it is essential to address the decline of intra-SADC trade. The reduction in intra-SADC trade is detrimental as it may result in poor export performance of SADC agricultural products.

Agricultural exports in the SADC region and other countries have significantly been affected by various challenges such as extreme weather events, instability in the market, natural disasters and environmental constraints (Cheng, Li & Cao 2022; Zhang, Chang & Gauger, 2006). Botswana, Zambia, Angola, Namibia, South Africa (SA) and Zimbabwe experienced severe drought between 2018 and 2019 (SADC 2020). These factors can lead to disruptions in agricultural supply chains and affect the performance of agricultural exports.

There are studies by Edwards and Hlatshwayo (2020), Khouiled, Chini and Benrouina (2023), Gizaw, Abafita and Merra (2022) and Pasricha (2020) that have shown a linear relationship between exchange rates and trade, while there have been other studies by Ali (2020), Utouh (2024), Kohler and Ferjani (2018) on exchange rates and agricultural exports in various economies. However, there are no studies yet that have analysed the effects of exchange rate changes in the SADC region, which will be the contribution of the study. Furthermore, the contribution of this study will be to employ the method of moments quantile regression (MMQR) model to examine the variations of exchange rates on agricultural exports in the SADC. This method is particularly beneficial in capturing the conditional effects of exchange rate fluctuations on agricultural exports, offering a comprehensive understanding of the dynamics between these variables and how the relationship between exchange rates and agricultural exports varies across different quantiles of the export distribution. Therefore, the results of the quantile moments method regression provide valuable insights into how exchange rate movements impact agricultural exports at various levels, shedding light on potential asymmetries and heterogeneities in the relationship. The results can give clarity to policymakers, economists and analysts seeking to gain a deeper understanding of the complex interactions between exchange rates and agricultural exports.

The study will comprehensively cover the following sections: literature review, model specification, data and methodology, empirical results, conclusion and policy recommendations.

Literature review

The exploration of the linear relationship between exchange rates and agricultural exports is a significant topic in trade and can impact trade dynamics globally. Various studies have identified both the direct and indirect effects of exchange rate fluctuations on export performance, particularly in developing countries where agriculture plays a vital role in economic activity. Using the conventional ordinary least squares (OLS) models, several researchers have looked at the close link between agricultural exports and exchange rates. For example, Gizaw et al. (2022) used an extended generalised Cobb–Douglas production function model to offer important insights into the relationship between coffee exports and the economic growth of Ethiopia. The researcher investigated the connection between Ethiopia's economic growth and coffee exports between 1980 and 2017 using a vector error correction model (VECM). According to the researchers' findings, Ethiopia's economy has grown significantly because of coffee exports. The researchers recommend that improving the coffee industry's efficiency and enhancing coffee beans' quality prior to exporting could help Ethiopia raise more money to support its economic expansion. A similar study by Poku (2017) indicated that exchange rates significantly affect domestic prices and influence the supply and export levels for both cocoa and maize in Ghana.

Mpungose, Ngubane and Sekome (2023) revisited the effects of exchange rates on imports and exports in SA with the use of the vector auto-regression (VAR) method. The study revealed that fluctuations in exchange rates significantly impact exports, imports and inflation, ultimately influencing the trade balance and economic growth. Therefore, this research analysed agricultural export flows from SA to SADC economies, providing insights into the multifaceted effects of exchange rate dynamics on trade performance in the agricultural sector.

Pasricha (2020) analysed trade data and the country's foreign exchange rate annual values from 1991 to 2019 to investigate how currency rate fluctuations affect India's international trade. Using the OLS regression model, the study found a connection between India's foreign trade and exchange rates. Furthermore, utilising quarterly data spanning from the first quarter of 2002 to the first quarter of 2019, Karahan (2020) discovered an inverse casual of exchange rate fluctuations on economic growth using the Granger causality test, the Johansen cointegration test and innovation accounting techniques. The findings support the arguments of structuralist economists.

In their article, Edwards and Hlatshwayo (2020) argue that South African exporters have relatively lower responses to exchange rate fluctuations, which means that a decline in trade may only deepen this insensitivity and reduce export volumes, even when currency depreciation offers a price advantage. This is supported by a study by Aye et al. (2015), which shows that exchange rate volatility has a negative effect on export performance in SA, meaning that reduced trade might further enhance the risk aversion of exporters. Also, exchange rate volatility is equally damaging to intra-SADC, as Pamba (2023) observes that exchange rate volatility has a large impact on the competitive position of exports, meaning that a decrease in intra-SADC trade may well be associated with increased volatility and uncertainty. In the same vein, Seti (2023) identified constraints that may affect intra-African agricultural trade and therefore may slow down the capacity of SA to unlock its agricultural export opportunities, which will, in turn, deepen the effects of reduced trade on the region's economy, regional integration and growth. Therefore, based on the theoretical framework of regional integration, one can assume that the elimination of trade barriers in the Southern African Development

Community-Free Trade Agreement (SADC-FTA) as well as the enhancement of cooperation among member countries might lead to an improvement of the trade and economic results (Moyo, Kwarambo & Nchake 2020). The fluctuations in exchange rates cannot be overlooked, as they significantly influence the trade balance of SA and other SADC nations, subsequently impacting the export competitiveness of agricultural products.

These studies have added to the vast number of linear studies in the literature that showed that, in most economies, exchange rates should be stable to maintain and enhance exports. It is significant to indicate that this relationship is affected by various factors such as domestic economic conditions, regional conditions, market dynamics, macroeconomic factors, trade agreements and political contexts. Therefore, there exists an extensive body of work within the literature review of the linear relationship of exchange rates on agricultural exports in developed and developing economies, which has been presented in studies by Pamba (2023), Edwards and Hlatshwayo (2020), Ali (2020), Karahan (2020), Burakov (2016) and Aye et al. (2015).

Methods

Model specification

This study examines the effect of exchange rates on agricultural export from SA to SADC. The study adopts and modifies the model of Machado and Silva (2019), where as they introduced an augmented panel quantile regression (QR) known as the MMQR technique considering fixed effects. Their estimation of the conditional quantiles can be written as Equation 1:

$$Q_Y(\tau \mid X_{it} = (\alpha i + \delta_i q(\tau) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \quad \text{[Eqn 1]}$$

In equation 1, $Q_Y(\tau \mid X_{it}$ element is the dependent variable that denotes the scale, while $X'_{it}\beta + Z'_{it}\gamma q(\tau)$ represents the scale estimate of the fixed effect. Equation 1 of the MMQR is adopted and modified as equation 3.2 to examine the objective of the study as Equation 2:

$$Q_{AEij}(\tau k \mid X_{it} = (\alpha i + \delta i q(\tau) + \beta_{1\tau}\, REER_{ij} + \beta_{2\tau}\, GDP_{it} + \beta_{3\tau}\, GDP_{ij} + \beta_{4\tau}\, POP_{it} + \beta_{5\tau}\, POP_{ij} + \beta_{6\tau}\, INF_{ij} + Z'_{it}\gamma q(\tau) \quad \text{[Eqn 2]}$$

where $Q_Y(\tau \mid X_{it}$ is agricultural exports denoted as $LGEX_{ij}$, the real effective exchange rates is $REER_{ij}$, SA economic activity is GDP_{it}, SADC gross domestic product (GDP) is, GDP_{it}, POP_{it} is SA population, POP_{it} is SADC population and SADC inflation is INF_{ij}. All these explanatory variables are chosen to explain the objectives and gap of the study.

