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Real Exchange Rate Dynamics and Agricultural Export Performance in Kenya: Asymmetric Effects, Commodity Heterogeneity, and Structural Transmission Channels

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ABSTRACT

This study examines whether real effective exchange rate movements affect Kenyan agricultural export performance, and whether these effects differ across appreciation and depreciation episodes. Using annual data from 1999 to 2024 and a Nonlinear Autoregressive Distributed Lag framework, this paper estimates separate long-run and short-run exchange rate elasticities for tea, coffee, and cut flowers. Tea export volumes respond positively to both appreciation and depreciation in the long run, with the depreciation elasticity of 1.314 ($p = 0.014$) larger than the appreciation elasticity of 0.619 ($p = 0.003$), and the error correction term of minus 2.441 confirming rapid adjustment. Coffee exports are not responsive to the real effective exchange rate; global Arabica prices are the dominant driver, with a long-run price elasticity of minus 0.358 ($p = 0.001$). Cut flowers show the strongest exchange rate sensitivity of the three commodities, with significant long-run appreciation and depreciation elasticities of 1.080 ($p = 0.009$) and 1.242 ($p = 0.032$) respectively, alongside highly significant short-run impacts. Robustness checks using Fully Modified OLS and Dynamic OLS confirm the flowers finding, with long-run REER elasticities of approximately 0.87 to 0.88 across both estimators. The results indicate that exchange rate policy is most effective as an export promotion tool for horticulture, while coffee sector performance requires attention to global price conditions rather than currency management.

Keywords:
real effective exchange rate; NARDL; agricultural exports; Kenya; tea; coffee; cut flowers; asymmetric effects; cointegration

INTRODUCTION

Agriculture remains a central pillar of the Kenyan economy. The sector provides livelihoods for more than 60 percent of the rural population and accounts for a substantial share of foreign exchange earnings (World Bank, 2024). Among agricultural exports, tea is the most important commodity, contributing approximately 16 percent of total export earnings in 2024 and ranking as the second largest source of foreign exchange after diaspora remittances. Coffee and cut flowers are the second and third leading agricultural exports, and together they add several billion Kenya Shillings to the annual export bill. The performance of these three commodities therefore directly shapes macroeconomic stability, rural incomes, and the current account position.

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The exchange rate is one of the most studied policy instruments in the trade and development economics literature. Classical theory, grounded in the Marshall-Lerner condition and purchasing power parity, predicts that a real depreciation of the domestic currency improves export competitiveness by reducing the cost of domestic goods relative to foreign competitors (Krugman, Obstfeld and Melitz, 2022). However, a large body of empirical evidence shows that this prediction does not hold uniformly across sectors, time horizons, or exchange rate regimes. The response of exports to exchange rate movements depends on invoicing currency, supply-side constraints, the structure of pricing in the export market, and the degree of vertical integration in the value chain. Thorbecke (2011) showed that the exchange rate transmission mechanism for East Asian exporters depends critically on product market structure, and Berman, Martin and Mayer (2012) demonstrated that high-performance exporters absorb a greater share of exchange rate changes into their margins, producing smaller volume responses than standard models predict.

For Kenya, this question carries particular practical relevance. The Kenya Shilling experienced considerable volatility between 1999 and 2024, moving from below 70 Kenya Shillings per US Dollar in the early 2000s to a peak of more than 141 Shillings per Dollar in late 2023 before recovering to around 130 Shillings per Dollar in 2024, as recorded in the BIS bilateral exchange rate database (BIS, 2026; Darvas, 2026). These swings represent large changes in the price competitiveness of Kenyan exports, a concern documented for Kenya by both Kiptui (2007) and Nyambariga (2017). Yet empirical evidence on whether these movements translated into measurable changes in agricultural export volumes is limited, and existing studies do not account for the possibility that appreciation and depreciation episodes may have different magnitudes of effect.

This study addresses three research questions. First, does the real effective exchange rate have a statistically significant long-run effect on Kenyan agricultural export volumes? Second, are these effects asymmetric, in the sense that appreciation and depreciation episodes have different magnitudes? Third, does the exchange rate transmission mechanism differ across tea, coffee, and cut flowers? These three commodities are deliberately chosen because they operate in very different pricing environments. Tea is sold at the Mombasa Auction where prices are quoted in US Dollars, meaning that KES depreciation raises Kenya Shilling revenues directly. Coffee is sold through the Nairobi Coffee Exchange underpricing benchmarked to ICO composite indicators, making it potentially less sensitive to bilateral exchange rate movements. Cut flowers are exported primarily to the Netherlands through the Dutch Flower Auction, with prices quoted in Euros, creating a third distinct transmission channel.

The paper makes three contributions to the literature. First, it applies the Nonlinear ARDL framework of Shin, Yu and Greenwood-Nimmo (2014) to Kenyan agricultural exports at the commodity level, testing explicitly for asymmetric long-run and short-run effects. Second, it constructs a commodity-specific supply shock variable using CHIRPS satellite rainfall anomaly data (Funk et al., 2015; WFP, 2025) aggregated over tea and coffee growing counties, which allows clean identification of weather-driven supply shocks separate from price competitiveness effects. Third, the study covers the 2020 to 2024 period, which includes the COVID-19 disruption, the Red Sea shipping crisis, and the 2023 KES depreciation episode. The structural stability of the model parameters over this turbulent period is confirmed using the recursive CUSUM procedure of Brown, Durbin and Evans (1975).

The remainder of the paper is organized as follows. The next section reviews the relevant theoretical and empirical literature. The data and variable construction are then described, followed by the empirical methodology. The results are then reported and interpreted in detail. The findings are subsequently discussed in relation to the existing literature and their policy

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implications. A concluding section closes the paper.

LITERATURE REVIEW

Exchange Rate and Export Theory

The theoretical relationship between the real exchange rate and export volumes rests on the standard trade model in which a real depreciation lowers the domestic cost of production relative to world market prices, improving the price competitiveness of exporters (Krugman, Obstfeld and Melitz, 2022). For this competitiveness effect to translate into higher export volumes, the export supply curve must be elastic enough to respond to the improved price signal, and international demand for the exported good must be sufficiently price-sensitive. In primary commodity markets, the second condition is frequently violated because many agricultural goods are differentiated by quality and origin and face relatively inelastic demand from established trading partners, as documented for Sub-Saharan African exporters by Sekkat and Varoudakis (2000).

The standard symmetric relationship between the exchange rate and trade flows has been challenged on several grounds. Hysteresis theory, developed by Baldwin and Krugman (1989) and extended by Roberts and Tybout (1997), argues that sunk entry costs in export markets make it rational for exporters to maintain participation even when exchange rates move against them temporarily, and to delay entry even when conditions improve. This produces asymmetry: a depreciation may fail to stimulate new export entry as readily as an appreciation will cause exit. In a small open economy like Kenya, where many tea and horticultural exporters are already established market participants with long-term contracts, this hysteresis mechanism may operate differently across commodities depending on the investment required to enter or exit each market.

Pricing-to-market theory provides a second explanation for non-standard exchange rate effects. Knetter (1993) showed that exporters in imperfectly competitive markets adjust their markups in response to exchange rate changes rather than passing them fully through to prices, implying that export volumes are partially insulated from exchange rate movements. Berman, Martin and Mayer (2012) confirmed this at the firm level for French exporters, finding that high-performance exporters absorb a substantially larger proportion of exchange rate movements into their margins compared to lower-productivity competitors. This mechanism is particularly relevant for Kenyan cut flowers, where the country competes with Ethiopia and Colombia in the Dutch Auction market and where pricing behavior reflects the competitive dynamics of a multi-origin spot market.

Bahmani-Oskooee and Harvey (2021) provide a comprehensive review of the nonlinear trade literature and conclude that treating exchange rate effects as symmetric is generally inappropriate, particularly for developing country exporters whose export structures are concentrated in a few primary commodities. Bahmani-Oskooee and Aftab (2017) applied the Nonlinear ARDL model to Malaysian sectoral exports and found significant asymmetry in eight of thirteen sectors. The NARDL approach, by decomposing the exchange rate into partial sums of positive and negative changes, provides a direct test of this asymmetry hypothesis without imposing the symmetric restriction a priori.

Evidence from Sub-Saharan Africa and Kenya

Empirical studies on exchange rates and agricultural trade in Sub-Saharan Africa are relatively sparse, and findings vary considerably by country, commodity, and methodology. Sekkat and Varoudakis (2000) found that real exchange rate misalignment significantly depressed manufactured exports in Sub-Saharan Africa, establishing an important empirical baseline for the region. Arize, Malindretos and Igwe (2017) applied nonlinear cointegration methods to thirteen African countries and found that depreciation generally stimulates exports more effectively than appreciation suppresses them, an asymmetric pattern consistent with the hysteresis hypothesis. More recently, Wainaina (2025)

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examined impulse responses to exchange rate shocks for Kenya using a VAR framework and found that exports respond positively to depreciation shocks over a two-year horizon, though the effect dissipates by the third year.

For Kenya specifically, Kiptui (2007) applied an ARDL Bounds Testing approach to tea and horticultural exports and found that exchange rate volatility was a significant determinant of export performance, particularly for tea exports to the United Kingdom. Kiptui and Ndirangu (2015) extended this line of research by examining REER misalignment and found that the Kenya Shilling was broadly aligned with fundamentals during most of the post-liberalization period, with notable misalignment episodes coinciding with major external shocks. Nyambariga (2017) confirmed the importance of the exchange rate for Kenya's aggregate export performance using an error correction framework, finding that both imports and exports respond significantly to exchange rate changes in both the short run and the long run.

At the commodity level, Muthamia and Muturi (2015) examined the determinants of tea export earnings in Kenya over 1980 to 2011 using cointegration and error correction methods, finding that real exchange rates, tea prices, and agricultural value added all had positive influences on export earnings, while inflation did not show a significant effect. Chirchir, Muse and Jagongo (2015) specifically studied exchange rate volatility and the export performance of tea firms in Kenya, finding that exchange rate volatility and domestic tea prices were jointly significant determinants of monthly export performance across 54 KTDA factories. Neither study applied asymmetric methods or used the NARDL framework developed by Shin et al. (2014).

The Tea Board of Kenya (2025) reports that export volumes reached a record 652.8 million kilograms in 2025, up from 594.5 million kilograms in 2024, during a period when the Bruegel REER was declining, providing prima facie support for a negative relationship between REER appreciation and tea export volumes. Freund and Pierola (2012) showed for a broad panel of developing countries that export surges are often triggered by exchange rate depreciations, but that the duration and magnitude of the surge depend heavily on the export structure and institutional environment of the exporting country.

The NARDL Framework

The Nonlinear ARDL model developed by Shin et al. (2014) builds on the ARDL Bounds Testing approach of Pesaran, Shin and Smith (2001) and extends it to accommodate asymmetric long-run and short-run responses. The model decomposes the exchange rate variable into partial sums of positive changes, representing appreciation episodes, and partial sums of negative changes, representing depreciation episodes. These two partial sum processes are then included as separate regressors in the error correction model. The null hypothesis of long-run symmetry is tested using a standard Wald test on the level coefficients of the two partial sum variables.

The NARDL framework is particularly appropriate for this study for several reasons. First, as the unit root tests in Table 2 show, the exchange rate and export volume variables are a mixture of I(0) and I(1) processes, which satisfies the requirement of the ARDL Bounds approach and violates the requirement of standard cointegration tests that require all variables to be I(1). Pesaran, Shin and Smith (2001) showed that the ARDL Bounds test is valid regardless of whether regressors are I(0), I(1), or a mixture of both, making it the natural choice when the integration orders are uncertain or mixed. Second, the partial sum decomposition directly captures the history of appreciation and depreciation episodes visible in the Kenya REER data from the Darvas (2026) Bruegel database, allowing the model to match the economic narrative of the 2011 to 2012 depreciation cycle, the 2013 to 2019 appreciation period, and the sharp 2022 to 2023 depreciation. Third, the approach produces both short-run and long-run elasticity estimates in a single estimable equation, which is computationally efficient given sample sizes of 18 to 26 annual observations.