The abovementioned equation 2 will be modified in equation 3.3 into natural logarithms except for real effective exchange rates $REER_{ij}$ and INF_{ij} as their in-percentage form and written as Equation 3:

$$Q_{LAEij}(\tau k \mid X_{it} = (\alpha i + \delta_i q(\tau) + \beta_{1\tau}\, REER_{ij} + \beta_{2\tau}\, LGDP_{it} + \beta_{3\tau}\, LGDP_{ij} + \beta_{4\tau}\, LPOP_{it} + \beta_{5\tau}\, LPOP_{ij} + \beta_{6\tau}\, INF_{ij} + Z_{it}'\gamma q(\tau) \quad \text{[Eqn 3]}$$

The study examines the relationship between exchange rates and agricultural exports across different points in the distribution.

Data description and sources

In this study, a balanced panel annual dataset was utilised to model exchange rates and agricultural export flows from SA to selected SADC economies for the period 2010 to 2022. The dataset includes data from 13 SADC economies, namely Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, Swaziland, Tanzania and Zambia. Data for Zimbabwe and Comoros were excluded because of the unavailability of data for the exchange rate. The description, data sources and selected SADC economies are depicted in Table 1:

Panel estimation techniques

The panel QR technique was initially proposed by Koenker and Bassett (1978) to estimate the dependent conditional mean and variance with respect to explanatory parameters (Rehman et al. 2021). This method allows for a more detailed examination of the relationship between agricultural exports and exchange rates. This method will show how this relationship varies across different quantiles of the distribution (Koenker 2004).

Panel QR is considered a more robust alternative to traditional techniques such as OLS, as it can capture heterogeneous effects across various quantiles of the data distribution (Sarkodie & Strezov 2019). In this study, the utilised MMQR with fixed effects proposed by Machado and Silva (2019) is employed to model the relationship between exchange rates and agricultural exports within SA and selected SADC economies. This methodology is chosen in this study for its ability to account for the covariance effects of conditional heterogeneity that may be present in the analysis, providing a more accurate understanding of the dynamics between exchange rates and agricultural exports in the region (Machado & Silva 2019).

The OLS regression has certain limitations, as it primarily focuses on the mean of the dependent variable, assuming a linear relationship between the dependent and independent

TABLE 1: Variable description and sources.

Variable	Measure	Source
Agricultural exports (LGEXij)	Gross exports in $ 1000 of all products	World Integrated Trade Solution (n.d.)
Real effective exchange rates (REERij)	LCU per US$, period average	International Monetary Fund (n.d.)
SA economic activity (LGDPit)	Current US$	World Bank (n.d.)
SADC Gross domestic product (GDPij)	Current US$	World Bank (n.d.)
SA population, (POPit)	Total	World Bank (n.d.)
SADC population (LPOPij)	Total	World Bank (n.d.)
SADC inflation (INFij)	Annual %	World Bank (n.d.)

Note: Please see the full reference list: Nthebe, T.C. & Mosikari, T.J., 2025, 'Heterogeneous effects of real effective exchange rates on agricultural exports', *South African Journal of Economic and Management Sciences* 28(1), a6082. https://doi.org/10.4102/sajems.v28i1.6082 for more information.

LCU, local currency units.

variables, and, as a result, the MMQR will be employed. This technique was introduced by Koenker and Bassett (1982), Koenker and Zhao (1994) and Zhao (2000), who incorporated the estimates of location and scale functions. This methodology is an extension of OLS regression. The difference between the traditional OLS and QR is that it employs and evaluates the conditional median of various responded quantiles and not following the linear relationship. This approach allows for a more flexible and robust modelling strategy compared to traditional least squares regression. Therefore, panel QR is more vigorous to the prevalence of outliers in estimations and is also useful in explaining the weak association of the conditional means of two variables (Anwar et al. 2021).

Machado and Silva (2019) introduced an augmented panel QR known as the MMQR technique. Considering fixed effects, this model will be adopted and modified to examine the objective of the study. Methods of moments quantile regression is a statistical method that combines moments estimation with QR to provide more efficient and robust estimates of parameters. The regression considers the individual effects on exogenous explanatory variables for the location scale model as Equation 4:

$$Y_{it} = \alpha_i + X'_{it}\beta + (\sigma_i + Z'_{it}\gamma)U_{it} \qquad \text{[Eqn 4]}$$

where $\{\sigma_i + Z'_{it}\gamma > 0 = 1$ and $(\alpha, \beta', \delta, \gamma')'$ represents the parameters of the probabilities and discrete fixed effect is represented by $(\alpha i, \delta i)$, $i = 1, 2, \ldots ., n$. Z denotes the K-vector of covariates X for location scale, which are various modifications of j. The model can be written as Equation 5:

$$Z_l = Z_l(X), l = 1, \ldots, k; \qquad \text{[Eqn 5]}$$

where Z is a K-vector of the known differentiable with probability 1 that transforms the components of X with an *l*.

The MMQR by Machado and Silva (2019) is the same as in equation 1, and the model can be written as Equation 6:

$$Q_y(\tau \mid X_{it} = (\alpha i + \delta_i q(\tau) + X'_{it}\beta + Z'_{it}\gamma q(\tau)) \qquad \text{[Eqn 6]}$$

Equation 7 is explained in equation 1. Therefore, this equation model is modified as stated in equations 2 and 3:

$$\min_q \Sigma_i \Sigma \rho_\tau (\hat{R}_{it} - (\hat{\delta}_i + Z'_{it}\hat{\gamma})q \qquad \text{[Eqn 7]}$$

where $\rho_\tau(A) = (\tau - 1)AI\{A \leq 0\} + \tau AI\{A \geq 0\}$ denotes the check function. The $\hat{U} = \hat{R}_{it}/(\hat{\delta}_i + Z'_{it}\hat{\gamma})$ equation represents the standardised residuals and estimates the $\tau - t$h sample quantile. Lastly, the study will conduct the quantile slope and symmetric test to access the asymmetric in the analysis.