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DATA CONSTRUCTION

Dependent Variables

The three dependent variables are the natural logarithms of annual export volumes in metric tons for tea, coffee, and cut flowers. Tea and coffee volume and value data are sourced from the Central Bank of Kenya monthly bulletin on Principal Exports (CBK, 2025), which covers the period from August 1998 to December 2024. The monthly data are aggregated to annual totals. Cut flower export volumes and unit values are obtained from ITC Trade Map under HS code 0603, which specifically covers cut flowers and flower buds and distinguishes these from other horticultural products such as vegetables and fruits (ITC, 2025). Flower data are available from 2005 onwards, giving a shorter sample of 20 observations for the flowers equation.

The use of log volumes as the dependent variable, rather than log values, is deliberate. Export values in Kenya Shillings are mechanically affected by the exchange rate through the valuation channel, meaning that any regression of Kenya Shilling values on the REER will partly capture an accounting identity rather than a behavioral response. Log volumes capture the real quantity response, which is the economically meaningful measure of whether exchange rate changes alter the competitive position of Kenyan exporters in international markets. This approach follows the practice of Chirchir, Muse and Jagongo (2015) and Wainaina (2025) for Kenyan export data.

Exchange Rate Variables

The primary exchange rate measure is the Real Effective Exchange Rate from the Bruegel database (Darvas, 2026), which provides monthly CPI-deflated trade-weighted REER indices for 178 countries updated to February 2026. An increase in the REER index represents appreciation of the Kenya Shilling in real terms, meaning that Kenyan exports become more expensive relative to competitors. The REER is based on a 2007 = 100 base year and covers 65 trading partners with weights reflecting bilateral trade shares. As robustness checks, the study also uses the IMF CPI-based REER and the nominal bilateral KES per US Dollar rate from the BIS Data Portal (BIS, 2026).

For the NARDL estimation, the REER series is decomposed into partial sum processes following Shin et al. (2014). The positive partial sum, REER+, captures the cumulative history of appreciation shocks, and the negative partial sum, REER-, captures the cumulative history of depreciation shocks. The REER appreciated from 73.9 index points in 1999 to a peak of 158.7 in 2019 before declining to 137.0 in 2023 following the KES depreciation episode. REER volatility, constructed as the annual standard deviation of monthly log-differences of the Bruegel REER (Darvas, 2026), is also included as a control variable following Couharde et al. (2018), who emphasize the importance of controlling for exchange rate uncertainty in export supply equations.

Control Variables

The study uses five control variables, chosen on theoretical grounds and constrained to avoid over-specification given the sample sizes. Global commodity prices are included for each equation: the Mombasa auction tea price in USD per kilogram for tea and the ICO Arabica composite indicator for coffee, both from the World Bank Pink Sheet (World Bank, 2026), and the ITC Trade Map unit value in USD per kilogram for cut flowers. These prices capture global demand and supply conditions in each commodity market and are essential controls to separate the REER competitiveness effect from global price cycle effects. Muthamia and Muturi (2015) showed that global tea prices were among the most important determinants of Kenyan tea export earnings, providing theoretical justification for this inclusion.

A trade-weighted partner demand index is constructed from IMF World Economic Outlook GDP data (IMF, 2025) to control for income effects in each commodity market. For tea, the index weights Pakistan at 35 percent, Egypt at 15 percent, and the United Kingdom at 10 percent, reflecting their shares of Kenyan tea exports as documented in the Tea Board of Kenya (2024)

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annual performance report. For coffee, the weights reflect Germany, the Netherlands, and the United Kingdom as the dominant processing and consuming markets. For flowers, the Netherlands accounts for 50 percent and the United Kingdom for 20 percent of the index weight, consistent with the structure of the Dutch Flower Auction as the primary pricing and sales venue.

A rainfall anomaly variable, constructed from CHIRPS satellite precipitation data (Funk et al., 2015; WFP, 2025) aggregated over the relevant agricultural counties, captures supply-side weather shocks. The 3-month rolling anomaly as a percentage of the 1989 to 2018 long-term average is used, with separate series for tea-growing counties in the West Rift and East Rift and for coffee and flower growing zones. Weather shocks have been identified as important supply-side determinants of Kenyan tea output by the Tea Board of Kenya (2025), which attributed the production decline in 2025 to erratic and poorly distributed rainfall across the main tea growing regions.

METHODOLOGY

ARDL Bounds Testing

The empirical strategy begins with the ARDL Bounds Testing approach of Pesaran, Shin and Smith (2001). This approach is appropriate when regressors are a mixture of I(0) and I(1) processes, as confirmed by the unit root tests reported in Table 2. The symmetric ARDL error correction model for each commodity takes the form:

Delta ln(Vol_t) = alpha + rho * ln(Vol_t-1) + beta_1 * ln(REER_t-1) + beta_2 * ln(Price_t-1) + beta_3 * ln(Demand_t-1) + beta_4 * Rain_t-1 + beta_5 * Vol_t + [short-run dynamics] + epsilon_t

where rho is the error correction coefficient, which must be negative and statistically significant for long-run cointegration to hold, and the long-run elasticity of export volume with respect to the REER is given by minus beta_1 divided by rho. The null hypothesis of no long-run relationship is tested using the Bounds F-statistic, which is compared to the critical value bands of Pesaran, Shin and Smith (2001, Case III) at the 5 percent significance level: I(0) lower bound 3.79 and I(1) upper bound 4.85.

Nonlinear ARDL Asymmetric Extension

The Nonlinear ARDL model of Shin et al. (2014) extends the symmetric model by replacing the single ln(REER) variable with two partial sum processes. REER+ is the cumulative sum of positive log-REER changes, representing appreciation, and REER- is the cumulative sum of negative log-REER changes, representing depreciation. The NARDL error correction model becomes:

Delta ln(Vol_t) = alpha + rho * ln(Vol_t-1) + theta_pos * REER+_t-1 + theta_neg * REER-_t-1 + [control variable levels and short-run dynamics] + epsilon_t

Long-run elasticities are recovered as beta_pos = minus theta_pos divided by rho and beta_neg = minus theta_neg divided by rho. Standard errors for these derived long-run coefficients are obtained using the delta method. The null hypothesis of long-run symmetry (beta_pos = beta_neg) is tested using a Wald F-test on the level coefficients theta_pos and theta_neg. Standard errors throughout are computed using Newey-West heteroskedasticity and autocorrelation consistent estimation with a lag truncation of 1. The model is estimated with lag order p = 1, selected by the Akaike Information Criterion. This lag length also eliminates the serial correlation that appeared in preliminary estimates with two lags.

Robustness Estimators

Two additional estimators are used for robustness. The Fully Modified OLS estimator of Phillips and Hansen (1990) provides a semiparametric correction for endogeneity and serial correlation in the cointegrating regression without requiring a parametric model of the dynamics. The Dynamic OLS estimator of Stock and Watson (1993) controls for endogeneity by augmenting the regression with leads and lags of the first differences of the regressors, with a leads-lags order of 1. Both estimators use Newey-West long-run variance estimation. Consistency of the key

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elasticities across NARDL, FMOLS, and DOLS strengthens confidence in the robustness of the main findings.

Structural Stability

Structural stability is assessed using recursive CUSUM tests of Brown, Durbin and Evans (1975). The CUSUM statistic is plotted against the 5 percent significance bands, and stability is confirmed when the statistic remains within bounds throughout the sample. This test is important given the multiple macroeconomic shocks experienced over the study period, including the 2008 global financial crisis, the 2020 COVID-19 disruption, and the 2022 to 2023 KES depreciation episode. Structural stability of the model parameters across these events is a prerequisite for drawing reliable conclusions about the long-run elasticities. The recursive tests confirm parameter stability for all three commodity equations, with CUSUM statistics remaining within the 5 percent bands throughout the sample.

EMPIRICAL RESULTS

Preliminary Diagnostics

Table 1 presents descriptive statistics for all key variables over the full sample. Kenya tea export volumes grew from 217,282 tons in 2000 to 625,554 tons in 2024, reflecting the broad expansion of the tea industry driven by government fertilizer subsidies, additional factory licensing, and growth in demand from Pakistan and Egypt (Tea Board of Kenya, 2025). The mean annual export volume was 418,247 tons with a standard deviation of 118,547 tons, indicating substantial year-to-year variation. Coffee export volumes showed no sustained upward trend, fluctuating between 37,570 and 86,982 tons with a mean of 50,268 tons, consistent with the structural challenges facing the sector. Cut flower export volumes grew from 84,672 tons in 2005 to a peak of 179,875 tons in 2023, averaging 146,310 tons annually.

Table 1: Descriptive statistics

Variable	N	Mean	Std Dev	Min	Median	Max	ADF (Level)
Exchange Rate Variables							
REER Bruegel (2007=100)	26	117	26.400	73.900	118	159	-1.36
ln(REER)	26	4.730	0.250	4.300	4.730	5.070	-1.36
REER+ Partial Sum (ln)	26	1.330	0.310	0.820	1.310	1.770	-2.32
REER- Partial Sum (ln)	26	-1.160	0.070	-1.350	-1.180	-1.080	-2.46
REER Volatility	26	0.018	0.010	0.008	0.015	0.042	-4.92***
KES/USD (BIS annual avg)	26	95.800	22.400	67.200	89.400	141	-1.50
Tea Export Variables							
Tea Export Volume (tons)	26	418247	118547	217282	432899	625554	-3.86**
Tea Export Value (USD million)	26	383	139	153	362	571	-3.21
Tea Price Mombasa (USD/kg)	26	2.240	0.520	1.500	2.220	3.050	-1.79
ln(Tea Export Volume)	26	12.880	0.290	12.290	12.900	13.350	-3.86**
ln(Tea Price Mombasa)	26	0.750	0.220	0.390	0.790	1.090	-1.79
Coffee Export Variables							
Coffee Export Volume (tons)	26	50268	9821	37570	49727	86982	0.37
Coffee Export Value (USD million)	26	162	68.100	93.100	152	347	-1.41
Coffee Price Arabica (USD/kg)	26	3.240	1.480	1.360	2.990	8.470	-4.45***
ln(Coffee Export Volume)	26	10.820	0.200	10.530	10.810	11.370	-0.90
ln(Coffee Price Arabica)	26	1.010	0.450	0.310	0.960	2.140	-4.45***
Cut Flowers Variables (2005-2024, N=20)							
Flowers Export Volume (tons)	20	146310	24870	97869	143180	179875	-2.84
Flowers Export Value (USD million)	20	500	141	243	480	726	-3.04
Flowers Unit Value (USD/kg)	20	3.740	0.320	2.830	3.720	4.190	-2.69
ln(Flowers Export Volume)	20	11.870	0.170	11.490	11.870	12.100	-2.84
Rainfall Anomaly Variables							
Rain Anomaly Tea West Rift (% LTA)	26	108	17.200	80.900	105	160	-4.88***
Rain Anomaly Coffee Zone (% LTA)	26	104	20.700	73.200	101	163	-2.86
Rain Anomaly Flowers Zone (% LTA)	26	104	18.900	72.100	100	155	-4.21***

*Notes: ADF = Augmented Dickey-Fuller test statistic with constant and trend specification. LTA = long-term average (CHIRPS reference period 1989 to 2018). *** p<0.01, ** p<0.05, * p<0.10. Flowers sample is 2005 to 2024 (N=20).*

Sources: CBK (2025), ITC (2025), Darvas (2026), World Bank (2026), Funk et al. (2015), WFP (2025), IMF (2025).

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The Bruegel REER appreciated from 73.9 index points in 1999 to a peak of 158.7 in 2019 before declining to 137.0 in 2023 following the KES depreciation episode and recovering slightly to 144.7 in 2024 (Darvas, 2026). The KES per USD nominal rate rose from 70.9 in 1999 to 141.2 in 2023 (BIS, 2026). REER volatility averaged 0.018 per year with a maximum of 0.042, reflecting the 2011 episode of sharp depreciation. The global Mombasa tea price ranged from 1.50 to 3.05 USD per kilogram over the full sample, and coffee Arabica prices showed wider swings from 1.36 to 8.47 USD per kilogram (World Bank, 2026).

Table 2 presents unit root test results. The log REER and its partial sums are I(1), confirming that the exchange rate has a stochastic trend in levels but is stationary in first differences. Log tea export volume is I(0), consistent with mean-reversion around a deterministic trend. Log coffee export volume is near I(2), reflecting the strong structural decline in the series during the early 2000s followed by recovery. Rainfall anomalies and REER volatility are I(0) throughout. The mixed integration orders confirm that the ARDL Bounds approach is more appropriate than Johansen cointegration, which requires all variables to be I(1).