Diagnostics of the analysis

In this study, the correlation analysis is estimated to measure the magnitude of the relationship between two variables. Moreover, Pesaran's (2004) Cross-sectional Dependence (CD) test is appropriate, as the number of observations is greater than the period. The correlation matrix will enable the study to estimate whether the dependent and explanatory variables used in the study correlate. Furthermore, the study will employ three-unit root tests including the Levin, Lin and Chu (LLC) test (Levin et al. 2002), Harris and Tzavalis (HT) (1999) test and the Im, Pesaran and Shin (IPS) test (Im, Pesaran & Shin, 2003) to examine the stationarity of the time series data. The first unit root test accounts for homogeneity (LLC), and the other two tests consider the heterogeneity (HT and Cross-sectionally augmented IPS [CIPS]) in the data.

Panel data considers individual-specific characteristics and heterogeneity. The next procedure will be the cointegration analysis, where the Kao (1999), Pedroni (2004) and Westerlund (2007) tests are used to investigate the long-term relationship between variables. Also, the existence of cointegration confirmed that it can better capture the dynamics of casual relationships that exist between agricultural exports and exchange rates in the SADC region (Hsiao 2014). Furthermore, the Jarque–Bera (JB) test for normality is significant to verify whether the variables show linearity or non-linearity. If the JB results are non-linear, then the study will be motivated to proceed by examining the QR.

Ethical considerations

An application for full ethical approval was made to the Economic and Management Sciences Research Ethics Committee (EMS-REC), and ethics consent was received on 25 November 2020 (reference no: NWU-00924-20-A4).

Empirical results and discussion

The objective of the study is to model the agricultural exports and exchange rates from SA to selected SADC countries using the MMQR. The empirical results of the study will consist of preliminary tests that are unit roots tests, cointegration tests, normality test, slope homogeneity test and model results including the MMQR test, quantile graphs output, slope equality test and symmetric quantile test.

Descriptive statistics

The descriptive statistics are significant to analyse the summary of data of the variables used in the study. Also, estimating the descriptive analysis is significant in ensuring the quality and reliability of the data before conducting more advanced econometric analyses. The study used 169 observations, which constitutes a large dataset, and the scale variables can be shown in summary in Table 2:

Table 2 outlines the results of the descriptive statistics of the analysis. Descriptive statistics help in providing a concise summary of the data. Measures such as mean, median, mode, standard deviation, skewness and kurtosis offer an overview of the central tendency, dispersion and shape of the data distribution. On average, the real effective exchange rates

(REERij) are 98.83, which is the highest varying with a minimum of 65.33 and maximum of 148.47, while inflation (INFij) has an average value of 7.433, ranging from a low of -10 to a high of 30.7. Also, the gross domestic product for SADC economies (LGDPij) has a mean of 23.20 with minimum and maximum values of 20.71 and 25.65, respectively. This is followed by agricultural exports (LGEXij) as the second lowest average of 13.63, which ranges between 10.73 and 15.58. Lastly, the domestic population of SA (LPOPi) is around 19%, and the population of SADC's (LPOPij) average is 15%; the GDP of SA (LGDPi) is 25.33% for the period of 2010 to 2022. The higher population in SA at 26.76%, compared to the SADC economies, could be attributed to SA being the economy with the largest share of GDP in the region from 2010 to 2022.

Correlation analysis

Table 3 shows the correlation results as follows:

The correlation matrix will enable the study to estimate whether the dependent and explanatory variables used in the study correlate. This test examined multicollinearity in the study, and all the variables indicated a weaker correlation. The results in Table 3 show that agricultural exports are correlated with the mentioned explanatory variables. A coefficient between 0.10 and 0.30 indicates a weak correlation, whereas a coefficient from 0.30 to 0.60 signifies a moderate correlation. A coefficient of 0.70 to 0.90 denotes a strong correlation. The correlation of agricultural exports with real effective exchange rates (REERij) coefficient is 0.24 is negative and weak, while LGDPi, LGDPij and INFij have weaker negative correlations of 0.03, 0.28 and 0.08 as shown in Table 3. However, LPOPi and LPOPij show a positive weaker correlation with a coefficient 0.03.

Cross-sectional independence test

Table 4 presents the Pesaran's test to determine the existence of cross-sectional dependence of the variables in the study.

The Pesaran's test of cross-sectional independence in Table 4 yielded a test statistic of 1.752 with a *p*-value of 0.0798. The null hypothesis (H0) for Pesaran's test states that there is no cross-sectional dependence among the residuals, while the alternative hypothesis posits the existence of cross-sectional dependence (Pesaran's 2004). The results suggest that there is some evidence to reject the null hypothesis of cross-sectional independence at the 10% significance level.

Preliminary test results

This study shows the preliminary results of the relationship between exchange rates and agricultural exports across different points in the distribution from SA to SADC. The results include unit roots tests, normality test, slope homogeneity test, cointegration tests, MMQR test, quantile graphs output, slope equality test and symmetric quantile test.

Unit root tests results

Table 5 shows the unit root results of LLC test, HT (1999) test and the IPS test as follows:

The unit root tests employed in the study are Levin et al. (2002) (LLC), HT (1999) and the cross-sectionally augmented IPS (CIPS). The LLC unit root considers the homogeneity that exists in the model, and both the HT and CIPS account for the heterogeneity that exists in the parameters. Table 5 shows the results of stationary on the variables in the study. The LLC

TABLE 3: Correlation analysis results.

Variables	LGEXij	REERij	LGDPi	LGDPij	LPOPi	LPOPij	INFij
LGEXij	1.00	-	-	-	-	-	-
REERij	-0.25	1.00	-	-	-	-	-
LGDPi	-0.03	0.06	1.00	-	-	-	-
LGDPij	-0.28	0.29	-0.08	1.00	-	-	-
LPOPi	0.03	-0.06	-1.00	0.08	1.00	-	-
LPOPij	0.23	0.18	-0.03	0.75	0.02	1.00	-
INFij	-0.09	-0.14	-0.20	0.25	1.00	0.23	1.00

LGEXij, agricultural exports; LPOPi, domestic population of SA; LGDPi, GDP of SA; REERij, real effective exchange rates; GDPij, SADC gross domestic product; POPit, SA population; LPOPij, SADC population; INFij SADC inflation; LGDPij, logarithms of gross domestic product of SADC countries; GDP, gross domestic product; SA, South Africa.

TABLE 4: Pesaran's test results.

Pesaran's test of cross-sectional independence	*p*-value
1.752	0.0798

TABLE 2: Descriptive statistics.