Table 2: Unit root and stationarity tests

Variable	ADF Stat (Level)	p-value	ADF Stat (First Diff.)	p-value	Order	Implication for ARDL
ln(REER Bruegel)	-1.36	0.872	-4.91	0.000	I(1)	Non-stationary level; ECM appropriate
REER+ Partial Sum	-2.32	0.422	-4.61	0.000	I(1)	Included as level in ECM
REER- Partial Sum	-2.46	0.347	-5.13	0.000	I(1)	Included as level in ECM
ln(Tea Volume)	-3.86	0.014	-4.44	0.000	I(0)	Level-stationary; valid regressor
ln(Coffee Volume)	0.37	0.997	0.45	0.983	I(2)?	Near-I(2); ECM specification accommodates
ln(Tea Price)	-1.79	0.711	-7.00	0.000	I(1)	First-difference stationary
ln(Coffee Price)	-4.45	0.002	-3.51	0.008	I(0)	Level-stationary; valid regressor
ln(Flowers Volume)	-2.84	0.181	-4.92	0.000	I(1)	First-difference stationary
ln(Tea Demand Index)	-2.59	0.283	-1.41	0.576	I(2)?	Strong trend; ECM structure mitigates
Rain Anom. Tea West	-4.88	0.000	-8.80	0.000	I(0)	Stationary; mean-reverting anomaly
REER Volatility	-4.92	0.000	-6.03	0.000	I(0)	Stationary by construction

Notes: Augmented Dickey-Fuller test with constant and trend. H0: unit root. Optimal lag length selected by AIC. KPSS test also conducted (H0: stationarity) with consistent results. Zivot-Andrews (1992) structural break unit root tests were also applied and confirmed similar integration orders. Mixed I(0) and I(1) processes support the ARDL Bounds Testing approach (Pesaran, Shin and Smith, 2001), which is valid under mixed integration orders.

NARDL Results

Table 3 presents the main NARDL results for all three commodity equations.

Tea Exports

The tea equation produces a Bounds F-statistic of 18.09, which far exceeds the 1 percent I(1) critical value of 5.58, confirming long-run cointegration. The error correction term of minus 2.441 ($p < 0.001$) indicates that tea export volumes adjust toward the long-run equilibrium at a rapid rate, implying more than full correction within a single year. This fast adjustment is economically plausible in the tea sector, where auction-based sales allow volumes to respond quickly to prevailing exchange rate and price conditions, a finding consistent with Kiptui (2007), who also found rapid error correction in Kenyan tea export equations.

The long-run appreciation elasticity is 0.619 ($p = 0.003$) and the long-run depreciation elasticity is 1.314 ($p = 0.014$). The positive sign on both elasticities requires careful interpretation. A positive long-run appreciation elasticity means that higher real exchange rate levels are associated with higher tea export volumes over the long run. This is consistent with the observation that the sustained appreciation of the Kenya Shilling from 1999 to 2019 coincided with strong growth in tea export volumes driven primarily by supply-side expansion, as documented by Muthamia and Muturi (2015), who found that agricultural value added and partner income, rather than exchange

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rate competitiveness, explained most of the variation in earnings over that period. Fertilizer subsidies, new factory licensing, and favorable rainfall conditions drove the volume growth, while the REER appreciation reduced per-kilogram Kenya Shilling revenues without preventing volume growth. The depreciation elasticity of 1.314, which is larger than the appreciation coefficient, indicates that REER depreciation has a stronger long-run stimulating effect on export volumes, consistent with the asymmetric pricing-to-market behavior documented by Berman, Martin and Mayer (2012), where exporters expand volume more aggressively when depreciation improves their competitive position than they contract when appreciation reduces it.

The Wald asymmetry test yields F = 2.427 with p = 0.163, which does not reject long-run symmetry at conventional significance levels. This is consistent with the finding of Bahmani-Oskooee and Harvey (2021) that Wald tests for long-run symmetry have limited power in small samples. The world commodity price elasticity is minus 0.154 (p = 0.002), and the partner demand index contributes a positive long-run elasticity of 0.659 (p = 0.009), confirming that income growth in Pakistan, Egypt, and the United Kingdom drives tea import demand from Kenya. The rainfall anomaly coefficient of minus 0.001 (p = 0.050) is statistically significant, suggesting that rainfall deficits in West Rift tea growing counties modestly reduce export volumes through supply shortfalls.

Coffee Exports

The coffee equation produces a Bounds F-statistic of 17.229, also confirming long-run cointegration. The error correction term is minus 0.895 (p < 0.001), indicating an adjustment speed of approximately 90 percent per year, somewhat slower than tea but still rapid relative to other commodity markets. The central finding for coffee is that neither the long-run appreciation elasticity (minus 0.032, p = 0.910) nor the long-run depreciation elasticity (0.463, p = 0.718) is statistically significant. The real effective exchange rate has no discernible long-run effect on Kenyan coffee export volumes. This finding is consistent with the broader Kenya-specific literature. Kiptui and Ndirangu (2015) found that REER misalignment episodes had limited effects on commodity exports compared with structural factors, and Chirchir, Muse and Jagongo (2015) found that domestic price factors rather than exchange rate competitiveness dominated tea and coffee export outcomes at the firm level.

The dominant driver of coffee exports is the global Arabica price, with a long-run elasticity of minus 0.358 (p = 0.001). The negative sign indicates that higher global Arabica prices are associated with lower Kenyan coffee export volumes. This is consistent with supply-side substitution: when global prices are high, Kenyan farmers divert more coffee to higher-value specialty channels or delay sales while awaiting further price appreciation, while buyers in lower-value segments reduce their offtake. This result also reflects the market structure of premium-grade Arabica coffee, where Kenyan AA grade fetches prices based on quality positioning and origin reputation rather than exchange rate competitiveness, consistent with Knetter's (1993) theory of pricing-to-market in imperfectly competitive export markets. The partner demand index is marginally significant at the 10 percent level (0.950, p = 0.054), confirming a secondary role for income conditions in Germany, the Netherlands, and the United Kingdom.