Descriptive tests	LGEXij	REERij	LGDPij	LGDPi	LPOPij	LPOPi	INFij
Mean	13.6330	98.83	23.210	25.33	15.70000	19.21	7.43
Median	13.8700	100.00	23.280	26.67	16.56000	17.85	5.72
Maximum	15.5800	148.47	25.650	26.85	18.41000	26.76	30.70
Minimum	10.7300	65.33	20.710	17.90	11.38000	17.76	-10.00
Std. dev.	1.2400	14.58	1.105	3.18	1.89000	3.23	6.46
Skewness	-0.5600	0.24	-0.220	-1.91	-0.61000	1.92	1.53
Kurtosis	2.5900	3.24	2.920	4.67	2.58000	4.68	5.61
Jarque–Bera	9.9437	1.95	1.341	123.05	11.92000	123.54	113.81
Probability	0.0100	0.38	0.510	0.00	0.00258	0.00	0.00
Sum	2303.9900	16702.95	3922.320	4281.16	2652.93000	3244.93	1256.26
Sum sq. dev.	258.2300	35701.07	205.050	1696.57	596.73000	1749.09	7010.67
Observations	169.0000	169.00	169.000	169.00	169.00000	169.00	169.00

Std. dev., standard deviation; Sum sq. dev., XXX; LGEXij, agricultural exports; LPOPi, domestic population of SA; LGDPi, GDP of SA; REERij, real effective exchange rates; GDPij, SADC gross domestic product; POPit, SA population; LPOPij, SADC population; INFij SADC inflation; LGDPij, logarithms of gross domestic product of SADC countries; GDP, gross domestic product; SA, South Africa.

and HT unit root tests indicate that variables are stationarity at trend and intercept at the first difference. The null hypothesis for both tests LLC and HT is that there is a unit root present in the panel data, and the study fails to reject the null hypothesis of a unit root in favour of stationarity in the analysis at the 1% level. Furthermore, the CIPS test shows that all variables (agricultural exports, real exchange rates (REERij), domestic GDPi, SADC GDP, population of SA, SADC population and inflation) are integrated at both levels and first difference at 5% level. Unit root results how stationarity at levels for LGEXij, LGPDij, LGDPi, LPOPi and LPOPij. These variables LGEXij, REERij, LGPDij, LGDPi, LPOPi, LPOPij and INFij are stationarity at first difference. Therefore, among the three specified unit root tests, all indicate a mixture of I (0) and I (1). This resulted in the study proceeding to investigate unit root at I (1), and all variables confirmed stationarity. The next step is estimating the long-run relationship between agricultural exports and the exchange rates, which is examined using three cointegration tests in Table 6.

Cointegration results

The Pedroni (1999), Kao (1999) and Westerlund (2007) cointegration tests are used in analysing the long-run relationship between agricultural exports and exchange rate. The results of the cointegration tests are presented in Table 6.

The cointegration results of the analysis are presented in Table 6. The results confirm that long-run relationships exist between agricultural exports and exchange rates. The cointegration test determines the long-term association between variables while accounting for heterogeneity across individual units. In the study, the cointegration tests are all significant except for Kao (Dickey–Fuller t, unadjusted modified Dickey–Fuller and unadjusted Dickey–Fuller) at 1% and 5%, respectively. Furthermore, Table 6 results conclude the rejection of the null hypothesis of no long-run cointegration relationship. This implies that cointegration exists between agricultural exports and exchange rates in the SADC. Therefore, it is significant that exchange rates are stable and remain competitive to enhance export performance in agricultural exports. Lastly, the study will explore the normality, slope homogeneity tests in Table 7 and MMQR in Table 8.

Normality test and slope homogeneity results

The normality test and slope homogeneity results are shown next:

There exists nonlinearity in the data[1]; hence, this finding highlights the significance of conducting QR analysis to account for this non-normality based on Table 7 results. Furthermore, the study conducted the slope homogeneity, which facilitates the exploration of regional integration effects. The SADC aims to promote sustainable and equitable economic growth through integration. Analysing whether economic relationships, such as those between agricultural exports and economic growth, are homogeneous across member countries can provide insights into the effectiveness of regional integration efforts and highlight areas where further harmonisation is needed. However, if the SADC economies exhibit heterogeneity, then it would imply that each policy should be individually specific to suit each economy. Therefore, it is significant to examine the slope homogeneity. The null hypothesis for this test assumes slope homogeneity. However, the test results in Table 7 indicate heterogeneity, resulting in the rejection of the null hypothesis of slope homogeneity. This confirms that the agricultural exports and the explanatory variables from one SADC country to another will vary across the different cross-sections. To address the heterogeneity that exists in the model, this study takes into account examining tests for unit root such as CIPS and HT. Therefore, the study will explore the MMQR in Table 8.

Panel quantile regression model results

The outcomes of the MMQR model are presented and analysed in Table 8 of the study. To establish the statistical significance of location, scale and quantile coefficients in an output generated through MMQR, it is imperative to consider their respective *p*-values. According to Machado and Silva (2019),

1.The results are available in Appendix 1 Table 1-A1.

TABLE 5: LLC, HT and CIPS unit root test results.

Tests (Variables)	LLC		HT		CIPS	
	Trend and intercept	ΔTrend and intercept	Trend and intercept	ΔTrend and intercept	Trend and intercept	ΔTrend and intercept
LGEXij	-11.87***	-13.08***	0.28**	0.10***	-1.61	-2.67****
REERij	-11.47***	-11.02***	0.41	0.10***	-1.57*	-2.22*
LGDPi	-4.79	-11.01***	0.64**	-0.01***	-2.61***	2.61***
LGDPij	-13.85***	-12.11***	0.52***	0.04***	-1.38	-2.88***
LPOPi	-0.48	-11.21***	0.63	-0.10***	2.61**	2.61***
LPOPij	-6.74***	-13.48***	0.12***	-0.11***	-2.12	-3.16***
INFij	-11.47***	-19.15***	0.40	-0.00***	-2.52**	-4.24***

LLC, Levin, Lin and Chu; HT, Harris and Tzavalis; CIPS; cross-sectionally augmented IPS; LGEXij, agricultural exports; LPOPi, domestic population of SA; LGDPi, GDP of SA; REERij, real effective exchange rates; GDPij, SADC gross domestic product; POPit, SA population; LPOPij, SADC population; INFij SADC inflation; LGDPij, logarithms of gross domestic product of SADC countries; GDP, gross domestic product; SA, South Africa.

*, significant level at 10%; **, significant level at 5%; ***, significant level at 1%.

TABLE 6: Cointegration test results.

Method	Test name	Test statistic	*p*-value
	Modified Dickey–Fuller	5.98***	0.0000
Pedroni	Phillips–Perron	-19.66***	0.0000
	Augmented Dickey–Fuller	-9.32***	0.0000
	Modified Dickey–Fuller test	-1.66**	0.0493
Kao	Dickey–Fuller test	-0.87	0.1919
	Augmented Dickey–Fuller	-2.32***	0.0102
	Unadjusted modified Dickey–Fuller	-1.56**	0.0592
	Unadjusted Dickey–Fuller	-0.82	0.2049
Westerlund	Variance ratio	2.23***	0.0126

, coefficient significant level at 5%; *, coefficient significant level at 1%.

TABLE 7: Normality test and slope homogeneity test.

Test	Value	*p*-value
$\hat{\Delta}$	3.89	0.000***
$\hat{\hat{\Delta}}$ adjusted	6.27	0.000 ***

***, significant level at 1%.

TABLE 8: Method of Moments Quantile Regression results.

Variables		Location	scale	Lower Quantile			Middle Quantile		Higher Quantile			
				0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
REERij	coefficient	-0.0358***	0.0073***	-0.0469***	-0.0443***	-0.0418***	-0.3898***	-0.0337***	-0.0313***	-0.0300***	-0.0277***	-0.0253***
	p-value	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LGDPi	coefficient	0.9050	0.2618	0.5107	0.6013	0.6899	0.7926	0.9800	1.0638	1.1123	1.1912	1.2779
	p-value	0.414	0.620	0.739	0.669	0.595	0.507	0.364	0.319	0.300	0.280	0.270
LGDPij	coefficient	0.4898***	-0.0812	0.6123***	0.5841***	0.5566***	0.5247***	0.4666***	0.4406***	0.4255***	0.4010***	0.3741***
	p-value	0.000	0.157	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003
LPOPi	coefficient	0.9005	0.2534	0.5188	0.6065	0.6923	0.7917	0.9731	1.0542	1.1012	1.1776	1.2615
	p-value	0.410	0.626	0.731	0.662	0.588	0.500	0.360	0.316	0.297	0.277	0.268
LPOPij	coefficient	0.0255***	-0.0021	0.0288	0.0280	0.0273	0.0264	0.0248	0.0241	0.023	0.0231	0.0224
	p-value	0.000	0.948	0.766	0.753	0.739	0.726	0.715	0.720	0.726	0.740	0.749
INFij	coefficient	-0.0513	0.010	-0.0529***	-0.0525***	-0.0521***	-0.0517***	-0.0510***	-0.0506***	-0.0504***	-0.0501***	-0.0497***
	p-value	0.482	0.688	0.008	0.004	0.002	0.0000	0.000	0.000	0.000	0.000	0.001

LPOPi, domestic population of SA; LGDPi, GDP of SA; REERij, real effective exchange rates; GDPij, SADC gross domestic product; POPit, SA population; LPOPij, SADC population; INFij SADC inflation; LGDPij, logarithms of gross domestic product of SADC countries; GDP, gross domestic product; SA, South Africa.

***, significant level at 1%.

the location coefficient indicates how predictor variables impact the median of the response variable, whereas the scale coefficient demonstrates their effect on the dispersion of response variable around its median in fixed-effect panel data.

Table 8 shows the results of MMQR for panel data analysis. The table presents estimates for the lower quantile (0.10–0.30), middle quantile (0.50) and higher quantile (0.90) for the variables $REER_{ij}$, GDP_i, GDP_{ij}, POP_i, POP_{ij}, and INF_{ij}. The study employed nine quantiles for robust results in the regression analysis.

The quantiles of REERij coefficients decline and are significant in all distributions. This implies that in all quantiles' real effective exchange rates have a negative and significant impact on agricultural exports. This will result in a depreciating currency that can make agricultural products cheaper for foreign buyers, leading to an increase in exports (Lieffer & Persaud 2009). The findings confirm to those of Ndou (2022), Kayani et al. (2023), Polodoo, Seetanah and Sannassee (2016) and Oumansour and Azghour (2024). Therefore, exchange rates play a crucial role in determining the competitiveness of agricultural exports in international markets.

The variables LGDPij and LGDPi both have positive coefficients across all quantiles, which correlates with the economic theory. The LGDPij quantile is significant between quantile 0.1 and 0.9 (lower, middle and upper). This indicates that the SADC economic activity quantile is significant to agricultural exports in all quantiles. This suggests that an increase in LGDPij leads to an increase in agricultural exports. The results correlate with findings by Eita (2016), Bulut and Yasar (2023) and Adebayo et al. (2022). However, the LGDPij is insignificant and denotes that the SA GDP coefficient does not influence different quantile results across all quantiles and is insignificant. This implies that the SA economic activity quantile does not have an impact on agricultural exports. Also, inflation (INFij) is negative and significant as expected in economic theory.

Lastly, the SA population (LPOPi) denotes a positive sign that may result in a positive relationship on agricultural exports. This indicates that an increase in SA population levels is not associated with increased reliance on agricultural output, while LPOPF is positive but does not affect agricultural exports across all quantiles. The insignificance of these variables provides new findings considering that the large majority of the SADC population is employed in the agricultural sector. Therefore, these findings are supported by Ulya (2022), Peter and Bakari (2018), and Zhu et al. (2016). These results provide insights into how different variables impact agricultural exports across various quantiles in the panel data analysis. Figure 1 shows the quantile graphs of MMQR.

Quantile graphs output

In the MMQR analysis, it is crucial to assess both the location and scale coefficients to understand how predictor variables influence different quantiles of the response variable distribution (Machado & Silva 2019). The observations of the MMQR graphs on the effects of agricultural exports and exchange rates are displayed in Figure 1.

The MMQR graphs are outlined in Figure 1, and the results for REERij indicate a wide U-shape, which implies that a higher variability in the exchange rates, with significant fluctuations in both directions because of the instability of markets, can negatively affect agricultural exports. While LGDPij, under observation, shows a U-shape, this could suggest that as agriculture export levels increase, the SADC's GDP may initially decrease before increasing again between quantiles 0.6 and 0.9. Lastly, INFij is negative across all quantiles and shows a W-shape that suggests the varied intensity in the impact of agricultural exports on inflation across different levels. This is evident in lower and middle quantiles, where the negative impact on inflation might be weaker. Therefore, policies could focus on improving the changes of demand on export volumes. At upper quantiles, where the negative effect is stronger, this implies that measures could be directed towards stabilising prices to prevent deflationary and inflation spirals.