Cut Flowers

The cut flowers equation produces the most striking results of the three commodities studied. The Bounds F-statistic of 583 leaves no ambiguity about long-run cointegration. The model fit is exceptional, with an adjusted R-squared of 0.923. The error correction coefficient of minus 1.669 (p < 0.001) indicates that nearly all deviations from the long-run relationship are corrected within a single year, the fastest adjustment of the three equations. Both long-run exchange rate elasticities are statistically significant: the appreciation elasticity is 1.080 (p = 0.009) and the depreciation elasticity is 1.242 (p = 0.032).

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Unlike the tea case, both flower elasticities have the economically expected sign: REER appreciation is associated with higher export volumes and depreciation with lower volumes. This result reflects the EUR billing mechanism of the Dutch Flower Auction. Since flowers are priced in Euros and Kenya Shilling production costs are converted through the KES to EUR cross rate, an appreciation of the KES against the Euro raises the cost burden for buyers when expressed in their domestic currency and reduces the volume they demand from Kenya. This channel is consistent with the broader evidence on exchange rate transmission documented by Thorbecke (2011) for East Asian exporters facing major commodity auctions, who found that the invoicing currency and the competitive structure of the auction market jointly determine how exchange rate movements translate into export volume changes.

Short-run effects are highly significant and their magnitudes are larger than the long-run values. The impact period appreciation coefficient is 1.408 ($p < 0.001$), meaning that a 1 percent REER appreciation in the current year is associated with a 1.4 percent increase in flower export volumes contemporaneously. The impact period depreciation coefficient is minus 0.690 ($p < 0.001$). These strong immediate responses reflect the high-frequency spot-market structure of Dutch Auction trading, where buyers adjust sourcing decisions rapidly in response to exchange rate signals. The Wald asymmetry test gives $p = 0.203$, which does not reject long-run symmetry, though the short-run responses are asymmetric in magnitude. The rainfall anomaly in Kiambu and Nakuru counties carries a negative long-run elasticity of minus 0.003 ($p = 0.016$), suggesting that abnormally high rainfall reduces flower export volumes, possibly through flooding and quality deterioration.

Table 3: NARDL asymmetric model results

Variable / Statistic	Tea Exports		Coffee Exports		Cut Flowers	
	Coeff.	(t-stat)	Coeff.	(t-stat)	Coeff.	(t-stat)
Panel A: Long-run Elasticities (ECM Level Coefficients)						
REER Appreciation (beta+, LR)	0.6189**	(4.602)	-0.0320	(-0.117)	1.0799**	(12.209)
REER Depreciation (beta-, LR)	1.3135**	(3.272)	0.4630	(0.376)	1.2424*	(3.423)
World Commodity Price (LR)	-0.1544**	(-3.566)	-0.3580***	(-3.566)	0.1956*	(2.424)
Partner Demand Index (LR)	0.6592**	(2.862)	0.9501*	(1.960)	-0.1774*	(-1.412)
Rainfall Anomaly (LR)	-0.0011**	(-2.014)	-0.0035	(-1.661)	-0.0031**	(-2.418)
Panel B: Short-run Dynamics						
Delta REER+ (impact period)	0.6758*	(1.877)	-0.6907	(-1.530)	1.4084***	(5.621)
Delta REER- (impact period)	-0.9225	(-1.640)	0.0572	(0.063)	-0.6896***	(-3.312)
Error Correction Term (ECT)	-2.4412***	(-8.007)	-0.8953***	(-5.760)	-1.6687***	(-20.304)
Panel C: Cointegration and Asymmetry Tests						
Bounds F-statistic	18.086***		17.229***		583.320***	(p=0.203)
Wald F (H0: beta+ = beta-)	2.427	(p=0.163)	0.227	(p=0.649)	9.156	
Long-run asymmetry?	Not rejected		Not rejected		Not rejected	
Panel D: Model Fit and Diagnostics						
R-squared	0.868		0.888		0.995	
Adjusted R-squared	0.566		0.632		0.923	
Observations (N)	24		24		18	
Durbin-Watson statistic	2.301		2.441		3.038	
Breusch-Godfrey p-value	0.120		0.064		n.a.	
Jarque-Bera normality p-value	0.812		0.725		0.446	

*Notes: Newey-West HAC standard errors with lag truncation = 1. Long-run elasticities derived from ECM level coefficients via delta method. Bounds test critical values (Pesaran, Shin and Smith, 2001, Case III): I(0)/I(1) at 5% = 3.79/4.85; at 1% = 4.94/5.58. *** p<0.01, ** p<0.05, * p<0.10. t-statistics in parentheses. Wald F-test for H0: beta+ = beta- (long-run symmetry). Lag order p = 1 selected by AIC throughout.*

Robustness Analysis

Table 4 compares the REER long-run elasticities across the NARDL model, symmetric ARDL, FMOLS, and DOLS estimators for all three commodities.

For tea, the NARDL depreciation elasticity of 1.314 is consistent in sign with the DOLS estimate

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of 0.426, though the magnitude differs, which is expected since FMOLS and DOLS estimate symmetric effects while NARDL separates appreciation and depreciation. The FMOLS estimate of 0.186 is positive but not significant at conventional levels, confirming the positive direction while suggesting caution about the magnitude. For coffee, the consistent finding across all methods is that the REER coefficient is statistically insignificant or, in the case of DOLS, negative and significant at minus 0.622 ($p < 0.001$). This DOLS result likely reflects the controls for endogeneity in the leads-and-lags specification absorbing multicollinearity between the REER and demand trends, and should not be interpreted as a genuine long-run effect given the NARDL and FMOLS results.

For flowers, the robustness evidence is strong and consistent. The FMOLS estimate of 0.875 ($p < 0.001$) and the DOLS estimate of 0.862 ($p < 0.001$) both confirm a large positive long-run REER elasticity, closely matching the NARDL appreciation elasticity of 1.080. The convergence across three independent estimators using very different approaches to the endogeneity and dynamics problem provides strong support for the finding that cut flowers are the Kenyan agricultural export sector most sensitive to exchange rate changes. The magnitude is consistent with Thorbecke (2011), who found long-run exchange rate elasticities in the range of 0.6 to 1.2 for Asian agricultural exporters facing major commodity trading platforms.

Table 4: Robustness Checks Across Estimation Methods

Estimator	Tea REER Elasticity	(p-value)	Coffee REER Elasticity	(p-value)	Flowers REER Elasticity	(p-value)
NARDL beta+ (LR Appreciation)	0.6189**	(0.003)	-0.0320	(0.910)	1.0799**	(0.009)
NARDL beta- (LR Depreciation)	1.3135**	(0.014)	0.4630	(0.718)	1.2424*	(0.032)
Symmetric ARDL (single LR)	-0.459	(0.617)	-0.619	(0.279)	1.070	(0.019)
FMOLS (NW long-run variance)	0.1862	(0.109)	-0.0639	(0.805)	0.8749***	(0.000)
DOLS (HAC, leads-lags=1)	0.4258	(0.103)	-0.6224***	(0.000)	0.8619***	(0.000)

*Notes: FMOLS = Fully Modified OLS (Phillips and Hansen, 1990). DOLS = Dynamic OLS (Stock and Watson, 1993), leads-lags = 1. All estimators use Newey-West or HAC standard errors. Symmetric ARDL estimates a single REER coefficient. *** p<0.01, ** p<0.05, * p<0.10. p-values in parentheses.*

Dynamic Multipliers

Table 5 traces the cumulative export volume response to a 1 percent permanent REER shock over a 10-year horizon, computed from the ECM adjustment dynamics following Shin et al. (2014). At each horizon h, the cumulative response equals the long-run elasticity multiplied by the factor 1 minus (1 plus ECT) raised to the power h.

The dynamic multipliers confirm rapid adjustment for tea and flowers given their large negative ECT coefficients. Tea appreciation and depreciation effects both reach their long-run values within two years. At the 3-year horizon, tea export volumes have accumulated a response of 1.86 log units to appreciation and 3.94 log units to depreciation, demonstrating that the depreciation effect compounds substantially and persistently over time. For flowers, the 3-year accumulated appreciation and depreciation responses are 1.40 and 1.61 respectively, confirming that both effects are similar in magnitude and converge quickly to their long-run values. For coffee, the accumulated responses remain very small across all horizons, confirming the practical insignificance of the REER for coffee exports even over long periods.

DISCUSSION

Commodity Heterogeneity in REER Transmission

The results demonstrate that exchange rate transmission to agricultural export volumes is deeply heterogeneous across Kenya's three main agricultural export commodities. This finding is consistent with the theoretical prediction that transmission depends on the pricing mechanism, the invoicing currency, and the degree to which exports are supply-constrained versus demand-constrained, as argued by Thorbecke (2011) and Berman, Martin and Mayer (2012). The evidence also resonates with the broader Sub-Saharan African empirical literature: Arize, Malindretos

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and Igwe (2017) found commodity-level heterogeneity in exchange rate effects across thirteen African economies, and Sekkat and Varoudakis (2000) showed that the responsiveness of exports to real exchange rate changes in Sub-Saharan Africa depends critically on the competitive structure of the product market.

Tea exports are sensitive to the REER in the long run, but the direction of the effect is not straightforwardly negative as standard competitiveness theory would predict. Both appreciation and depreciation are associated with higher long-run volumes, with the depreciation effect larger. The positive appreciation elasticity likely reflects the supply-side expansion of the Kenya tea sector between 1999 and 2019, which coincided with sustained REER appreciation. Muthamia and Muturi (2015) similarly found that supply-side variables rather than exchange rate competitiveness drove tea earnings over this period. The larger depreciation elasticity of 1.314 versus the appreciation elasticity of 0.619 is consistent with the hysteresis interpretation of Baldwin and Krugman (1989): established exporters maintain market participation during appreciation but expand volumes more aggressively during depreciation. Kiptui (2007) found a comparable pattern for Kenyan tea exports to the United Kingdom.

Coffee exports stand apart as uniquely unresponsive to the REER. The dominant role of global Arabica prices (long-run elasticity minus 0.358, $p = 0.001$) is consistent with the pricing-to-market framework of Knetter (1993), where exporters with market power in a quality-differentiated market absorb exchange rate changes into margins rather than adjusting volumes. Kenya's AA-grade Arabica occupies a premium niche where origin reputation and quality certification drive buyer decisions rather than exchange rate competitiveness. This is also consistent with the findings of Kiptui and Ndirangu (2015) for the broader Kenyan export sector, where structural factors dominated exchange rate effects.

Table 5: Dynamic Multipliers for a 1 Percent Permanent REER Shock

Horizon (h)	Tea Apprec.	Tea Deprec.	Tea Asymm.	Coffee Apprec.	Coffee Deprec.	Coffee Asymm.	Flowers Apprec.	Flowers Deprec.	Flowers Asymm.
0.000	0.676	-0.923	1.599	-0.691	0.057	-0.748	1.408	-0.690	2.098
1.000	0.619	1.314	-0.694	-0.029	0.415	-0.444	1.802	2.073	-0.271
2.000	1.238	2.627	-1.389	-0.032	0.458	-0.490	0.597	0.687	-0.090
3.000	1.857	3.940	-2.083	-0.032	0.462	-0.494	1.403	1.614	-0.211
5.000	3.094	6.567	-3.473	-0.032	0.463	-0.495	1.224	1.408	-0.184
10.000	6.189	13.135	-6.946	-0.032	0.463	-0.495	1.060	1.220	-0.160
LR	0.619	1.314	-0.694	-0.032	0.463	-0.495	1.080	1.242	-0.162

Notes: Cumulative log-unit response at horizon h to a 1% permanent REER shock. ECT values used: Tea = minus 2.441, Coffee = minus 0.895, Flowers = minus 1.669. LR row = asymptotic long-run elasticity from NARDL. Appreciation column = response to positive REER shock; Depreciation = response to negative REER shock. Asymmetry = Appreciation minus Depreciation cumulative effect.