Slope and symmetric tests

Table 9 presents the slope and symmetric tests as shown next:

In Table 9, the results indicate that there is heterogeneity in both slope and symmetric tests between agricultural exports and exchange rates within SA and selected SADC economies. The hypothesis is that the slopes are equal across all cross-sectional units in the dataset. Specifically, the chi-square statistic value of 33.7654 for 'slope equality' results demonstrates significance at a level of 1%, leading to the rejection of the null hypothesis regarding quantiles. This aligns with Figure 1's observations, indicating that varying quantitative relationships exist when considering factors such as exchange rate, GDP (South African) and population size (SADC). These findings highlight how important it is to evaluate not just linear links among these variables but also their corresponding correlations across different quantiles, which will validate the robustness of the analysis. Also, the symmetry test shows that there are more differences than similarities between symmetric quantiles and the results of the chi-square statistic denote 33.2087, which signifies a symmetric quantile. Hence, the test is based on the assumption that the null hypothesis posits symmetric quantiles. The study rejects the null hypothesis with a significance level of 1%; therefore, the significance of further investigation into non-symmetrical on agricultural export and exchange rate in the SADC region is needed.

Conclusion and policy recommendations

The objective of the study was to determine the different variables that impact the agricultural export flows across various quantiles in the panel data analysis for the period 2010 to 2022. This study employed the quantile moments regression model (MMQR), and the analysis revealed that a

TABLE 9: Slope equality test and symmetric quantile test results.

Tests	Chi-square statistics	*p*-value
Slope equality test	33.76*	0.0007
Symmetric quantile test	33.21*	0.0000

*, significant level at 1%.

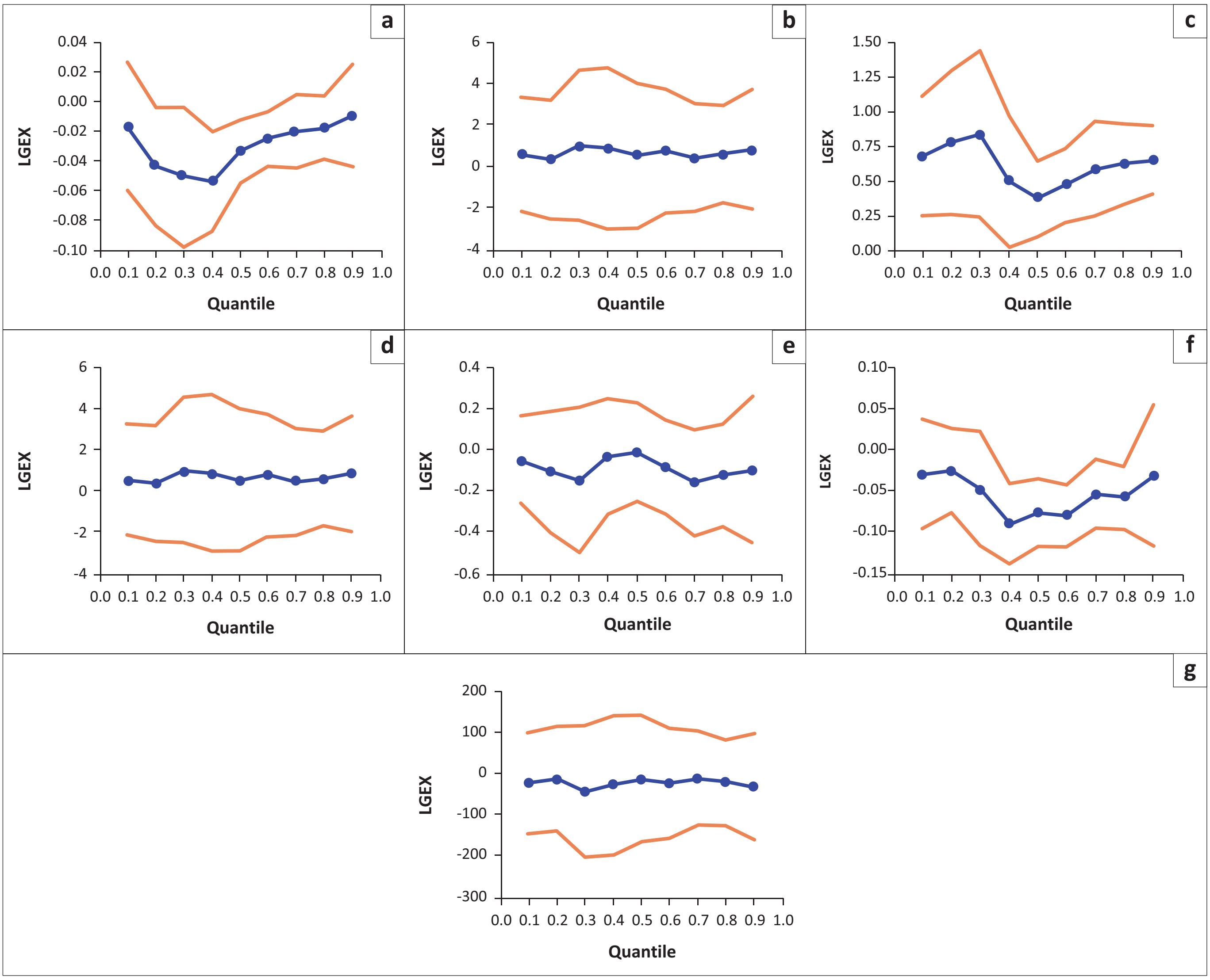

FIGURE 1: Quantile process graphs: (a) REERij (b) LGDPi (c) LGDPij (d) LPOPi (e) LPOPij (f) INFLij (g) C.

depreciating currency can have a positive impact on agricultural exports, making agricultural products more competitive in international markets. The quantile MMQR graphs, on observation, indicate a wider U-shape, which implies that higher variability in the real effective exchange rates, with significant fluctuations in both directions because of the instability of markets, can negatively affect agricultural exports. Also, the SADC GDP shows a U-shape, which could suggest that as agricultural export levels increase, the SADC's GDP may initially decrease, before increasing again between quantiles 0.6 and 0.9. Lastly, INFij is negative across all quantiles and shows a W-shape that suggests the varied intensity in the impact of agricultural exports on inflation across different levels. Therefore, SADC economic activity, inflation and real effective exchange rates are found to influence agricultural exports at different quantiles. These results provide valuable insights for policymakers looking to manage exchange rates fluctuations and promote agricultural export growth within the region.

This study contributes to the existing literature by employing the MMQR model to determine the effects of exchange rates and agricultural exports in the SADC region. Lastly, policymakers can use the insights to formulate targeted policies aimed at fostering regional trade agreements and maintain stable exchange rates to promote agricultural exports in the region. Moreover, businesses can leverage the insights to make informed decisions regarding market expansion, supply chain management and investment strategies within the SADC region.

Acknowledgements

This article is partially based on the author, Tselane C. Nthebe's PhD thesis entitled 'The effect of exchange rates on agricultural exports from South Africa to Southern African Development Community' towards the degree of Doctor of Philosophy in Economic and Management Science with Economics in the Department of Economics, North-West University, South Africa, with supervisor Prof. Teboho J. Mosikari, received May 2025.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

T.C.N. wrote the manuscript, collected data and analysed the article. T.J.M. contributed to the method and supervised the initial research study.

Funding information

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Data availability

The data that support the findings of this study are available from the corresponding author, T.C.N., upon reasonable request.

Disclaimer

The views and opinions expressed in this article are those of the authors and are the product of professional research. It does not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher. The authors are responsible for this article's results, findings and content.

References

Adebayo, O.O., Ogunjobi, J.O., Eseyin, O., Opaola, O. & Aransiola, I.J., 2022, 'Exchange rate and agricultural exports: Evidence from Nigeria (1981–2019)', *International Journal of Research and Scientific Innovation* 9(4), 89–101. https://doi.org/10.51244/IJRSI.2022.9410

Ali, D., 2023, 'Impact of international trade on economic growth in Kenya', *International Journal of Economics and Finance* 15(3), 1–13. https://doi.org/10.5539/ijef.v15n3p13

Anwar, A., Siddique, M., Dogan, E. & Sharif, A., 2021, 'The moderating role of renewable and non-renewable energy in environment-income nexus for ASEAN countries: Evidence from Method of Moments Quantile Regression', *Renewable Energy* 164, 956–967. https://doi.org/10.1016/j.renene.2020.09.128

Aye, G.C., Gupta, R., Moyo, P.S. & Pillay, N., 2015, 'The impact of exchange rate uncertainty on exports in South Africa', *Journal of International Commerce, Economics and Policy* 6(1), 1550004. https://doi.org/10.1142/S1793993315500040

Bulut, E. & Yaşar, Z., 2023, 'Determinants of export performance in emerging market economies: New evidence from a panel quantile regression model', *Istanbul Journal of Economics/*İstanbul İktisat *Dergisi* 73(1), 453–472. https://doi.org/10.26650/ISTJECON2022-1213878

Burakov, D., 2016, 'Oil prices, exchange rate and prices for agricultural commodities: Empirical evidence from Russia', *Agris On-Line Papers in Economics and Informatics* 8(02), 33–47. https://doi.org/10.7160/aol.2016.080203

Chen, C., Polemis, M. & Stengos, T., 2019, 'Exchange rate pass-through and its implications for domestic prices', *Energy Economics* 81(C), 1–12. https://doi.org/10.1016/j.eneco.2019.03.010

Cheng, S., Li, X. & Cao, Y., 2022, 'Global evidence of the exposure-lag-response associations between temperature anomalies and food markets', *Journal of Environmental Management* 325(pt B), 116592. https://doi.org/10.1016/j.jenvman.2022.116592

Edwards, L. & Hlatshwayo, A., 2020, *Exchange rates and firm export performance in South Africa*, WIDER Working Paper 2020/758-3, UNU-WIDER, Helsinki.

Eita, J.H., 2016, 'Estimating export potential for a small open economy using a gravity model approach: Evidence from Namibia', *Journal of Developing Areas* 50, 273–288. https://doi.org/10.1353/jda.2016.0165

Food and Agriculture Organization of the United Nations (FAO), 2022, *Support towards the operationalization of the SADC regional agriculture policy (STOSAR). Bulletin*, 2nd edn., Rome, viewed 10 October 2024, from https://openknowledge.fao.org/server/api/core/bitstreams/6b154d3c-38a5-4d58-aeb9-3759c1b41779/content.

Gizaw, N., Abafita, J. & Merra, T.M., 2022, 'Impact of coffee exports on economic growth in Ethiopia; An empirical investigation', *Cogent Economics & Finance* 10(1), 2041260. https://doi.org/10.1080/23322039.2022.2041260

Harris, R.D.F. & Tzavalis, E., 1999, 'Inference for unit roots in dynamic panels where the time dimension is fixed', *Journal of Econometrics* 91(2), 201–226. https://doi.org/10.1016/S0304-4076(98)00076-1

Hsiao, C., 2014, *Analysis of panel data*, 3rd edn., Cambridge University Press, viewed 10 March 2023, from https://www.cambridge.org/core/books/analysis-of-panel-data/A774C63FF969DA1944A3F91501702C65.

Im, K.S., Pesaran, M.H. & Shin, Y., 2003, 'Testing for unit roots in heterogeneous panels', *Journal of Econometrics* 115(1), 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7

International Monetary Fund n.d., *Effective exchange rate*, viewed n.d., from https://data.imf.org/en/Data-Explorer?datasetUrn=IMF.STA:COFER(7.0.0)

Kao, C., 1999, 'Spurious regression and residual-based tests for cointegration in panel data', *Journal of Econometrics* 90(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2

Karahan, Ö., 2020, 'Influence of exchange rate on the economic growth in the Turkish economy', *Financial Assets and Investing* 11(1), 21–34. https://doi.org/10.5817/FAI2020-1-2

Kayani, U.N., Aysan, A.F., Gul, A., Haider, S.A. & Ahmad, S., 2023, 'Unpacking the asymmetric impact of exchange rate volatility on trade flows: A study of selected developed and developing Asian economies', *PLoS One* 18(10), e0291261. https://doi.org/10.1371/journal.pone.0291261

Khouiled, B., Chini, S.-E. & Benrouina, M., 2023, 'Dynamic relationship between exchange rate and trade balance', *SocioEconomic Challenges* 7(3), 164–173. https://doi.org/10.61093/sec.7(3).164-173.2023

Koenker, R. & Bassett Jr, G., 1978, 'Regression quantiles', *Econometrica: Journal of the Econometric Society* 46(1), 33–50. https://doi.org/10.2307/1913643

Koenker, R. & Zhao, Q., 1994, 'L-Estimation `for linear heteroscedastic models', *Journal of Nonparametric Statistics* 3(3–4), 223–235. https://doi.org/10.1080/10485259408832584

Koenker, R., 2004, 'Quantile regression for longitudinal data', *Journal of Multivariate Analysis* 91(1), 74–89. https://doi.org/10.1016/j.jmva.2004.05.006

Kohler, A. & Ferjani, A., 2018, 'Exchange rate effects: A case study of the export performance of the Swiss agriculture and food sector', *The World Economy* 41(2), 494–518. https://doi.org/10.1111/twec.12611

Levin, A., Lin, C.F. & Chu, C.S.J., 2002, 'Unit root tests in panel data: Asymptotic and finite-sample properties', *Journal of Econometrics* 108(1), 1–24. https://doi.org/10.1016/S0304-4076(01)00098-7

Lieffer, W. & Persaud, S., 2009, *The transmission of exchange rate changes to agricultural prices*, viewed 15 January 2024, from https://www.ers.usda.gov/webdocs/publications/46188/9451_err76_1_.pdf?v=0.