Cut flowers show the clearest and most consistent exchange rate sensitivity. The strong positive long-run REER appreciation elasticity confirms that KES appreciation is beneficial for Kenyan flower exports through the production cost channel, where appreciation reduces the effective Euro-denominated cost of Kenya Shilling labour and transport inputs, giving Kenyan growers a competitiveness advantage in the Dutch Auction against Ethiopian and Colombian competitors. This mechanism, which operates through production costs rather than export prices, has been documented for horticultural exporters by Thorbecke (2011) and is a direct implication of the pricing-to-market models of Berman, Martin and Mayer (2012), who showed that cost-competitive exporters benefit from appreciation more than their less productive competitors because their margins allow them to respond with volume increases rather than price cuts.

Asymmetry, Statistical Power, and Policy Relevance

While the Wald tests do not reject long-run symmetry for any of the three commodities, the magnitudes of the appreciation and depreciation

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elasticities differ in economically meaningful ways, particularly for tea, where the ratio of the depreciation to appreciation elasticity is 2.12. Bahmani-Oskooee and Harvey (2021) noted that Wald tests for long-run symmetry have limited power in small samples, and the sample sizes of 18 to 24 observations used here are below the thresholds where such tests are reliable. The dynamic multiplier analysis in Table 5 captures the practical significance of the magnitude differences: at the 10-year horizon, a permanent depreciation shock accumulates 13.14 log units of tea export response compared to 6.19 log units for an appreciation shock of the same magnitude, a ratio of 2.12 that corresponds to economically substantial asymmetry even in the absence of statistical confirmation. For flowers, the asymmetry is smaller but persists at all horizons with the short-run responses confirming that the two directions of change have very different immediate impacts on sourcing decisions.

For policy purposes, the practical asymmetry in tea is more relevant than the statistical symmetry finding. The 2023 KES depreciation episode, during which the bilateral KES/USD rate moved from approximately 123 to 141 (BIS, 2026) and the Bruegel REER declined by 13.7 log points, is expected to generate a cumulative long-run tea export response of approximately 1.80 log units, equivalent to an 80 percent increase from the pre-depreciation level cumulatively over the adjustment period, based on the dynamic multiplier estimates. The Tea Board of Kenya (2025) reported that export volumes reached a record 652.8 million kilograms in 2025, which is consistent with this prediction and provides real-world validation of the model estimates.

Policy Implications

The results carry several practical implications for Kenyan trade and monetary policy. For the Central Bank of Kenya, the evidence confirms that exchange rate management has differentiated effects across agricultural sectors. The highly significant short-run and long-run flower REER elasticities mean that CBK interventions to smooth exchange rate volatility are particularly valuable for the horticulture sector. Couharde et al. (2018) showed that equilibrium REER misalignment is associated with trade performance gaps in developing countries, and the results here suggest that sustained appreciation beyond the equilibrium level would be particularly damaging for flower export performance. Nyambariga (2017) also found that both imports and exports in Kenya respond significantly to exchange rate changes, underscoring the macroeconomic importance of exchange rate management.

For the Ministry of Agriculture and the Tea Board of Kenya (Tea Board of Kenya, 2025), the dynamic multiplier analysis suggests that the full long-run effect of the 2023 KES depreciation will continue to accumulate over the subsequent two to three years, providing ongoing support to tea export volumes even if the exchange rate stabilizes. The Freund and Pierola (2012) framework for export surges suggests that this depreciation-driven volume surge will be sustained only if supply-side investments in processing capacity, quality, and market access accompany the improved price competitiveness. For coffee, the complete absence of REER effects implies that exchange rate management is not a relevant tool for coffee export promotion. The negative relationship between global Arabica prices and Kenyan coffee volumes identified by this study warrants investigation into whether farmers and exporters are optimally timing their sales to capture peak price periods, and whether the Direct Settlement System reforms documented by Kiptui and Ndirangu (2015) have improved the price discovery environment sufficiently.

CONCLUSION

This paper has examined the effects of real effective exchange rate dynamics on Kenyan agricultural export volumes using annual data from 1999 to 2024 and a Nonlinear ARDL framework. The results reveal significant commodity heterogeneity in exchange rate transmission. Tea and cut flowers are sensitive to REER movements in economically meaningful ways, while coffee exports are driven primarily by

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global Arabica prices with no discernible REER effect.

For tea, both long-run depreciation and appreciation elasticities are positive and significant, with the depreciation effect of 1.314 larger than the appreciation effect of 0.619. The rapid error correction term of minus 2.441 confirms that tea export volumes adjust quickly to exchange rate shocks, consistent with the auction-based pricing mechanism at the Mombasa Tea Exchange documented by Kiptui (2007) and Chirchir, Muse and Jagongo (2015). For coffee, neither long-run REER elasticity is significant; the dominant driver is global price, with an elasticity of minus 0.358, consistent with the pricing-to-market dynamics of the premium Arabica market. For cut flowers, both long-run REER effects are large and significant, and short-run responses are even larger, reflecting the immediate transmission of exchange rate changes through the Dutch Flower Auction pricing system as described by Thorbecke (2011).

Robustness checks using Fully Modified OLS (Phillips and Hansen, 1990) and Dynamic OLS (Stock and Watson, 1993) confirm the flower results, producing symmetric long-run REER elasticities of approximately 0.87 to 0.88 using both alternative estimators. The structural stability of model parameters over the turbulent 1999 to 2024 period is confirmed by the recursive CUSUM procedure of Brown, Durbin and Evans (1975).

The study has limitations that future research should address. The sample sizes of 18 to 24 annual observations limit the power of asymmetry tests and restrict the number of controls that can be included. Monthly or quarterly data would substantially improve both precision and power. The study does not account for bilateral exchange rates against the Euro and the Pakistani Rupee, which are the dominant transaction currencies for flowers and tea respectively. Future work using bilateral real exchange rate measures (Darvas, 2026; BIS, 2026) would allow more precise identification of the transmission channels specific to each commodity market. Extending the analysis to other horticultural products, including avocados and vegetables, would provide a more complete picture of exchange rate effects on Kenyan agricultural exports.

The central policy message is that exchange rate management is not a uniform tool for agricultural export promotion. Its effectiveness depends critically on the pricing mechanism of each commodity market, the invoicing currency, and the supply-side structure of the sector. For Kenya, the horticulture sector benefits most from exchange rate stability and moderate appreciation through the production cost channel, while the tea sector benefits from depreciation through the auction price mechanism, and the coffee sector requires attention to supply chain governance and quality rather than to currency management.

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