Machado, J.A. & Silva, J.S., 2019, ;Quantiles via moments', *Journal of Econometrics* 213(1), 145–173. https://doi.org/10.1016/j.jeconom.2019.04.009

Moyo, B., Kwarambo, M. & Nchake, M., 2020, 'Regional integration Southern Africa', in B. Antoine; P.O. Odjo & Z. Chahir (eds.), *Africa agriculture trade monitor 2020*, Chapter 6, pp. 149–174, International Food Policy Research Institute (IFPRI), Washington, DC.

Mpungose, N., Ngubane, M. & Sekome, M., 2023, 'Revisiting the effect of exchange rates on imports and exports in South Africa', *Acta Universitatis Danubius. Œconomica* 19(4), 144–162, viewed 15 April 2024, from https://dj.univ-danubius.ro/index.php/AUDOE/article/view/2380.

Ndou, E., 2022, 'Exchange rate changes on export volumes in South Africa under the inflation targeting period', *SN Business & Economics* 2(6), 59. https://doi.org/10.1007/s43546-022-00217-2

Oumansour, N.E. & Azghour, Z., 2024, 'Exchange rate misalignment and trade fluctuations in Morocco: Empirical evidence', *Japanese Political Economy* 50(1), 66–90. https://doi.org/10.1080/2329194X.2024.2321436

Pamba, D., 2023, *Does foreign direct investment crowd in or crowd out domestic investment in South Africa? An ARDL-ECM approach*, viewed n.d., from https://www.svedbergopen.com/files/1680520570_(2)_IJMRE2022MNL758TBK23_(p_18-35).pdf.

Pasricha, S., 2020, 'The effect of exchange rate fluctuations on international trade of India', *International Journal of Current Research* 12(9), 13628–13631. https://doi.org/10.24941/ijcr.39662.09.2020

Pedroni, A., 1999, 'Critical values for cointegration tests in heterogeneous panels with multiple regressors', *Oxford Bulletin of Economics and Statistics* 61, 653–670. https://doi.org/10.1111/1468-0084.61.s1.14

Pedroni, P., 2004, 'Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis', *Econometric Theory* 20(3), 597–625. https://doi.org/10.1017/S0266466604203073

Pesaran, M.H., 2004, *General diagnostic tests for cross section dependence in panels*, University of Cambridge, Faculty of Economics, Cambridge.

Peter, A. & Bakari, I., 2018, 'Impact of population growth on economic growth in Africa: A dynamic panel data approach (1980–2015)', *Pakistan Journal of Humanities and Social Sciences* 6(4), 412–427. https://doi.org/10.2139/ssrn.3432263

Poku, A.G., 2017, 'The influence of exchange rate changes on agricultural prices: The case of cocoa and maize in Ghana (1966–2008)', *American Journal of Rural Development* 5(3), 81–89. https://doi.org/10.12691/ajrd-5-3-4

Polodoo, V., Seetanah, B. & Sannassee, R.V., 2016, 'Exchange rate volatility and manufacturing trade: Evidence from Africa', *Journal of Developing Areas* 50(5), 241–256. https://doi.org/10.1353/jda.2016.0070

Rehman, M.A., Fareed, Z., Salem, S., Kanwal, A. & Pata, U.K., 2021, 'Do diversified export, agriculture, and cleaner energy consumption induce atmospheric pollution in Asia? Application of method of moments quantile regression', *Frontiers in Environmental Science* 9, 781097. https://doi.org/10.3389/fenvs.2021.781097

Ryu, A., 2023, *Ranked: Number of agricultural workers by country*, viewed 01 February 2024, from https://www.visualcapitalist.com/cp/agricultural-workers-by-country/.

Southern African Development Community (SADC), 2020, *Regional Indicative Strategic Development Plan (RISDP) 2020–2030*, Gaborone, Botswana, viewed 14 February 2023, from https://www.sadc.int/sites/default/files/2021-08/RISDP_2020-2030.pdf.

Southern African Development Community (SADC), 2023, *SADC Statistics*, viewed 17 April 2023, from https://www.sadc.int/pages/sadc-statistics.

Sarkodie, S.A. & Strezov, V., 2019, 'A review on environmental Kuznets curve hypothesis using quantile regression analysis', *Journal of Cleaner Production* 230, 517–535.

Seti, T.M., 2023, 'Determinants of South African agricultural exports to African markets', *Journal of Economic and Financial Sciences* 16(1), a898. https://doi.org/10.4102/jef.v16i1.898

Ulya, Z., 2022, 'The influence of export, import and population values on the gross domestic product of ASEAN countries period 2000–2009', *el-Jizya: Jurnal Ekonomi Islam* 10(2), 217–232. https://doi.org/10.24090/ej.v10i2.7060

Utouh, H.M.L., 2024, 'The dynamics of trade liberalization, export performance, and economic growth in Tanzania: A time series analysis 1980–2020', *Journal of Social and Economic Development*. https://doi.org/10.1007/s40847-024-00395-9

Westerlund, J., 2007, 'Testing for error correction in panel data', *Oxford Bulletin of Economics and Statistics* 69(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

World Integrated Trade Solution n.d., *Agricultural exports*, viewed n.d., from https://wits.worldbank.org/WITS/QuickQuery/ComtradeByProduct

World Bank n.d., *World development indicator*, viewed n.d., from https://databank.worldbank.org/source/world-development-indicators

Zhang, Y., Chang, H.S. & Gauger, J., 2006, 'The threshold effect of exchange rate volatility on trade volume: Evidence from G-7 countries', *International Economic Journal* 20(4), 461–476. https://doi.org/10.1080/10168730601027039

Zhao, Q., 2000, 'Restricted regression quantiles', *Journal of Multivariate Analysis* 72(1), 78–99. https://doi.org/10.1006/jmva.1999.1849

Zhu, H., Duan, L., Guo, Y. & Yu, K., 2016, 'The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: Evidence from panel quantile regression', *Economic Modelling* 58, 237–248. https://doi.org/10.1016/j.econmod.2016.05.003t

Appendix starts on the next page →

Appendix 1

TABLE 1-A1: Test statistic compares all coefficients.

Wald test	Test Summary		
	Chi-Sq. Statistic	**Chi-Sq. *df***	**Prob.**
Quantile Slope Equality	33,76549	12	0,0007
Symmetric Quantiles	33,20877	7	0

Note: Equation: UNTITLED; Specification: LGEX REER LGDPS LGDPF LPOPS LPOPF INFL C; Estimated equation quantile tau = 0.5; Number of test quantiles: 4